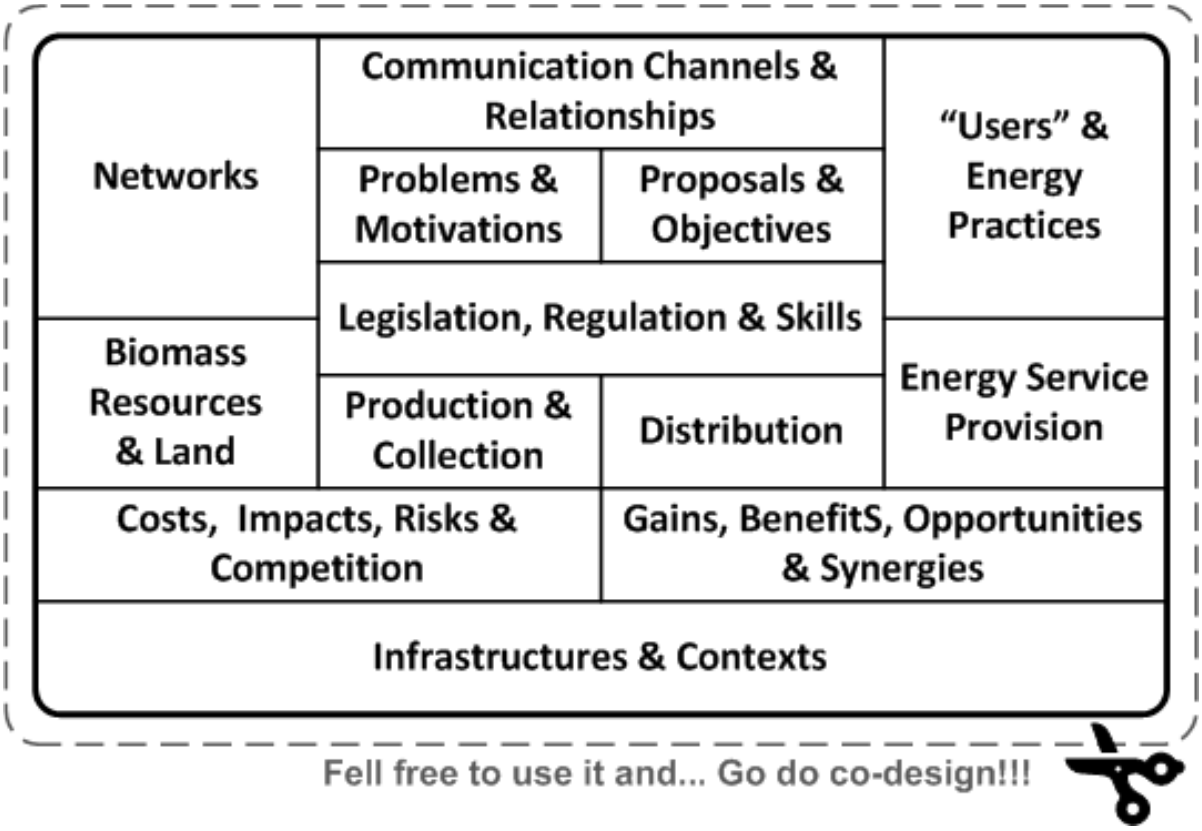
2MW THE WOOD FUEL ENERGY SYSTEMS CONCEPTUAL DESIGN METAMODEL

A Novel Approach to Participatory Design

Contextualised to the case of Mozambique



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Thesis submitted for the degree of Doctor of Philosophy

Centre for Environmental Policy

Imperial College London

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Charcoal Seller in Mozambique
(Manuel Santana, 1935

Mawoco, Nkululeko, Kutchuseka

Ni Moçambique, Swua Moçambique, A Nsiko Linwe a Moçambique

A Missinha Lexi Iyenshaka, Atiko Leli Hisaka, A Co Hisa Ukalaka Ungahimfuni Hinchumo Sia-Vuma

[Mãos, Liberdade, Criatividade, Para Moçambique, Com Moçambique, Um Dia Em Moçambique, À Terra Que Nos Arde, Às Árvores Que Nos Fazem, Ao Lume Que Nos Alimenta]

[Hands, Freedom, Creativity | With Mozambique, For Mozambique, One Day In Mozambique | To The land, For The Trees, By The Fire]

DECLARATION OF ORIGINALITY & COPYRIGHT DECLARATION

I hereby declare that this thesis and the entire research described herein is my original work. Information and data obtained from the work of others is acknowledged in the text and fully referenced.

(Ricardo Jorge de Albuquerque Martins)

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LIST OF ACRONYMS AND ABBREVIATIONS

10KC	10 Key Capitals for Sustainable Design
2MW	Conceptual Design Wood Fuel Energy System Metamodel
5CM	Five Capitals Model
ADB	African Development Bank
AIA	American Institute of Architects
ALRI	Acute Lower Respiratory Infections
AUSAID	Australian Aid Agency
BC	Livelihood, Behavioural & Socio-cultural Design Dimension
BMC	Business Model Canvas
BMO	Business Model Ontology
CBNRM	Community-Based Natural Resource Management
CEF	Co-Evolutionary Framework
ChF	Choices Framework
DC	Developing Country
DD	Design Dimension
DDF	Design Dimensions Framework
DST	Decision Support Tools
EC	Economic, Finance & Business Design Dimension
ESMAP	Energy Sector Management Assistance Programme
ESy	Energy Systems
ETP	Energy Transition Paradigm
EU	European Union
FAO	The Food and Agriculture Organisation of The United Nations
FEM	Fondation Energies pour le Monde
FEMA	The Forum of Energy Ministers in Africa
FF	Forum for the Future
FRES	Framework for Rural Energy Service
GIS	Geographical Information System
GMB	Group Modelling Building
HDI	Human Development Index
IAP	Indoor Air Pollution
ICT	Information and Communication Technology
IEA	International Energy Association

IEC	International Electrotechnical Commission
IFAD	International Fund for Agricultural Development
IP	Institutional & Policy Design Dimension
ISO	International Organisation for Standardisation
KI	Knowledge, Skills & Communication Design Dimension
KM	Knowledge Management
LCA	Life Cycle Analysis
MCDA	Multi-Criteria Decision Analysis/Aid
MD	Modelling Dimension
MdE	Ministry of Energy of Mozambique
MDGs	Millennium Development Goals
MICOA	Ministry of Environmental Coordination of Mozambique
MINAG	Ministry of Agriculture of Mozambique
MPF	Ministry of Planning and Finance in Mozambique
NGO	Non Governmental Organisation
NT	Nature Design Dimension
OEM	Optimisation Models Based On Chain Models
OSM	Optimisation Models Based On Esy Models
PAR	Participatory Action Research
PD	Participatory Design
PDW	Participatory Design Workshops
PM	Participatory Modelling
PRA	Participatory Rural Appraisal
PSM	Problem Structuring Methods
PV	Photovoltaic
RE	Renewable Energy
REED+	Reduced Emission from Degradation and Deforestation +
REEEP	Renewable Energy and Energy Efficiency Partnership
RET	Renewable Energy Technology
SC	Integrated Infrastructure & Networking Design Dimension
SDI	Sustainability Indicators
SLA	Sustainable Livelihoods Approach
SM	Simulation Models For WES
SSA	Sub-Saharan Africa

SWOT	Strengths, Weaknesses, Opportunities and Threats
TOPB	Tree Of Problems For Biomass in Mozambique
TT	Technological Design Dimension
UN	The United Nations
UNCHS	United Nations Centre for Human Settlement
UNCSD	Division for Sustainable Development in the United Nations
UNDP	United Nations Development Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNIDO	United Nations Industrial Development Organisation
WB	The World Bank
WBGU	German Advisory Council on Global Change
WCC	Wood Fuel Commodity Chain
WES	Wood Fuel Energy Systems
WF	Wood Fuel
WHO	World Health Organisation
WSC	Wood Fuel Supply Chain

BRIEF GLOSSARY OF TERMS USED IN THIS WORK

BIOENERGY- The energy produced directly or indirectly from biomass (FAO 2004).

BIOFUEL- The fuel produced directly or indirectly from biomass (FAO 2004).

BIOMASS- All material of biological origin excluding material embedded in geological formations and transformed to fossil (FAO 2004). Thus biomass refers to any non-fossil organic substance with high energy content, typically including: wood; residues from agriculture or forestry; the organic component of municipal and industrial wastes.

DEVELOPING COUNTRY- This work follows (for convenience rather than conviction) the UN's Human Development Report where, e, g., most African countries are labelled DCs while, e.g., Japan is labelled as developed. However, the concept and divide "developed/non-developed or developing" countries has been criticised since the 1980s, particularly by post-development authors (e.g. Escobar 1995) and according to the UN the term is "intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process" (UNSD 2014).

GROSS DOMESTIC PRODCUT GROWTH- According to the WB/WDB means: the annual percentage growth rate of GROSS DOMESTIC PRODCUT at market prices based on constant local currency. Aggregates are based on constant 2005 U.S. dollars. GROSS DOMESTIC PRODCUT is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources.

ONE TONNE OF OIL EQUIVALENT- The amount of energy released by burning one tonne of crude oil which is approximately 42 GJ (Giga Joule).

PARADIGM- The term is controversial (see Wendel 2008), but here is considered as the general set of philosophical assumptions that define the nature of possible action in terms of: ontology (what is assumed to exist); epistemology (what can be known); and praxiology (how to act in an informed and reflective manner) (Mingers & Brocklesby 1997). Praxilogy can be further sub-divided into effectiveness (the extent to which desired ends are achieved), Ethics (the value and desirability of courses of action) and morals (the effects of one's actions on other people) (Habermas 1993).

TOTAL PRIMARY ENERGY USE- Also *Total Primary Energy Supply* is calculated by the International Energy Agency as production of the sum of fuels, inputs from other sources and imports less the exports, international marine bunkers and stock changes (UNSD 2005).

WOOD FUEL- All wood used as fuels including: entire trees, part of trees (e.g. tops, roots, branches), obtained from thinning, pruning and/or harvesting in forest (wild or dedicated plantations) and non-forest land (e.g. farms); industrial by-products from primary and secondary forest industries; and recovered wood (e.g. construction materials; pallets) (FAO 2004). In practical terms in Mozambique wood fuel consists almost exclusively of charcoal and firewood.

ABSTRACT

This research endorsed, built and tested a metamodel, the 2MW: a novel design tool to assist all knowledgeable actors on wood fuel (e.g. firewood users, charcoal makers, policy makers) in the participatory conceptual design of wood fuel energy systems (WES), i.e., in the process of co-conception, co-specification and co-modelling of WES.

The 2MW relevance is twofold. First the 2MW fulfils a gap in the portfolio of design tools for WES. Second the conceptual design of WES is a fundamental concern since billions of people in "Developing Countries" (DCs) rely heavily on WES for energy needs; and the WES are mutually embedded within global priorities, including deforestation and poverty. In the context of this work, Mozambique, over 70% of the population rely exclusively on WES, and the charcoal business has an estimated value of 520million US$/year.

Despite the documented drawbacks, the few available or applicable WES design tools simplify the WES complexity into a set of parameters to be optimised/simulated into normative and prescriptive tools, mostly computer based and designed exclusively by/for experts to facilitate the analysis/decision on the *transition* towards what are considered to be more sustainable, efficient and modern solutions.

The 2MW represents a fundamental departure from this *energy transitions paradigm* in a number of interwoven aspects. Based on systems and design thinking the 2MW embraces WES as a complex design problem favouring full participation, reflective practice, learning, sensemaking and suitability to the intended users and contexts. Therefore, the 2MW is not a parametric simulation model, but a design metamodel made of 13 design elements, which make explicit what WES actors *think about when they think about WES design*. The 2MW is non-computer based and visually presented as 13 boxes drawn on paper or the ground suitable for low literacy and resource limitations in DCs. The 13 design elements have been derived through ontological analysis of relevant literature and semi-structured interviews with 131 pertinent actors in the WES in Mozambique and elsewhere and the 2MW has been extensively and intensively tested in 7 participatory design workshops conducted in rural and urban Mozambique involving over 50 persons covering a wide range of WES perspectives. The results consistently confirmed: 1) the 13 design elements are meaningful, sufficient and necessary intuitively easy to understand and interact, with 2) the 2MW is an effective, efficient, explicit and interactive common ground/language facilitating the debate, knowledge sharing, sensemaking and learning on participants' terms (by-passing predefined normative and concepts); 3) the WES conceptual designs produced with the 2MW is creative, comprehensive, easily shared and meaningful.

Finally, as an efficient and effective tool for WES participatory conceptual design the 2MW is potentially useful to complement other available design tools on wider and more integrated WES design, analysis and implementation.

SECTION **A**

THE RESEARCH IN A NUTSHELL

Good management is the art of making problems so interesting and their solutions so constructive that everyone wants to get to work and deal with them.

Paul Hawken, in *Growing a Business* (1988)

What we call the beginning is often the end. And to make an end is to make a beginning. The end is where we start from.

T. S. Eliot, in *The Little Gidding, Four Quartets* (1943)

…Where the Reader is introduced to the research specificity, approach, main topics, arguments and thesis layout to be explored and fully developed in the following sections…

1 WOOD FUEL: BEYOND THE ENERGY TRANSITION PARADIGM

The acquisition, use and management of wood fuel (WF) are essential activities to ensure the basic existence of billions of people in the so called Developing Countries (DCs) (§5). In Mozambique, incidentally a net exporter of electricity DC, more than 70% of the population rely exclusively on WF for energy services (essentially cooking). While rural communities use firewood collected mostly by women and children in long extenuating hours of work, the growing urban population uses more than 24million m^3/year of charcoal in an estimated 800millions €/year business. While the numbers attest the dramatic importance of energy in DCs livelihoods, they also relate WF with complex topics like: deforestation; forest resources management; land rights; energy technology options; cultural energy practices; gender bias; poverty; energy policies/legislation; and health (§5.2). Remarkably, each of these topics represents an analytical dimension on WF, and thus research on WF can easily unfold in a multitude of multiples, where perspectives are plural and often contradictory and interactions with WF are ambiguous, dynamic and unpredictable (§5-8). In other words, research on, or involving, WF in DCs is both an outstandingly relevant and complex challenge (§Annex 1).

Considering the impact and importance of WF in the socio-ecological reality of it, it would be expected that the *way that consumption and production of WF are conceived and modelled* would be a top research and political priority. They are not (§6.3). With very few exceptions, WF is seen as a "dirty fuel" or a "delicate problem better left alone", say several experts and government officials (§5.3.2). In research, the few tools available to deal with WF (§6.3, §10.1) focus on theory (*why things are the way they are*) and decision support for managers and policy makers (*what to do and how to do it* based on *qualitative and quantitative data*).

However, and despite the diversity of initiatives and analysis, distinct disciplines and purposes involved, both research and political agendas on WF share a feature: the *energy transition paradigm* (ETP). The ETP is a normative, prescriptive technologically-centred political stand which endorses renewable energy sources, technology and/or practices as a vector for economic development, better environment and social benefits (e.g. poverty eradication) in DCs. For ETP these "modern" WF technologies/practices are efficient, sustainable and cleaner and should replace the current "traditional", unsustainable, inefficient, environmentally damaging and health hazardous WF technologies/ practices.

However, concepts such as sustainable or efficient are, at best, controversial and the results of ETP projects are quite modest (§7), even when blended with stakeholders participation. Many "stakeholders" (notably rural WF producers and urban users) might participate on problem definition and solutions assessment, but not on the actual definition of the WF project, models or tools as *full designers*. Moreover, most of the ETP

based tools, technologies and practices are complicated, culturally and physically unsuitable to local conditions and usable only by contextualised experts.

Note that the discussion above is not intended to dismiss completely normative and prescriptive tools, which are certainly useful for whom and what they have been developed. The critique underlines the fact that focusing on predefined normative solutions and prescriptive "how to do things" as formatted by expert represents a somewhat "uncritical" thought that bypasses a wealth of design ideas and knowledge that all WF actors certainly have. By actors it is meant not just stakeholders identified by experts, but all knowledgeable or interested, identified or self-motivated people, interacting in any form with WF issues (see §2). Considering the wealth of backgrounds and ideas in those actors, what might be needed is not a complicated decision support tool usable only by experts, but a tool that could support those actors in the process of understanding, expressing and debating those ideas in a coherent, comprehensive, structured participatory manner way. Therefore, this research, acknowledging the undoubted importance of WF, went beyond the overwhelming political, economic and technological wave of ETP, to address a persistent and ignored gap in the literature and practice, which could be expressed as:

> *The lack of easy to use tools to assist different WF actors (regardless of their background) in the definition, specification, analysis and communication of conceptualisations/ideas they might have on WF production and consumption;*

The following §2 explains how this gap was addressed in a novel way by this research.

2 SYSTEMS, DESIGN AND MODELLING DIMENSIONS

The research on WF and related issues represents a complex challenge researchable from many possible approaches, e.g. political, economical, technological. Therefore, since *what is researched affects how it is researched and vice-versa,* (e.g. O'Brien *et al.* 2012), through an interactive process a suitable research domain and approach were defined in the wider research context of WES in DCs. The research approach consists of an original combination of *systems thinking* (§9.2) and *design thinking* (§9.3) both considered effective to address complexity by a crescent number of authors. As for the research domain it was defined as *Wood Fuel Energy Systems (WES) design*.

Systems thinking is a form of structured analysis which explore, integrates and conceptualises into systems the multiple perspectives that complex realities generate (§9.2, Annex 2). Briefly explained, systems are a conceptualisation of reality as a set of related elements defined by a common boundary, dynamic interactions and purpose. Applying systems thinking it was possible to frame the complex network of WF and associated issues, topics and perspectives as *Wood Fuel Energy Systems* (WES). A WES can be defined as socio-ecological system comprising WF energy resources, technologies and derived services considered useful to people (users) in contexts defined by, e.g., knowledge, cultural practices, policies, laws and natural environment (§9.2, fig. 9.2-3).

Design thinking defines a specific *thinking style* to address, explain and facilitate the creation of or the *giving of form* to objects (tangible or intangible) in complex social contexts (§9.3). By applying design thinking to the research the definition of WES in DCs was reframed as a complex design problem. With such reframing it was possible to associate ETP to the design paradigm defined by Simon (1969: 129) as "devising courses of action aimed at changing current situations into preferred ones". Following this definition, Simon defends that design can actually produce optimal solutions for complex problems by reducing the problem to a set of smaller soluble problems. However, as Morin (1977, 1990) persuasively demonstrated, complexity cannot be divided, since that would imply a full knowledge and control of complexity which, by definition, is impossible. The result is, therefore, a profound *design mismatch* between the complex nature of WES design and the available WES design tools which are designed considering WES "simplifiable". Besides leading to the identification of a design mismatch the reframing of the ETP (§1) in design terms also allowed the reformulation of the indentified gap (§1) as:

> *What kind of model/tool, and modelling, should be designed to suitably support WES actors to address the design and complexity of WES?*

In other words, placed in the design thinking and systems thinking realm, the research on defining consumption/production of WF in DCs become a modelling challenge. A model is an abstract representation, or simplification, of what the designer (or group of designers) perceives and knows about the reality to be designed, while modelling is the process of

conceiving that model (§9.1). In operational terms, within the overall research context (§1) defining a model implies the definition of (§9.1) 6 other modelling aspects or dimensions (MDs):

1| Design paradigm, The set of principles that express how the designer (or group of designers) perceives the domain of interest;
2| Modelling purpose, what the model is suppose to do and for whom;
3| Model format, how the model should look;
4| Modelling methodology, how the model is designed;
5| The designers, who do the modelling and create the model;
6| The domain of interest, the reality the model is supposed to abstract.

The *design paradigm* was provided by a conceptualisation of reality as a network of mutually embedded, open systems co-evolving in a dynamic and non-deterministic interactive process wherein each change affects and is affected by all others changes (§9.2)[1]. The systems thinking approach (§9.2) implemented was a pluralist, multi-actor systems analysis close to Soft Systems Methodology (SSM, §13, Annex 2) while Schön (1983) "reflection-in-action" was taken as the suitable design thinking approach (§9.3). Schön addresses design as a dynamic, interactive and permanent dialogue between designers and all the remaining 6 design dimensions and thus focuses on supporting the learning, sensemaking and knowledge involved in the process of reformulating the design problems as they are solved, rather than on product, solution and Optimisation standpoint.

Regarding the *modelling purpose*, considering the design mismatch identified above, instead of trying to abstract the complex WES to achieve a parametric model, the focus went to the facilitation of participatory design process of WES. In accordance with this objective and the design approach, the model should act as a playground or design space, non-normative and non-prescriptive, promoting active dialogue among the diverse participants and between the participants and the model, resulting in knowledge sharing, learning dynamics and reflexive design practice. The model should also support conceptual design or ideation since in this design stage (virtually unassisted by design tools), it offers a unique window of opportunity, regardless of the technical background, and includes a wide range of knowledge, ideas and problem analysis in the design of WES at a minimum cost and with the highest impact in the final design (§9.4.4).

1 Philosophically this design paradigm is in line with a paradigm shift which embraces critical approaches to reality as the mutual embedment between the context, cognition and subject in a continuous and dynamic co-redefinition process. This is a depart from the old philosophical divide between radical empiricism (e.g. Hume 1738/2000) and pure rationalism (e.g. Descartes 1642/2008. Notably this philosophical shift is also mentioned in fields like: Cognitive Science (Maturana & Varela 1987; Varela *et al.* 1993), Ecological Anthropology (Ingold 1986; 2001), Social Anthropology (Bourdieu 1977, 1981, 1990), Ecological Psychology (Gibson 1950, 1966, 1979), Sociology (Giddens 1981, 1984), Ecological economics (Norgaard 1994, 2005), Artificial Iintelligence (Silva *et al.* 2008), Substantivist Economics (Granovetter & Swedberg 2011; Polanyi 1944).

A visual, non-computer based and modular metamodel (§11) seems to be the most appropriate *model format* to embrace the design purposes and paradigm fitted to the DCs design context. Specifically the model built and tested in this research is a *wood fuel energy systems conceptual design metamodel*, the **2MW**. Instead of a numeric/computational format, the 2MW is presented as a simple set of well defined and easy to understand 13 design elements (visually presented as boxes in a piece of paper) that once filled jointly by participants allow user to express the specification of a conceptual design model suitable to be further analysed, worked upon and communicated. Conversely, by identifying those 13 design elements, the 2MW makes them explicit, that is, visible and open to discussion. Therefore, the 2MW functions as a common ground or language to make sense of WES conceptual design which allows different users to establish a *dialogue around*, or *structured by*, those 13 design elements, while learning in interactive participatory environment. The 2MW provides the users with something like a box of LEGO™ blocks. Alone or in group the designer can play around with these blocks (the boxes drawn in paper) and create their own WES conceptual models limited only by his/her creativity, knowledge, experience, bias and the pieces supplied. Being visual, simple and non-computer based, the 2MW is accessible to a wider participation and easy to use in areas with minimal conditions (a piece of paper and a pen are enough) which is *a* major advantage in contexts where, e.g., electricity not available. Finally the design elements are modular, meaning that they could change position, other elements can be added, divided, subtracted and/or redefined according to the users will. As long as a reference with the original remains, it is always possible to translate between different versions of the 2MW.

To address the model format, design purpose and paradigm, the *modelling methodology* was based on a participatory ontological analysis (§13.2.1). Participatory modelling aims to involve all interested and knowledgeable actors in the Mozambican WES as co-modellers in all modelling design stages and not just at problem definition and solution assessment as it is usual in modelling processes (even those deemed participatory) (§9.4.1). Ontological analysis is an interactive and reflexive process that intends to extract, classify and relate what design elements composes the WES conceptual design, i.e., the WES conceptual building blocks. In an alternative to modelling that tries to identify parameters to construct models or theories as simplified versions of WES design (the principle behind the ETP normative and prescriptive modelling) the ontological analysis in this work made explicit, as clearly defined explicit design elements, what actors (and literature) *think about when they think about conceptual design of WES* in Mozambique. In practical terms the DEs emerged from the ontological analysis jointly conducted on data obtained in literature, interviews and participatory design exercises with WES *actor*s (potential 2MW users) such as: charcoal makers; farmers; WES entrepreneurs; technology providers; relevant NGOs and experts; WF transporters; local and government authorities; users/consumers.

Finally, the domain of interest, that started as the conjunction of the socio ecological WES (§5-6) and the contextual Mozambican reality (§5.3) had to be expanded to include the modelling of conceptual design support tools (§6.3, §10.1). Indeed, the nature of the research includes a socio-ecological environment, but also a conceptual and methodological complex design space for the *design of design tools*.

In fig. 2.2 the main design decisions taken in this thesis and described above are depicted in the form of mutually enclosed triangles relating MDs (triangles with all caps) with their associate specifications (triangles with normal text) organised within the research context by/with the designers (the author and the WES actors). Note that the specification of the MDs (i.e. the definition of what was actually done in each MD) was not trivial or sequential, but rather emergent from a continuous and reflexive interaction between the MDs, the design context and the designers. To express this idea of interaction dotted lines were used in fig. 2.1 to indicate free flow of information and effects across the MDs and associated specifications in the adjacent triangles. Moreover, to express the idea of MDs and specifications emerging from wider research context, the triangles are further organised from the centre, where the model 2MW lies as the major original and concrete research outcome while Mozambique (a decision on the modelling domain) is in the outer triangle as part of the broader contextual and abstracted subject in the research approach. Therefore, it is possible to navigate through the main decisions considered in the modelling of the 2MW by zooming in and out those levels of abstraction.

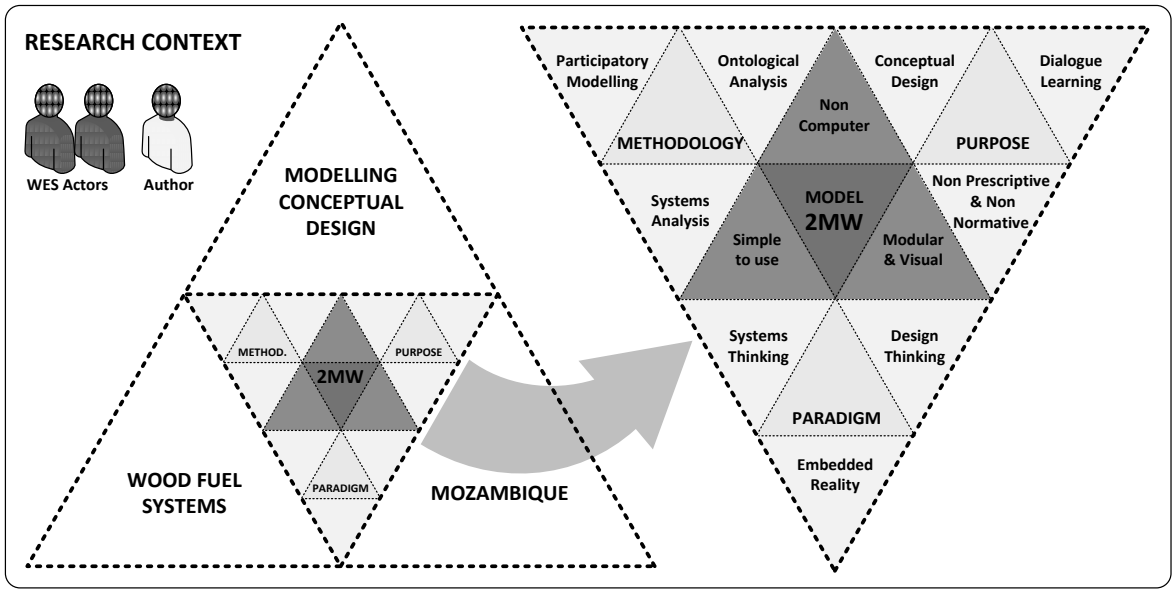


Figure 2.1| The thesis main design decisions expressed by the interactions and relative position of the MDs and associated specifications [Source: the Author]

With the thesis explained and the main design decision presented, it is possible to formalise the research goal (§3) and define the thesis layout (§4).

3 RESEARCH GOAL, QUESTIONS & OBJECTIVES

This work addresses a specific area not so well covered until now: modelling tools to support WES conceptual design in DCs outside the ETP. Following the brief research description above (§1-2) the thesis research goal is:

> *To build a non-normative, non-prescriptive model to support the participatory conceptual design of WES by different actors facilitating in the process learning, dialogue and sensemaking dynamics*.

To tackle this research goal, systems/design thinking were combined to reframe the research as a modelling challenge of/in a complex design to be scoped by a participatory ontological approach which translated the research goal into the research question:

> What is the sufficient and necessary set of DEs (conceptual building blocks) that allow the WES participatory conceptual design in a design space that promotes learning, sensemaking and reflexive interaction?

The answer that emerged from the research was the design and subsequent testing of a metamodel of/for the WES, which, in practical terms requires one to:

1| Define and explore WES in Mozambique and identify knowledgeable actors;
2| Identify/extract that WES with/from those actors the DEs that could represent and describe in an explicit and formalised form the shared design conceptualisations on WES in Mozambique;
3| Produce precise unambiguous text definitions for such DEs;
4| Identify terms to refer to those DEs, i.e., find titles for those DEs;
5| Define evaluation criteria, strategy and methods for the built design tool, the 2MW;
6| Find an agreement in all of the above.

The following chapter (§4) articulates these objectives within a coherent thesis layout.

4 THESIS LAYOUT

At this point it is possible to conclude that this work is guided by a systems/design thinking approach (§2) to WF in DC (§1) and uses a participatory ontological analysis on WES (§1-2) to model (build and evaluate) the 2MW, a tool to assist the participatory conceptual design of WES (§3). This rather interactive, emergent, reflexive and practical design process was translated for the sequential and linear body of this thesis in 5 articulated Sections, §A-E, supported by annexes (Section F) and bibliography (Section G).

The present Section A presented an overview and resume of the research as it was conducted to introduce and guide the reader to the thesis settings (§1-2). This section A also presented the research goals and questions (§3) and this §4 gives the thesis layout.

Section B critically and argumentatively explores WF and associated issues identified in the literature (§5.1-2) and/or by interviewed actors, with a special focus on Mozambique (§5.3), to compose the domain of interest (WES design) and expose the mismatch between the complex WF reality and the deterministic models available to support planning and decision making (§6). That mismatch is mostly attributed to the prevalence of ETP in WF research, particularly on modelling, and thus the basic fundaments of the ETP are critically and argumentatively quayside in §7.

That identified gap is then taken on Section C to justify a reframing of the research under a systems/design thinking approach (§9.2-3) which exposes the design mismatch identified in Section A as a complex design problem, requiring systemic tools. Based on a definition of model and modelling emergent from this work (§9.1) suitable design specifications (specs in fig. 4.1) are identified (§9.2-3) and explored (§9.4). These design specifications are used for a number of purposes: comparatively expose the originality of the work by identifying a lack of tools to assist participatory conceptual design of WES by actors (§10-11); theoretically endorse metamodels and meta-modelling as viable option to address that gap (§11); and to guide the actual design/modelling of the 2MW (§13-15).

While the 2MW design process started already in Section B, it is in Section D that the 2MW is created, gains form, through modelling grounded on participatory ontological analysis (the main methodology employed) (§13-14) and participatory evaluation (§13, 14). Section D encapsulates all the theoretical and empirical work developed in §B-C which justifies and simultaneously guides the creation and evaluation of the 2MW, as the linkages (arrows) in fig. 4.1 show.

Section E (not shown in fig. 4.1 for simplicity) discusses the major original outcomes and results (§16), presents limitations to the research (§17) and presents future work and potential uses for the 2MW (§18).

Finally, Annexes are presented in Section F and bibliography in Section G.

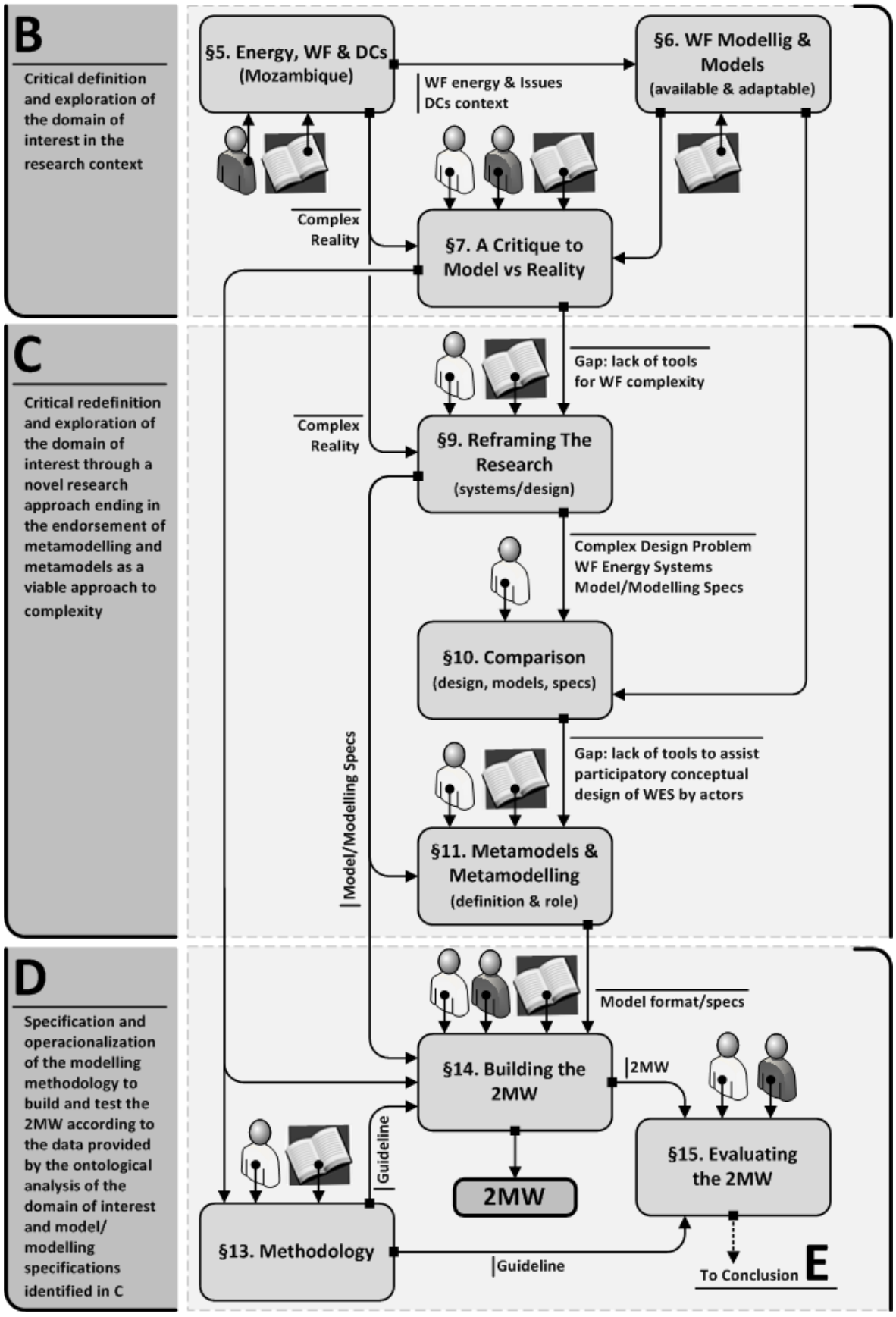


Figure 4.1| Representation of the thesis layout showing the several sections and relations between chapter (section A, the conclusion in section E and summary chapters §8 & 12 are not included for simplicity) (Specs- specifications; - the author; - other WES actors; - literature) [Source: the Author].

Note that implicit in fig. 4.1 is the reason why this thesis started with a resume section instead of a more usual introductory chapter. Essentially the justification is given by peculiar characteristic of the research subject and approach selected to address it. As already stated (§2) the ontological analysis scopes the design domain for the DEs to compose the 2MW, and, thus, is dependent on how the domain of interest (*what can be seen*) and design paradigm (*how it can be seen and classified*). However, at the start, there was no clearly identifiable or recognised research domain "WES" and even less "WF consumption and production", only a multitude of more or less isolated disciplinary research using their own paradigms, body of knowledge and models. It was necessary to prove the originality of 2MW against other WES design models (§10) while building the 2MW with an ontological analysis on WF reality, but what models, from what domain, which design criteria to compare? The option was to define the design domain, paradigm and criteria simultaneously with the ontological analysis on that *constructed domain*. Even the decision for the ontological analysis was itself taken during the critical exploration of the problem (hence the harrow from §7 to §13 in fig. 4.1).

In resume, the research process was rather exploratory and interactive which are dynamics difficult to incorporate in the highly formalised and linear nature of a thesis. The layout presented in fig. 4.1 is a compromise between the need to explain and ground the research results, the actual work flow of the research and the thesis as a technical academic document. Therefore, fig. 4.1 besides presenting and articulating the work into sections and chapters is also an expression of the original way the research was conducted and provides a visual map (like the 2MW) for the following reading.

SECTION **B**

MAKING SENSE OF WOOD FUEL IN DEVELOPING COUNTRIES & MOZAMBIQUE

Energy is the only life, and is from the Body; and Reason is the bound or outward circumference of Energy. Without contraries is no progression. Attraction and repulsion, reason and energy, love and hate, are necessary to human existence.

William Blake, In: *The Marriage Of Heaven And Hell* (1790)

Energia é vida... É tudo! [Energy is life… It's everything!]

Interviewee in Rural Maputo

… Where the domain of interest, wood fuels in Developing Countries, is defined and critically explored in terms of context, related issues, and models with special incidence on Mozambique…

5 WOOD FUEL IN DEVELOPING COUNTRIES: A RICH PICTURE

This chapter critically explores relevant literature on WF and associated issues in the context of DCs (§5.1-2) with special emphasis on Mozambique (§5.3). This critical literature review disclosed that WF (charcoal and firewood) is, and will continue to be in near future, the energy source of election for the large majority of people in DCs and Mozambique. This fact associated with the forestry nature of WF and the technology used in WF consumption and/or production unfolds complex issues between WF and deforestation, in-house pollution, gender discrimination among others (§5.2-3).

5.1 ENERGY IN DEVELOPING COUNTRIES

In the mid 1970s the alarm sounded, one "other energy crisis" (Eckholm 1975) was about to happen in the DCs as over-harvesting would turn forests into deserts. The gloomy prognostic was later dismissed (§5.2.3), but the image of burning forest in some "poor country" still persists. Recently, that problematic vision of WF production and consumption in DCs is returning to political, social and academic agendas, again in relation to possible ecological damage, but now within a wider network of complex topics, including poverty, forest management, gender and technology transfer (e.g. Bailis 2005; Birol 2007; Cecelski 2002). Implicitly or explicitly behind these linkages there is a dominating rhetoric based on the millennium development goals (MDGs), sustainability and technocratic view on development which dominates all analysis and initiatives on energy initiatives in development contexts (e.g. Leach & Scoones 2006).

With the turn of the century the international political agenda took shape around the millennium development goals (MDGs) and recognised poverty eradication as the overarching international development target (UN 2000). Since the large majority of the poor live in rural areas of DCs, the MDGs implicitly reinforced the agenda for rural development (e.g. Ramani & Heijndermans 2003). Simultaneously energy technologies and services have been increasingly recognised as a critical factor for all MDGs (e.g. Masud *et al.* 2007; Modi *et al.* 2005; Porcaro & Takada 2005; UNDP 2005). The mix is complete with the permanent reference to sustainability, sustainable development, climate change and a wide range of "linkable" disciplinary perspectives on WF.

The MDGs also increased (and might also be a result of) the growing interest in measurement and assessment (i.e. quantification) of development, the goals and the goal performance (e.g. Devereux 2003). In fig. 5.1, a quantification of that sort is carried out for illustrative purposes, relating: the human development index (HDI) a measure of Human development; the total energy consumption (TEC) which can be proxy of energy services assuming end-use efficiency as constant (Reddy 2002); the electrification rate, (ElecR); the electricity consumption (ElecC); CO2 emissions (CO2) a proxy for pollution; and the Biomass Consumption (BCn).

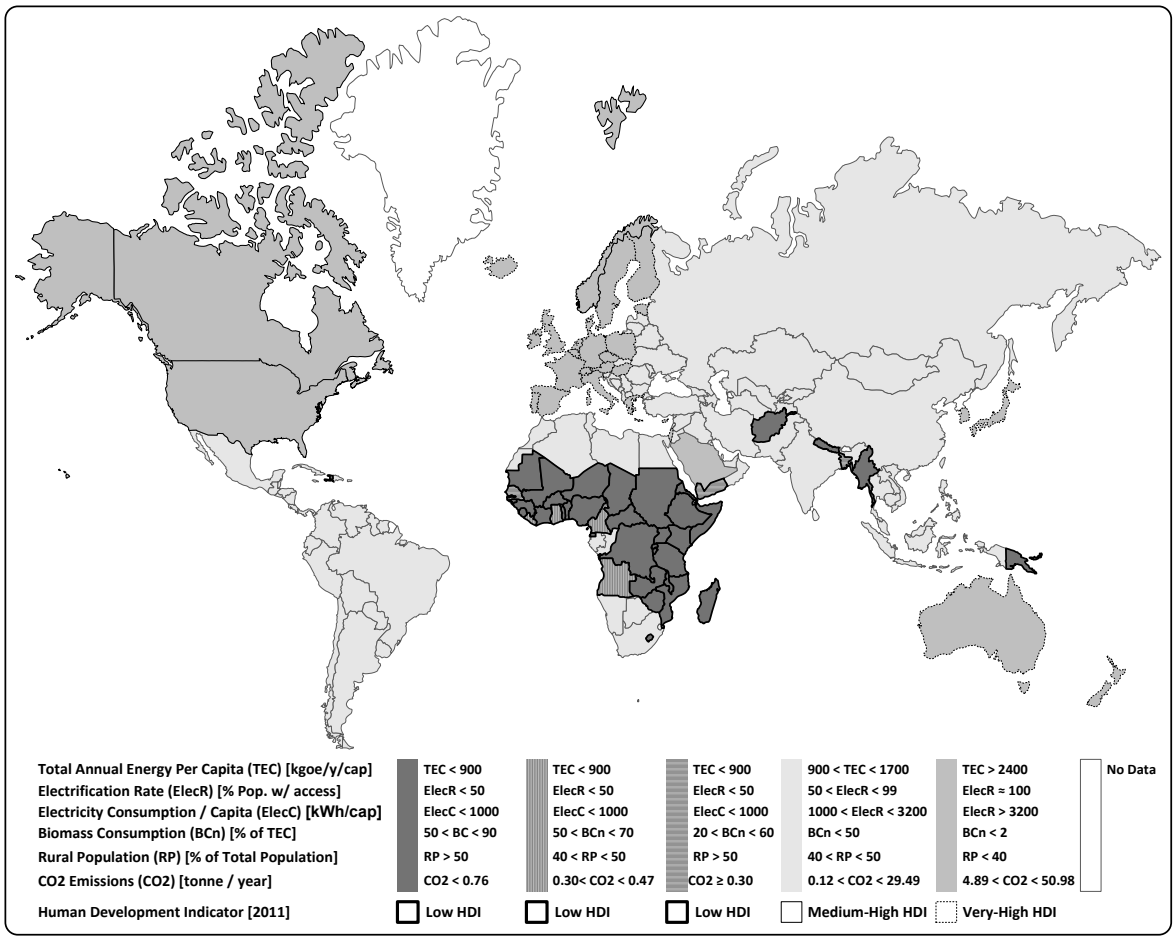


Figure 5.1| Mapping development and urbanisation levels in terms of energy consumption patterns and emission impact [Source: the Author with data from *IEA 2010; Klass 2004; Legros et al. 2009; OECD/IEA 2007; Rehfuess 2006; Takada et al. 2010; WB/ODB; WEO 2009, 2010; WRI 2007*].

The data on fig. 5.1 makes visible a high level of agreement between low HDI countries (i.e. DCs), prevalence or rural communities, low emissions and low energy consumption. In DCs at least over 50% of the population live in rural areas and emit less than 0.76tones of CO2 per year (more than 50 times less than developed countries). Regarding the energy consumptions patterns in DCs while the annual *per capita* consumption of is less than 900kgoe (against the 2400kgoe in developed countries), around 81.5% of the entire DCs population fulfils more than 60% of its energy needs with biomass. On the other hand, on average, less that 50% have access to electricity, and those who do, consume less than 1000kwh/capita.

In sharp contrast are the 100% electrified developed countries consuming in average more than 3200kwh/capita/year and fulfilling in average less than 2% of their energy needs with biomass (fig. 5.1). This global energy bipolarization becomes even more striking when considering the lower end of the HDI lists, the dark grey countries in fig. 6.1. For instance, in Sub-Saharan Africa, where the majority of the least developed countries (the countries with the lowest HDI) are located, biomass is the primary (if not the only) energy source for 94% of rural households against 41% in cities (REN21 2008). As for Africa, as a whole, biomass represents 47% of the total primary energy use against the

world average of 10% (IEA 2006a). Conversely, in Sub-Saharan Africa only 4% of rural population have access to electricity and 16% in urban areas (REN21 2008). The large majority of biomass is consumed, both in rural and urban areas, to cook. Indeed, despite the wide range of cooking fuels, with very few exceptions, in DCs between 48 and 88% of the population relies on biomass (as wood, charcoal or dung), a value that rises to 71 to 96% if only rural communities are considered, fig. 5.2. Furthermore, and again, it seems to exist a relationship (even if not linear) between the decreasing value of HDI from DCs to Less DCs and the increasing use of biomass, both in rural and urban areas, fig. 5.2.

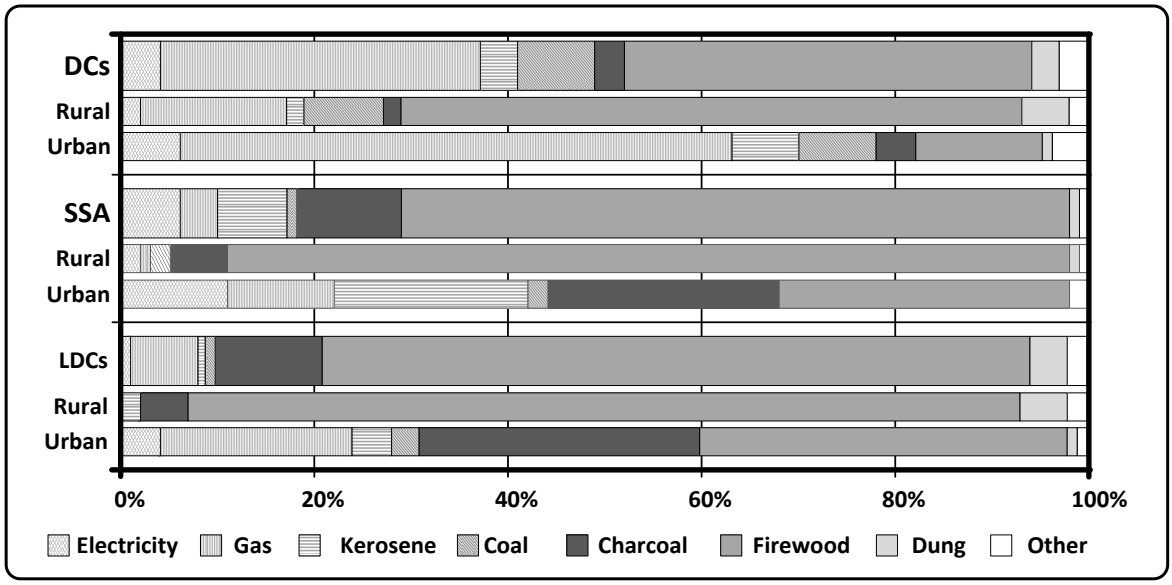


Figure 5.2| Share of total/rural/urban population according to cooking fuels in DCs, the 10 least developed countries (LDCs) and Sub-Saharan Africa (SSA) [Source: the Author based on *Legros et al. 2009*].

Besides the different energy consumption patterns, the access to energy services is also quite different across household income and geographical dwelling in DCs (e.g. WB 2004). In general poor people, and particularly in rural areas, pay proportionally higher prices (in absolute and relative terms) for lower quality energy services (Farinelli 1999; Heal & Kriström 2007; Peters *et al.* 2009), not to count the costs in terms of "time and labour, health and social inequality, particularly for women" (Batlivala 1995). Moreover rural and/or poor people have far more difficulty affording initial technology costs (e.g. fluorescent lights, improved stoves) (Masera *et al.* 2000; Morris & Kirubi 2009; Rajan 2000). Conversely, urban and/or higher income households have better access to information and a wider range of options on energy services and technology and are served with better logistics, quality and relative prices (e.g. Kirubi 2009).

5.2 Perspectives On Wood Fuel & Related Issues

With the importance of WF in DCs established in §5.1, this §5.2 will explore some of the social and ecological issues associated with WF production and use. These issues will be organised here according to already existent and relatively controversial debates on around WF, including: health problems due to smoke exposure; deforestation; gender

bias; forest management; and other aspects. Note., however, that the purpose is not to provide a full comprehensive review of all aspects of all WF related issues, but solely to illustrate how complex and multi-dimensional, ramified and prone to multiple perspectives those relations are. The references provided could lead the interested reader towards a more detailed analysis.

5.2.1 Human Health Energy And Wood Fuel

There are many ways in which WF could negatively impact human health. Technology used to produce or consume WF could injure people through direct physical means or by facilitating unhealthy lifestyles. For instance burning is a common consequence of cooking with firewood (WHO 2002) and growing, collecting, and transporting WF produce many serious occupational health risks (Poschen 1998). Other more environmentally negative impacts include the production of harmful emissions locally (e.g. household, workplace, community) and/or globally (e.g. atmosphere, ecosystems) which then might lead to climate change dynamics, further affecting human health (Wilkinson *et al.* 2007).

An example of local emissions is the so called *indoor air pollution* (IAP) resulting from incomplete combustion of WF in insufficiently ventilated areas resulting in considerable emission of small particles and several chemicals, e.g. carbon monoxide, formaldehyde, nitrogen dioxide, quinones/semiquinones, chlorinated acids. The amounts and relative proportions of the various pollutants generated by WF combustion depend on a number of factors, including fuel type and moisture content, technology, and user behaviour (e.g. Jetter *et al.* 2012). Conversely exposure depends on kitchen location, use and maintenance of stoves, household layout and ventilation, time-activity profiles of household members, and behavioural practices, geographic location, weather, and local vegetation (Smith *et al.* 2012). Among others, IAP has been strongly related with:

- Acute lower respiratory infections (ALRI) in children bellow 4 years (e.g. Ezzati & Kammen 2002; Rehfuess 2006; Smith *et al.* 2000);
- Chronic lung disease (CLD) (Bruce *et al.* 2000; Rehfuess 2006);
- Chronic obstructive pulmonary disease (COPD) (Smith *et al.* 2013);
- Possible higher risk of cancer (IARC 2010) possibly leading to lung cancer (if coal is used) (Hosgood *et al.* 2011; Mumford *et al.* 1987);
- Possible effect on child cognitive function (Dix-Cooper *et al.* 2012), low birth weight (Pope *et al.* 2010), cardiovascular disease (Baumgartner *et al.* 2011; Tolunay & Chockalingam 2012), asthma, cataracts, tuberculosis, and blindness (Rehfuess 2006; Legros *et al.* 2009; WHO 2002).

Overall, it is estimated that IAP caused by household cooking with WF is responsible for nearly 3.5 million premature deaths in 2010 (Lim *et al.* 2012). In sub-Saharan Africa, solid fuel use was the first or second most important risk factor for ill health (Smith *et al.* 2012). Remarkably, most of these deaths are from children and women since traditionally they

are the ones spending more time in the kitchen (UNDP/WHO 2009). In fact, in terms of lost healthy life years, IAP was the second most important risk factor for women worldwide (Lim *et al.* 2012). In addition, household cooking with solid fuels accounted for an average of 16% of outdoor particle air pollution in the world (Smith *et al.* 2012). These data imply that the total impact of household solid fuels was around 4.8% of world lost healthy life years and nearly 4 million premature deaths in 2010 (Lim *et al.* 2012).

Conversely the lack of access to energy might result in lacklustre medical assistance and consequentially affect health (Wilkinson *et al.* 2007). Indirect effects on health may occur when fuel becomes scarce or if wood energy prices rise. Protein-rich ''hard'' meals (e.g., with beans or meat) may be avoided or undercooked to conserve energy and families may rely heavily on low-protein ''soft'' foods (e.g., grains and greens) which can be prepared quickly (O'Keefe *et al.* 1984; Brouwer *et al.* 1997). In other cases, families may stop boiling drinking water when faced with an energy shortage (Plummer 1999). In rural Uganda with less access to forest WF rural household have to rely on lower quality and less quantity of WF, which is related with a 2.4% increase in the incidence of ARI for children under five in those areas (Jagger & Shively 2014)

To finalise, two relevant aspects should be mentioned. First, despite available data, most researchers avoid direct and simplistic links between WF and health problems, instead there is a concern to highlight the complexity of the issue and how contextual data is relevant to make a full analysis. Secondly, most users of WF do not perceive the possible associated health risk, and thus not mention it as a drawback in WF use (see §5.3.2).

5.2.2 Gender, Energy, Wood Fuels & Context

Men and women have different perceptions, and establish different relation with, energy but have also different access to resources and decision-making within the household (e.g. Cecelski 2004; Clancy *et al.* 2003, 2012; Tragett 2012). Women represent 70% of the world poor (Masud *et al.* 2007) and are traditionally the responsible/knowledgeable for the energy management chores which include enduring, e.g., the drudgery of long walks with heavy loads of firewood and smoke inhalation while cooking, §5.2.1. Women and men also "see" energy, or better said the services that energy provides, differently. In a synthesis report on micro-hydro power Khennas & Barnet (2000) noted that women in Sri Lanka saw the benefits largely in terms of reduced workloads, better health, and reduced expenditures, whereas men saw the benefits in terms of leisure, quality of life, and education of children. However, women have a usually restricted role in energy decision-making within the household and community (e.g. Masud *et al.* 2007), for instance in terms of fuels used, amounts of energy purchased, the devices and technology chosen, as well as domestic design characteristics (Agarwal 1986; Cecelski 2004; Masud *et al.* 2007). As an example, in the context of community based forest management, decisions regarding what trees should be grown in community forests and/or plantations are made

by men which tend to focus on cash money activities (e.g. construction materials) and this prevents the planting of trees for firewood (Agarwal 1986; Hyma & Nyamwange 1993; Leach & Mearns 1988). In other cases, local beliefs about whom is supposed to plant trees and what planting a tree on an unclaimed piece of land means, limits the access of women to higher quality wood resources, leaving available only marginal areas along roadsides or in gullies which are far away or difficult and risky to explore (Rocheleau & Edmunds 1997; Schroeder 1997). These perspectives and thinking have been used since the 1970s (Wamukonya 2004) to design initiatives specifically designed with and for women could hold great impact in local development, gender-based asymmetrical entitlements (e.g. access to land); and design of devices and energy systems (e.g. Cecelsi 2004). In general terms, these initiatives include the design improved stoves and provision of electricity, particularly decentralised and focused on productive because they alleviate WF chores and risks and give women direct control of acquisition, design, placement, and consumption decisions, whereas, for instance, they often exert less control over male-dominated, utility-cantered grid systems.

However, recent research trends (e.g. Cecelski 2004; Njeri 2002; Wamukonya 2004) re-examined these assumptions, questioning if the gender-based differentiation is the result of women being women, or rather the consequence of the household being poor. For instance it has been reported that (Wamukonya 2004): in well-off households at DCs, WF are gathered by paid help and/or delivered to the house mainly by men; men also collect wood in many DCs; and that households do move away from the hard and hazardous work related with WF once other option are available in terms of income, technology and resources. Furthermore, gender-based energy approaches tend to treat women as a homogeneous and unprotected group, mostly projecting a paternalistic and unfitted perspective to the wide range of marked differences in class, education, purposes, perspectives and political power (Cecelski 2004; Tragett 2012).

Related with this view is the belief that female decision makers would address women's energy needs more effectively. However, the policies engendering to increase the number women in decision places resulted in artificially adding women to fill quota, but with no real power, increased other disruptive dynamics (e.g. nepotism, women as "rubber stamps"), and realised that women might have (and normally do) other agendas (Tragett 2012; Wamukonya 2004). Therefore, several initiatives designed specifically to "facilitate" the life of women end up abandoned by the very same women they intended to "help", have been taken by better-off or more entrepreneurial women and even motivated the active confrontation by women. A case mentioned in one of the interviews [2] in Mozambique involved a community where women refused new technologies because it would make the traditional wood fetching unnecessary, and they

2 Throughout the thesis individual and group interviews will be designated simply as "interviews" and there will be no further identification of the origin for privacy and anonymity, since there was any agreed or explicit compromise between the author and the interviewee regarding the use of names.

enjoyed that time to socialise and pass knowledge to the younger. There are also records of women that refused to use the more efficient and less smoky improved stoves, since it only accepted small pieces of wood, which increased the cooking time many times (Cecelski 2004). A case reported in South Africa (but for sure existent in Mozambique) states that a woman, responsible for a house development programme in South-Africa was on the run from police for illegally charging neighbours she was supposed to assist, for electricity and refrigeration services she provided for a fee from her house (Wamukonya 2004).

Therefore, the extent to which the women and energy approaches have achieved the intended goals of relieving women's energy-related problems remains limited (Cecelski 2004; Clancy *et al.* 2012; Wamukonya 2004). It is likely that this could be attributed to the conception of the problem as a "technology for women" instead of what *particular and differentiable women* in a *particular social and cultural context* and assess their values in terms of energy services and provide them with tools to design their own views.

5.2.3 Energy And Ecology: Deforestation & Community Forest Management

Forests, and their management, are in the epicentre of the WF debate, linking poverty reduction, environmental conservation and energy consumption (e.g. Dubois 2003; Rudel 2013). In many DCs, and in Mozambique in particular, most poor live in, or near, a forest, and depend heavily on that forest for energy, food (e.g. mushrooms, honey, game), medicines, construction and clothing material (e.g. wood, fibres), and cultural and religious services (ecotourism, religious ceremonies, burial grounds). On a more global perspective forests are also important for carbon fixing which affects and regulates climate change, hydrographical basins and hydrologic regime regulation, biodiversity conservation and soil erosion (e.g. FAO 2013; Hicks *et al.* 2014). Therefore, deforestation is perceived as a central environmental and political problem (e.g. Humphreys 1996), which has insistently been linked with WF through the "firewood gap", i.e., the possibility that an excessive wood demand by a growing population in DCs would exceed sustainable supply causing deforestation and consequently global environmental disaster and acute energy scarcity for billions of people (Anderson 1986; Leach & Mearns 1988). Representing the forest version of the "tragedy of the commons" (Hardin 1968), the "firewood gap" has been consistently and extensively challenged on the grounds that deforestation is a complex and contextual process involving a number of dynamic and interwoven causes other than energetic needs (e.g. Bailis *et al.* 2012; Barnett 1990; Bradley & Campbell 1998). Hence, besides energy practices, studies had related deforestation with: agricultural practices, both by mega governmental projects (Angelsen & Kaimowitz2001) or local burn and slash agriculture (Clark 2012); natural or human caused fires (Cochrane 2009; Delmas *et al.* 1991); weather and demographic phenomena (Clark 2012; Rudel 2013); prevailing (or inexistent) energy policy (Humphreys 1996; Mwampamba 2007); and illegal and/or extensive logging (Poore 2004). According with

these studies, forests are dynamic ecosystems, and thus a cause of deforestation in one place can be part of regeneration in another place, or deforestation can be the result of mutually enforced causes. Moreover, it is not clear if the wood for energy comes from forests (Contreras-Hermosilla 2000) or from the agricultural landscape outside forests (O'Keefe & Van Gelder 1995). Nevertheless, energy needs do impose pressure on the tree cover particularly in DCs (Geist & Lambin 2001) where WF supply/demand has become an informal growing business (e.g. Bailis 2005). Besides these impacts, charcoal production on earth kilns accounts for an estimated 2% of global GHGs emissions and (Bertschi *et al.* 2003; IEA 2006b; Pennise *et al.* 2001) and effects the soil (Ogundele *et al.* 2012).

In the context of deforestation, rural communities tend to be portrait in the literature in one of two ways: as opportunistic forest managers and land users who choose fast income over long term conservation; or passive victims of poverty. Against this somewhat negative view on WF (particularly charcoal) and poor communities (particularly rural) three approaches have been proposed with relevancy for this work. The first endorses a "WF is sexy" campaign, mostly focused on charcoal, defending that, providing the right set of conditions, WF could sustainably provide many social, economic and environmental benefits, including poverty alleviation and forest conservation (Hosier & O'Keefe 1983; Miranda *et al.* 2010; Mwampamba *et al.* 2013; Openshaw 2010; Owen *et al.* 2013). According to this proposition, the set of conditions to be met should include: efficient management and operation from production to consumption; efficient and effective production/consumption technology; and the clear and consistent political, legal and market mechanisms. The second approach, partially a reaction to the "tragedy of the commons", emphasises that local people are not moved exclusively by economic or opportunistic behaviours towards forests and natural resources, but rather have valuable knowledge, sound practices and sophisticated systems for forest management that ecologically and socially benefits and suits their context (e.g. Berkes *et al.* 2003; Ghai 1994; Weir *et al.* 2013; Wiersum & Slingerland 1997).

This perspective on indigenous management has been operationalized through the community based natural resource management (CBNRM) defined as: a set of policies, practices and benefit-sharing arrangements involving rural communities knowledge and practices in the management of natural resources in their area of residence (after Adams & Hulme 1999). Finally, political-ecology and/or political economy provide the third and last perspective. Critical to the previous views, this perspective poses deforestation as part of a network of practices, knowledge and livelihoods in a wider socio-ecological and political context (e.g. Cline-Cole 2006; Meyer2011; Sander *et al.* 2013). The use of forest for WF is only one aspect of the overall local use-pattern of natural resources and is as much as a consequence as a sign of complex power relations established between all the intervenient in the process, from consumers to producers, from policy makers to International Donors and local NGOs. It has repeatedly been demonstrated (Atanassov *et al.* 2012; Meyer2011; Sander *et al.* 2013) that, for example, the linkage transporter–

wholesaler are the *de facto* controllers of the charcoal sector, however, policies are often targeted at consumers and producers (Sander *et al.* 2013). Moreover, between urban and rural households there is also a manifest cleavage regarding livelihood strategies and perceptions of "natural resources", which leads to different reactions towards political and international development interventions and can also lead to conflict (Meyer2011).

This divide is further extended to researchers, policy makers and forest managers (Adams & Hutton 2007), which tends to result in political speeches on deforestation in DCs that are contradictory and very often detached from reality (Adams & Hutton 2007; Sander *et al.* 2013). In another example, in Kenya, the prohibition to cut trees resulted in increased trees being cut inside a neighbouring national park, something they did not do before (Bailis 2005). Naughton-Treves *et al.* (2007) state that in Uganda domestic consumers use a wider range of species for fuelwood (>50), but they generally harvest fast-growing species from fallows on their own land or their neighbours, while charcoal producers prefer some few old-growth hardwood species and are, thus, responsible for the greatest loss of natural forests. This fact is further exacerbated by a license system that "undervalues natural forests and rewards rapid harvests across large areas" (Naughton-Treves *et al.* 2007). In resume this political-ecology/economy perspective highlights the complex and dynamic nature of the household strategies, "WF business", and the socio-ecological subtract where they both evolve.

Remarkably there is not much research linking these three approaches, and particularly liking CBNRM and WF. Unlike CBNRM, the "WF is sexy" approach perceives the forest as a provider of resources and, actually, tends to prefer plantations, that is, the creation of artificial forests, specially designed to fulfil the energy purpose. In other words, it seems that the "sexiness" of charcoal outshines all other dimensions of the forest or impacts on the forest since this approach has a utilitarian view of the forest, stripped of all social and cultural dimensions except for the biological and ecological fit based on best productivity. In this scenario local communities have little to offer in terms of dedicated and contextual knowledge except maybe, the information of geographical and biophysical conditions and labour force. Indeed, and again distinctively from CBNRM, expert knowledge, modern technology and top down policies and/or legislation tend to be the preferred options of the "WF is sexy" approach.

On the other hand, CBNRM while embracing a complex and multidimensional perspective of the forest, tends to favour trying simultaneously to conciliate local, national and global knowledge, perspectives and interests. CBNRM privileges the dialogue, knowledge transfer and participation as main methodological guideline, but always with the intention to conserve the resource from a centralised perspective. Therefore, CBNRM fails to address the use of WF as part a complex forest management. This might be explained by with the overarching concerns around forest conservation and biodiversity, which forces the focus to non-destructive activities, like non-wood forest products (e.g.

natural medicines; edible fruits) and activities (e.g. tourism) or, eventually, community run timber enterprises. With the insights that political economy/ecology approach provides some new bridges and approaches to deforestation in a wider socio-ecological context outside the mostly managerial perspectives of "WF is Sexy" and CBNRM, However, this approach seems to be caught up in the long standing "dialogue of the deaf" between political science and social sciences (Agrawal & Ostrom 2006; Boulanger & Bréchet 2005). This lack of productive interaction can also be caused by the absence of tools to support such dialogue, only a wide set of mainly prescriptive and normative best practices, analysis and arguments articulated normally around development projects in DCs (Mefalopulos2008).

Besides this realisation, for the purpose of this thesis (§3) three relevant aspects should be highlighted. First the acknowledgement that forest, deforestation and forest management are not isolated events, but interweaved complex realities with many dynamic and unpredictable consequences and motivations. Second, the existence of different perspectives in livelihood, research and policy that could be articulated across different: knowledge (expert, indigenous); levels of analysis and decision (e.g. local, global); and focus (e.g. political, technical). Thirdly, the need, exposed by all the three perspectives mentioned, for a more meaningful and engaging dialogue that acknowledge both the WF as part of a more complex reality and the disparity of power, knowledge and interests across different actors involved in WF (Adams & Hutton 2007; Chidumayo & Gumbo 2013; Naughton-Treves *et al.* 2007; Sander *et al.* 2013, see also §C).

5.3 Wood Fuel In Mozambique: A Contextualised Analysis

The previous §5.1-2 established a comprehensive and generic image of WF production and consumption and related issues in DC and simultaneously introduced some of the more relevant debates around them. Here these debates will be further explored in the context of Mozambican reality, keeping always in mind that this analysis will serve to define the envisioned design tool (§2-3, §D).

5.3.1 Energy In Mozambique: Wood Fuel

Mozambique is quite a paradigmatic case of the general picture described for DCs in §5.1 with a hint of paradox. Since the HDI have been reported by the UN in 1988, Mozambique has consistently occupied a position within the 23 least developed countries. Available data from 1999 to 2013 indicate that 44.1-79.3% of the population is poor or live in severe poverty[3] (e.g. MPF 1999; OPHI 2011; PARPA 2001; UNDP 2014). Moreover, with a growing population of more than 20 million (INE 2007) experiencing annual rates of urbanisation over 3% per year, Mozambique still has 70% of its population living in rural

3 This disparity in results is associated with the way poverty is defined and measured, see PARPA (2001), UNDP (2009), (WB/WDB) and (UNDP 2014) for definitions and data.

areas. Combining this data, it is possible to estimate that before 2003, 71 % of rural populations were poor against 62% in urban areas (Cuco *et al.* 2003), while data for 2009 indicates an incidence of poverty of 56.9% in rural areas and 49.6% in urban areas (WB-WDB). In total a calculated 72.1-82% of the Mozambican poor live in rural areas. Remarkably, and despite these dramatic numbers, Mozambique is also one of the fastest growing economies in the world with an average annual rate of Gross Domestic Product growth of 7.4% in the period from the end of the civil war in 1992/1993 and 2013 (WB-WDB).

Roughly covering the same period fig. 5.3 shows the Mozambican total national energy consumption growing from 4736ktoe in 1990 to 8078ktoe in 2011. With small industry and transportation consumption, the large majority of energy demand in Mozambique comes from the household sector with an average 77.8% of the national energy demand for the period considered. Coincident with the general energy profile of DCs (fig. 5.1), in average and for the same period, 98.3% of that household demand was supplied by WF, a fact represented in fig. 5.3 by the almost coincidence between WF for household (dotted line) and the residential sector energy demand (white square markers).

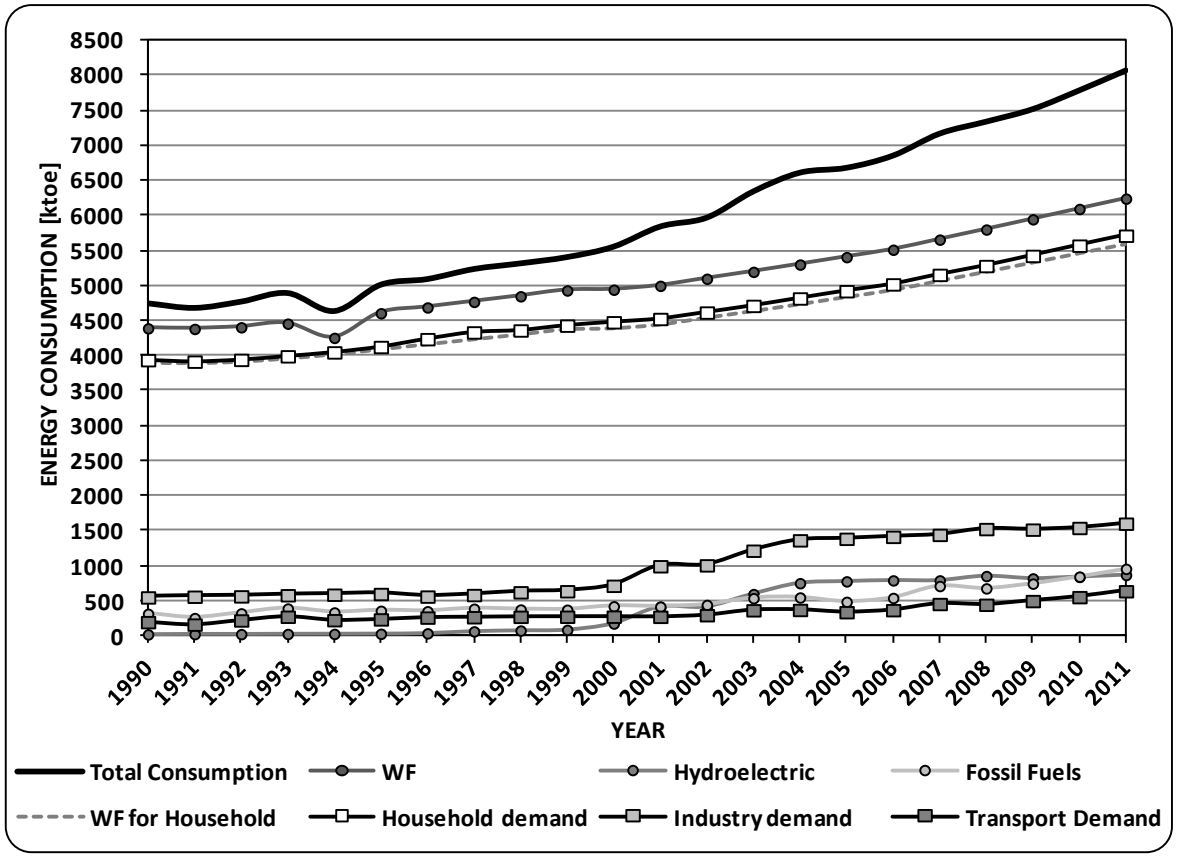


Figure 5.3| Total energy consumption in Mozambique from 1990 to 2011 according to energy source and economical sector [Source: the Author based on data from IEA-Stat].

Conversely, for the same 22 years, an average of 89.2% of all available WF was spent on supplying household needs, while the remaining WF were consumed in institutional services (e.g. in rural schools, hospitals, restaurants) small-scale industries, like beer

brewing, baking, brick production, and tobacco curing (e.g. Brawer & Falcão 2004; ZERO 1998). Household, and to a great extent institutional and commercial, use of WF, is almost entirely dedicated to boiling water and cooking, for which Mozambique cuisine requires long and intensive cooking times (e.g. Cumbe *et al.* 2005). Thus, not only the household sector relies almost exclusively on WF, but most WF is produced to fulfil household needs, particularly cooking needs, (EFI 2003; Fernandes 2013; Nacala & Cuamba 1998).

Considered isolated, the WF represents an average of 86.3%, and consistently over 77% of the total national energy consumption, which is a clear statement of the importance of WF in the Mozambican energy profile. Moreover, for the period considered in fig. 5.3, the WF consumption also increased steadily at an average rate of 1.6% per year, a trend also identified in other studies. For instance, the annual average consumption per capita of WF in urban areas of Maputo has been calculated as 0, 82m^3 (Bila 1992), 0.9-1.0m^3 (Brower & Falcão 2004), 1-1.20m^3 (Sitoe *et al.* 2007a) and around 1.32m^3 (based on Atanassov *et al.* 2012). However, despite its importance, WF and the household sector in the energy consumption have been decreasing in relative terms in of the overall energy consumption. If in 1990 4394ktoe/year of WF represented 92.8% of all energy consumed, in 2011 8078ktoe/year of WF represented 77.3% of the national demand. This result is related with the growing economic importance acquired in recent years by the industry and transportation, sector largely based on electricity and/or fossil fuels. In fig. 5.3 this dynamic is perceptible by the almost overlapping of these sectors and energy resources in lower right end of the graphic. Notably, here resides the energy paradox of Mozambique. Despite having one of the ten lowest electrification rates in the world, 17.1%-20.2% in urban areas and 0.7-2% of rural areas (IEA-Stat; Cumbe *et al.* 2005; Karekezi *et al.* 2005), and also having one of the twenty lowest energy consumption in the world, 0.415-0.425toe per capita (ADB/OECD 2004; WB-WDB; WRI 2010), Mozambique is a net exporter of energy. Cahora Bassa, one of the largest hydroelectric dams in Africa exports over 90 % of its total production (2075MW). In 2009 in Mozambique the proven reserves of natural gas were 127.4 billion m^3 (50th in the world) (CIA-WFB), a part of which is also exported. Part of the estimated 3 billion tonnes coal reserves in Mozambique are also being explored to be exported.

From the supply side, since Mozambique does not import WF, the energy pattern depicted in fig. 5.3 could be understood with low population density and large stock of "money-free" WF available to a large low income population (e.g. IEA 2006a; McDade *et al.* 2006). Indeed, Mozambique, a rural DC, has a population density of 25.7 people per km^2 (ranging from 9.2 people per km^2 in Niassa to 1861 people per km^2 in Maputo) (INE 2007)[4] and a road density of 3.8km per 100km^2 (WB-WDB). Hence many communities

4 which is rather low compared, for instance with the 256 people per km^2 in UK according with the last 2011 census (http://www.ons.gov.uk/ons/guide-method/census/2011/index.html).

(families) live isolated in rural areas. Supplying these communities with natural gas or grid electricity has high capital costs and low investment return since these low income households tend to have low energy consumptions (e.g. Zerriffi & Wilson 2010). Renewable energy technologies (RETs) available in Mozambique are still expensive and cannot provide enough power for the long and intensive cooking times, typical of Mozambican households. In these conditions culturally embedded WF seems a logical energy option basically because there is enough wood available and accessible as an overview over the several estimations on forest cover in Mozambique can show, tab. 5.1.

Table 5.1| Estimates of forest cover in Mozambique (% MZ AREA- percentage of the total Mozambican surface area) [Source: Adapted by the author from Sitoe *et al.* (2012)].

AUTHOR	COVER [1000 HA]	% MZ AREA	YEAR	OBSERVATIONS & INFORMATION SOURCE
Saket[1] (1994)	19700	25.1	1990	Canopy cover from 25% height Satellite images and aerial photograph
FAO (2001)	30601	38.9	2000	Data from the National Forest Inventory, Satellite images and opinion of experts
Marzoli[2] (2007)	40600	51.6	2002	Canopy cover from 10% height Satellite images and field measurements
FAOSTAT	43378 39022	55.2 49.6	1990 2010	Data from the National Forest Inventory, and model based on population density

NOTES: 1- First National Forest Inventory; **2**- Second National Forest Inventory.

As it can be seen in tab.5.1, depending on the definition of forest and the measurement technique used, the value of forest cover can be very different. However, considering only the less conservative criteria (i.e., excluding Saket 1994) the total forest cover is around 50%, quite a high value, particularly in Southern Africa. Moreover, besides the amount of available wood, it is important to know which is actually useful to produce energy. According to Marzoli (2007) 67.2% of the total forest cover is productive forest with high timber volume, that is, forest with over of 32m^3/ha located outside the protection and conservation zones (Marzoli 2007). While providing an indicative value, by law, species with commercial value cannot be used to produce WF, particularly charcoal. Likewise it is not clear if the remaining 32.8% 32m^3/ha located outside the protection and conservation zones can be used to produce WF.

Still in the supply side of this energy analysis on Mozambique, it should be noted that besides WF other biomass and bioenergy alternatives have been proposed and in some case implemented in Mozambique, notably trying to take advantage of the untapped agricultural potential to produce biofuels. There are two basic technological paths to produce biofuels: converting residues; or use dedicated energy crops. In both technological paths Mozambique is considered as one of the most promising countries in Africa (Arndt *et al.* 2003; Batidzirai *et al.* 2006; Econergy 2008; Schut *et al.* 2010). Nationwide forest related residues from timber processing industries and logging have an

estimated potential of about 2.7PJ (Smeets *et al.* 2004) and in the Maputo Province a GIS based measurement in 2004 estimated a total production of forest biomass residues around 1233412ton/year which could supply 236520MWh, the equivalent to 32% of the energy consumed in Maputo province in 2004 (Vasco & Costa 2009). However, the difficult logistics, high dependence on timber processing and low energy gain make it less attractive in commercial terms than, for instance, dedicated crops (e.g. Batidzirai *et al.* 2006; Fath 2002). Furthermore, the so called "residues", can have other purposes such as animal feed, fertiliser and energy, and net availability is therefore generally low (e.g. Maya *et al.* 1993). An exception could be processing residues from the sugar industry present in the country for centuries. Based on current and expected production it was estimated that 994000ton/year could be produced by 2010 (Deepchand 2001). Simultaneously, the Mozambican Government implemented a number of energy policies aiming to promote and regulate the biofuels market, promulgating, e.g., the Biofuels Strategy and Policy (BR 1-20). Nevertheless the majority of biofuels projects implemented were ultimately a failure (§7.2.1) and those which actually achieved some success (§7.2.1) represent a much localised local impact, e.g. small village project or specific sector in a localised area urban area (Schut *et al.* 2010; von Maltitz & Setzkorn 2013; Vissers & Chidamoio 2014). In relation with the forestry potential presented in tab. 5.1, there is also some investment in timber plantations, which represent less than 0.1 % of the total land area (Batidzirai *et al.* 2006). Finally Legros *et al.* (2009) mention that 0.2% of energy consumed in Mozambique comes from dung, and there are indeed less than 10 biodigesters, nationwide, most not working, and some households or industries might burn occasionally waste for energy[5].

In resume, this brief comparative demand/supply review of WF potential and biofuels experiences in Mozambique confirms what was pointed out countless times by experts and observed throughout the field work: the utmost consistent relevance of WF both in the national and household level; and the insignificant and very localised inputs (in geographical and time terms) that all other renewable energies provide to households[6].

However, for this analysis to be complete, it is necessary to go beyond the WF to address the household energy strategies, particularly considering the breach between rural and urban realities highlighted in §5.1 (fig. 5.2). Indeed, both rural and urban households rely heavily on WF for energy, although with distinct energy patterns, dynamics, practices and strategies.

In terms of quantity of energy consumed, the tendency in the literature is to indicate higher values for urban areas, However, only one study was found for Mozambique that

5 Mozambique also has potential for solar energy and limited potential for wind energy, but presently none of this energy sources is being explored at significant levels (REEEP 2009).

6 This result is important since the IEA-Stat (the data source for Fig. 5.3) does not consider WF as a database entry, but "combustible renewables and waste", i.e., bioenergy (see Glossary of Terms). However, as it analysis above shown, for the context of Mozambique "combustible renewables and waste" means WF.

actually quantifies that tendency. According to Sitoe *et al.* (2007a) rural consumption is around 9.3million tons/year against 5.5million tons/year in urban areas, which means an estimated annual consumption per capita of 602kg for rural areas and 816kg in urban areas (calculated by the Author based on WB-WDB data for rural and urban population in 2007). Another common assertion in Mozambique (as in other DCs, §5.1) is that rural households rely almost exclusively on WF while urban households fulfil 20-30% of their energy needs with other fuels (e.g. Bila 1992; SADCC 1998; Williams 1983). While for isolated rural areas these numbers might still be accurate, they do not tell the entire story, since the issue is not so much the energy, *per se*, but the energy service in a wider socio-ecological context, which is changing continuously. In the absence of recent quantitative rural consumption studies, two relatively recent urban energy will be compared, tab. 5.2. Despite the possible methodological and geographical differences in the studies, for indicative purposes, the number and diversity of household options and regional and chronologic variations in choice presented in tab. 5.2, are a clear expression that WF strategies are contextual, dynamic and do not follow linear cause-effect logic.

Table 5.2| Comparison of urban household WF strategies in 2004 for Maputo and in 2012 for Maputo, Beira and Nampula [Source: Adapted by the author from Brouwer & Falcão (2004) and Atanassov *et al.* (2012)].

PERIOD	**2004**	**2012**		
ENERGY OPTIONS	**MAPUTO**	**MAPUTO[1]**	**BEIRA**	**NAMPULA**
Charcoal Only	11.7%	35%	64%	77%
Charcoal/Others[2]	45%	41%	18%	9%
Firewood Only	2.1%	6%	8%	7%
Firewood/Others	1.7%	0%	0%	0%
Charcoal/Firewood	6.7%	9%	3%	7%
Charcoal/Firewood/Others	8.3%	2%	0%	0%
Others Only	24.7%	7%	8%	0%
SAMPLE SIZE[3]	**240[3]**	**710[4]**	**611[4]**	**699[4]**

NOTES: 1- Also includes Matola a neighbouring town; **2**- All non WF sources; **3**- Bakeries, restaurants; industries; hospitals and households; **4**- Producers, transporters, institutions and households.

In quantitative terms, tab. 5.2 shows the overwhelming use of WF in urban households regardless of the presence of other "modern" alternatives, including electricity, LPG and gas. Alone or combined, WF is presented in the strategies of 92-100% of all households in the three cities in 2012. This represents a kind of inverted or twisted energy ladder also identified by other authors (Arthur *et al.* 2010; Brouwer & Falcão 2004; §6.1, §7.5.1). In the case of Maputo, in 2004 24.7% of consumers did not consider WF for energy, while in 2012 only 7% followed that strategy. In the same direction, within 8 years, the use of a relative weight of WF used alone in households more than tripled. Notably, the change in WF type from firewood to charcoal in urban areas is relatively recent and strongly related with the recent history of Mozambique (§5.3.2). Before the end of the civil War, Mansur & Karlberg (1986) calculated that 91.1% in weight of all WF entering in Maputo was in the

form of firewood, while Williams (1993) soon after the end of the war estimated also for Maputo a per capita daily consumption of 1.16kg of firewood and 0.16kg of charcoal. However, less than 10 years later, Brouwer & Falcão (2004) not only show diametrically opposite results, with charcoal completely overthrowing firewood as the fuel of choice, but more importantly, doing so within a context of wider fuel options, tab. 5.2. This fact is more relevant when from 2004 to 2012 in Maputo the use of charcoal as the only option increased while the use in of non-WF decreased from 24.7% to 7%. Comparing data from the same study of 2012 and considering the three cities, however, it is possible to see that Maputo, where there are more energy options in terms of prices and quality, and more households with relative higher income (INE 2007) the diversity of strategies is wider (6 in seven possible) and the integration of non-WF in household strategies also higher (50% of strategies use other non-WF and 7% exclusively non-WF). To finish it should be mentioned that much of the firewood considered by Atanassov *et al.* (2012) is actually not for households, but for bakeries (bread tastes better with firewood people say), which numbers has increased dramatically over the last few years.

Returning to the rural-urban divide, besides the quantity, and relative weight of options in energy strategies, rural households tend to use firewood while urban households prefer charcoal. This difference in WF type implies different social, economic and environmental impacts on WF consumption. This difference in impact could be explained by the difference in production process. Firewood can be harvested from (more or less) nearby trees according to household energy needs, e.g., by cutting dry branches or trimming bushes (e.g. Convery 2010). In contrast charcoal making (Sitoe 2013)[7] requires cutting the entire tree, including small ones[8], wasting leaves and small brunches, to produce 1kg of charcoal for every 7-10Kg of wood (ABIODES 2009; Cumbe *et al.* 2005; Joaquim 2001; Schenkel *et al.* 1998). However, compared with firewood, the combustion of charcoal produces less smoke, less dangerous emissions and particles (e.g. Smith *et al.* 2012), has a higher calorific power and is more compact. Consequently charcoal has continuously been linked with deforestation in Mozambique (e.g. Cuambe 2008; Maússe 2013; Pereira *et al.* 2001; Sitoe *et al.* 2007a), while firewood is associated with IAP (Brauer 1998; da Costa *et al.* 2004; Elegard 1996; 1997; Legros *et al.* 2009). As it will be further explored in §5.3.2, this is not that simple, as Mozambicans in rural areas tend to cook in the open and can eventually cut entire trees for firewood, while charcoal making is only one of several reasons for deforestation alongside, or in combination with, e.g., agriculture expansion.

In economic terms, based on an estimated WF consumption in 2003 of 16million m3/year generating about US$ 706 million (e.g. Sitoe *et al.* 2007a), this research calculated that presently over 24million m3/year of WF are being consumed in a more than 800 €/year business (based on data from Atanassov *et al.* 2012). Considering the weight of charcoal

7 The most common process is known as “the boat kiln”. For a description see Manhiça & Duraisamy (2006).
8 Small trees (diameter at breast height < 20 cm) are preferable due to easy felling and handling, resulting in clear cutting (Sitoe *et al.* 2012).

in these numbers, and the inefficiency of charcoal making, these costs are much higher in terms of forest loss. Moreover while a few decades ago, Maputo was served with WF produced in a radius of no more than 60km, nowadays WF comes from 400-450km, which adds transportation and middle-men costs. Therefore, if Falcão (2000) calculated that considering the Consumer Price Index the real price of WF actually decreased from 1985 to 1999 when WF basically firewood was provided by nearby forest, today SNV (fig. 5.4) claims an average increase of 200% in charcoal price from production site to Maputo.

In conclusion, the insights and data from literature, interviews and scenario projections (e.g. Mulder 2007) seem to indicate that WES are, and will be in the near future, the accessible/preferred energy choice for large sectors of Mozambican society. The underpinning dynamics of this reality will be briefly explored in the following §5.3.2.

5.3.2 Wood Fuel In Mozambique: A Tree Of Problems

In 2007 SNV (the Dutch International Cooperation Agency) organised a meeting in its headquarters in Maputo where most of the experts, NGOs and governmental institutions related with the issue of biomass in Mozambique were present. A rather useful outcome of that meeting was a tree of problems for Biomass (TOPB), fig. 5.4 (next page). In accordance with the present work and Mozambican reality, for the invited experts and SNV, biomass meant, *de facto*, charcoal and firewood (WF), although considering the possible environmental impacts (§5.3.1) charcoal receives most of the emphasis. The TOPB integrates in a simple and visual format the main WF related topics similar to the one produced in §5.2 but completely focused on Mozambique, and thus, will be used as a platform to discuss some of the findings produced in interviews and literature review on WF in Mozambique. The only numbers provided, are within the values provided in §5.1 and will not be further analysed here except the informal character of the charcoal business, as an expression of the importance of legislation and policy in this market (§14.6.10). A common number advanced is that 98% of the WF business in Mozambique is carried through informal mechanisms and networks without any significant government intervention or taxation (Cumbe *et al.* 2005; Gatto 2003). With “low capacity to impose legislation” and “No law enforcement” as root problems, the TOPB exposes three important results. First not only the state loses substantial tax revenue from the profitable WF business, but the rural communities are also deprived since, by law, they are entitled to receive 20% of all profit done within or with resources within their land[9]. Second the informal character of WF business and the current power relations among the different actors involved result in rural producers and city retail sellers receiving much less from WF business than the transporters and wholesale traders (Atanassov *et al.* 2012; Brouwer & Magane 1999; Sepp 2008). This is a result are also found in Nicaragua

9 However, these 20% have to go through such a bureaucratic process, that the direct payment (bribery) by the charcoal transporter in the rural area is far more convenient transaction for the rural producer.

(van Buren 1990) and Senegal (Ribot 1998) which conclude that within WF networks, the distribution of wealth and labour is defined by class, gender and access to resources and markets (van Buren 1990; Ribot 1998). For the city of Maputo, it was estimated that transporters had an income double of the producers, wholesalers and retailers combined (Atanassov *et al.* 2012). Third there are also environmental costs. As mentioned in §5.3.1 according to the law, only trees without commercial value or unfit to other purposes (e.g. construction) and with a certain diameter can be used for charcoal, which greatly reduces the productive volume available for charcoal. However, since the absence of effective

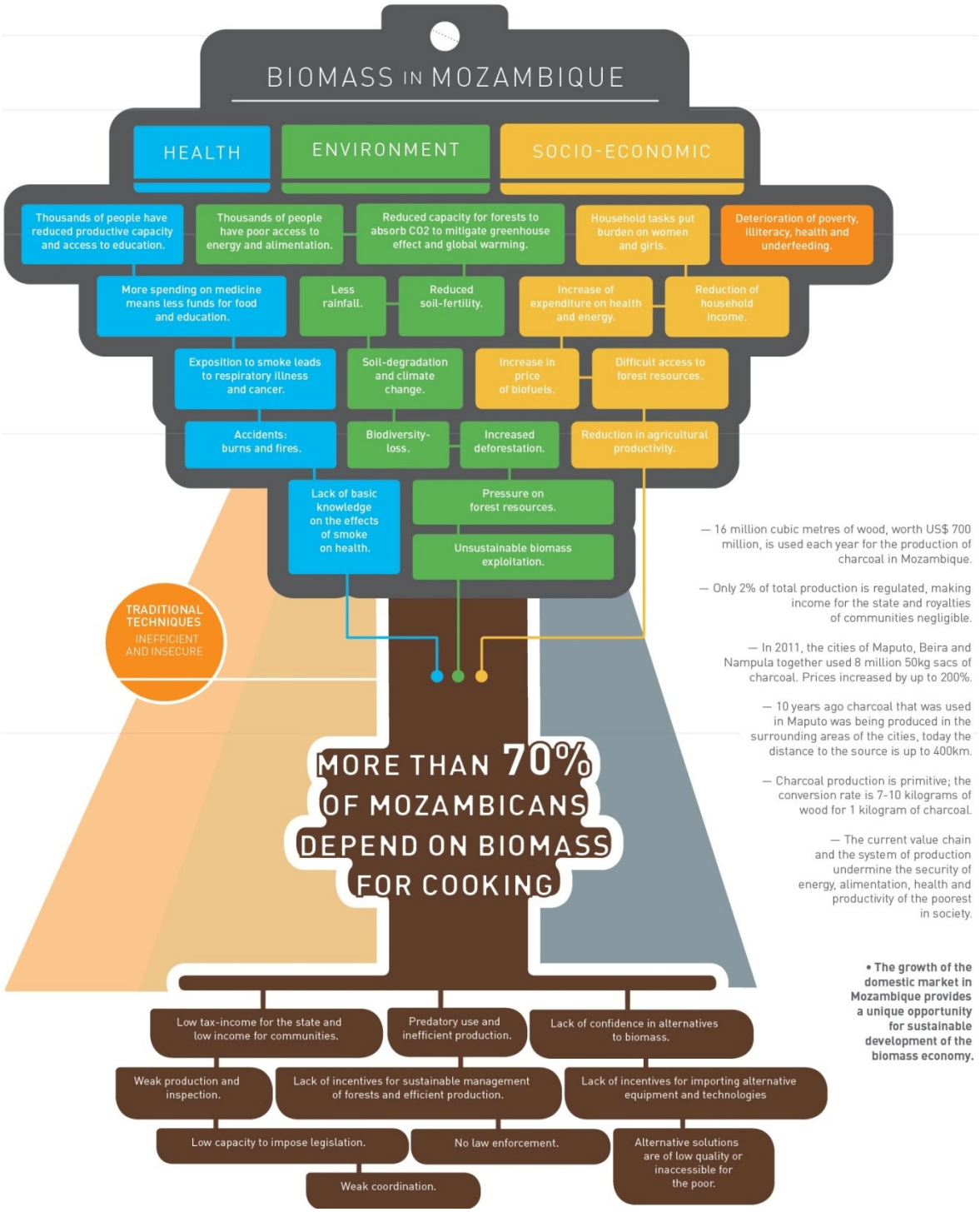


Figure 5.4| Biomass Tree of Problems, created in a 2007 Workshop by SNV at Maputo [Source: SNV].

control, clearly bypasses these regulations, they are not followed, especially because high density trees provide higher quality charcoal and small trees are easy to handle. Thus, there are several records of entire areas being cut including semi-precious, precious and culturally relevant trees[10].

Another related issue is the ownership and tenure of the land and trees where WF is consumed, that is, rural areas. According to the constitution, the land belongs to the State, However, local communities have a historical right over them and their own cultural beliefs, laws and practices for forest management (e.g. Albano 2001). However, the civil war forced populations to migrate disrupting the social fabric that legitimised those laws and practices (e.g. Convery 2006). This situation generated a scenario where nobody is really "local" to claim the land or specific forest management practices, while by law the land is belongs to the State, that is, to everybody, or some would say, to nobody. Simultaneously there is a complex "customary network" of laws, cultural beliefs and legitimisation issues regulating what can, and cannot be done, and who is and is not the true owner or tenant of the land. In this context WF, and particularly, charcoal production is carried out in "communitarian land" (or nobody's land) and operated seasonally by local farmers, and all year round by itinerant or licensed professional charcoal makers vaguely according with that "customary network".

Itinerant charcoal makers relocate when the production areas have been depleted, while licensed charcoal makers explore assigned areas. The "predatory use" referred in one of the "roots box" in the TOPB refers to those WF producers that operate in opportunistic manner for the economic gain only. These producers tend to have few bonds to the local community, and thus fail to respect tenure, legislations and practices both from the country and from the rural area (interviews). As a result, the continuous inability by the authorities to enforce the law and monitor the business, the pressing and profitable demand by a growing urban population, the need to raise income in increasingly monetized rural areas, the growing number of small industrial business in rural areas and the ambiguous status of forest land in Mozambique result in a continuous flow of illegal over loaded lorries with charcoal bags entering Maputo through all the well policed entrances of Maputo[11].

Another root of TOPB is the "lack of incentives for sustainable management of forests". These incentives could come from the Government, however, considering the importance and impact on the daily life of all Mozambicans, it is quite remarkable the lack of attention that charcoal receives in terms of National legislation and budget. The investment on charcoal related projects that could affect at the very least 70% of the

10 Sandalwood, a semi-precious wood which smoke is poisonous and used for sculpture work is being burned in bakeries for its high energy content (Nube 2003). An exception to this situation is Canhi, a very sacred tree that no one cuts.

11 Remarkably, several charcoal makers interviewed recognised the importance of following rules, but fail to perceive the benefits of doing so, for more details see Sepp (2008).

population are far lower than the investment on electricity which serves less than 20.2% (at most). In what seems yet another Mozambican energy paradox, the energy policies of the Mozambican government have not been pro-rural poor, because they focus mostly on electricity for urban centres, but even in the electrical sector, Governmental policies, have not been pro-poor (Ahlborg 2012; Nhete 2003). Moreover, in terms of bioenergy, despite the actual prevalence of WF, the priority seems to be biofuels and solar energy.

Consequently, unlike the biofuels, there is not a National Strategy for WES and the responsible Government Department for renewables, FUNAE (Fundo Nacional de Energia-National Energy Fund) runs far more projects of solar panels than any other combined. These facts did not pass unperceived in the TOPB which proposes several measures, SNV, including: market incentives (e.g. lower tax for importing alternative energy technology), political endorsement (e.g. legislation to motivate better production and management practices) and better inspection and law enforcement. This aspect is also related with the notorious lack of coordination between the ministries responsible for the WF, indicated in the TOPB as “week coordination” in the roots. The WF business spreads for the countryside to the city, falling therefore into the realm of, at least, three ministries, Agriculture (MINAG), Energy (MdE) and Environmental Coordination (MICOA). The coordination between these ministries was, and still is very poor, which is recurrently presented by experts interviewed as a major barrier for sound political action. Recently these ministries created a coordination platform, but with no impact on WF. However, this was not always the case. In 1977, the government officially declared the energy supply to urban areas to be a priority. In accordance, quite a comprehensive and integrated project was conceived with financial and technological support from Scandinavian governments through FAO. The project included the construction of industrial kilns near big cities (Maputo was one of those) side-by-side with dedicated plantations of fast growing species. For Maputo the selection was on eucalyptus in a sandy area in Marracuene (north of Maputo) that would also protect the cost and create a suitable environment for small farms. Additional a marketing and sales sector was established to promote and sell the charcoal. The project eventually failed due to a number of reasons, including (Saket 1994): charcoal of bad quality; unsuited kiln technology; lack of skilled people to operate the kilns; lack of funding; the civil war that started soon after.

After this experience the government was never that bold, and all WF energy related initiatives were implemented through the ministry of agriculture (MINAG) or the recent MdE. Particularly between mid 1900s and beginning of 2000s and then again from 2006 a number of initiatives conducted by all possible combinations of participants among the Mozambican Government, international and local NGOs, International and national aid agencies and private companies. Broadly the initiatives tried to reduce the impact of WF, and particularly charcoal, on deforestation by targeting the production and/or consumption of charcoal (eventually also considering firewood). The objective was to

prevent or slowdown deforestation, by reducing in absolute terms the production/consumption of charcoal and/or by increasing the overall process efficiency of production/consumption. The projects were few and quite diversified, but normally included: external funding and expertise; some form of participatory approach, sometimes within the framework of CBNRM (§5.2.3); assessment of forest resources; establishment of regulations (management plans for instance); and some form of technology, from improved kilns to improved stoves.

Eventually the results were far from the desired, for several reasons pointed in the literature and interviews, and also presented in the TOPB roots, including: bad technical designs (regarding the improved stoves); high cost; and inaccessibility to poor people. Indeed, an analysis of most outcomes of WF projects in Mozambique seems to lead to the same conclusion: they look much better on paper in DCs from where the funding comes, than in the real life in Mozambique where they are supposed to be used. In any case, either because of bad experiences with new technology involving one to all of these problems, either due to some sort of bias, there is a prevailing "lack of confidence in alternatives for biomass".

Going to the upper part of TOPB, the health effects associated with WF (blue boxes) are also discussed in the few papers published on the subject for Mozambique. However, as mentioned in the end of §5.2.1, researchers are not so positive regarding direct links between IAP and lung deceases. Instead the relation is expressed in terms of risk.

Therefore, Brauer (1998) mentioned, but did not quantify, a relation between IAP and lung cancer in a study conducted in Maputo. Elegard (1996; 1997) studied the association between exposure to IAP from cooking fuels and health aspects adult women at Maputo. Comparing firewood; charcoal; electricity; and liquefied petroleum gas (LPG) used to cook Ellegard (1996) registered that firewood users were found to have significantly more cough symptoms than other groups, but there was no difference in cough symptoms between charcoal users of LPG and electricity. Moreover other respiratory symptoms such as dyspnea, wheezing, and inhalation and exhalation difficulties were not associated with wood use Ellegard (1997). In 2004, a study conducted in Maputo, concluded that in-house smoke caused by charcoal and firewood increased the risk of otitis in small children (da Costa *et al.* 2004). Finally an international study on the health effects of WF use, estimates that in Mozambique per year, 9700 children under 5 die of pneumonia and 1400 adults over 30 die of CLD (Legros *et al.* 2009). It should be noted, however, that in rural areas, and in many households of urban areas, the cooking is done in the open air or in a well ventilated division outside the house, which partially reduces the formation of IAP. Indeed, in Maputo at least, it seems that cars, not charcoal or firewood from the suburbs are the responsible for the high levels of gases in the city (Cumbane 2007). An indication of this result was already implicit in Ellegard (1997) since in the level of particles was also high in the control sample of gas and electricity users.

The section of problems related with the environment (green boxes in TOPB) present a number of parameters, including reduced "capacity to absorb CO_2", "effects on soil fertility", rainfall, "biodiversity loss" some of which have been analysed for Mozambique (e.g. Nhamtumbo 2012) and in other generic studies (e.g. Breman & Kessler 1995; Scholes & Hall 1996). However, "increased deforestation" (which might also include "pressure on forest resources" and "unsustainable biomass exploitation") is probably the more frequently discussed environmental impact related with WF production.

Deforestation in Mozambique is quite problematic because there is no accurate and updated measurement of the variation in forest cover. This is a direct consequence of the diversity of forest definitions and measurement methods results exposed in tab. 5.1 (§5.2.1) which generate an equally wide diversity of not comparable deforestation rates. Therefore, while Saket (1994) points a deforestation rate of 0.24% for the period of 1972-1990, Marzoli (2007) estimates 0.58% for the 1990-2002 period and FAOSTAT and average of deforestation rate of 0.53% 1990-2010. Besides these national values, the deforestation is also varies across provinces (Marzoli 2007) and is more intense close to large cities (Pereira *et al.* .. 2001), areas of rapid economic development such as the Beira Corridor in Manica and Sofala (Argola 2004), and main arteries, e.g., the National Road 102 in Manica (Jansen *et al.* .. 2008). As for the direct causes, there are few references quantifying the causes of deforestation and none specifically quantifying the effect of WF production in deforestation. However, a number studies seem to agree that deforestation is the result of a network of conjugated drivers (e.g. Noronha 1998; Mapose 2003; Sitoe *et al.* 2012; Temudo & Silva 2012), strongly shaped by the history and socio-economic context of Mozambique (Sitoe *et al.* 2012). From 1977 to 1992 the civil war acted as "passive conservation" since access to rural areas was difficult and massive migration to neighbouring countries occurred and/or cities (Sitoe *et al.* 2012).

At this point, charcoal was difficult to produce in rural areas and most urban settlers were recent and poor, and thus could not afford electricity and retain the habit of use firewood (interviews). With the end of the war, the data on deforestation and visual evidence from the country side (particularly evident in the study area near Maputo) indicate a marked increase in deforestation. Once more this increase in deforestation has a socio-political context to it (as exposed by several expert interviews and confirmed with charcoal makers). With the end of the civil war, there were all over the country several ex-soldiers with basically no professional skills, bonds to their former area of residence and essentially poor. To avoid discontent, that could possibly lead to social unrest the Government and several NGOs actually promoted, directly or indirectly, the production of charcoal as an income source for these soldiers. Another aspect is the need for income. Many charcoal makers interviewed were actually farmers. As part of shifting agriculture, every time a new field was open, the wood gathered would serve to make charcoal. This was not a year round activity, but rather done only in the dry season when for the farmer work was less. In other words, charcoal was not a job, but an "extra" source of income

they needed, for instance, to buy commodities in the local shop and books for their children. The monetization of rural areas and the assumption that a demand existed for charcoal were strong motives to make charcoal. However, agriculture, alone, is also pointed as a main cause of deforestation in Mozambique (Jansen *et al.* .. 2008; Marzoli 2007; Saket 1994; Sitoe *et al.* 2012), particularly by the action of small producers from the family sector, in most cases working without inputs and using shifting cultivation (Sitoe *et al.* 2012).

Besides WF production and agricultures uncontrolled fires; commercial logging; mining; infrastructure development; and natural calamities also have an indirect impact and more limited impact on deforestation (Sitoe *et al.* 2012). Some authors defend that fire degrades the forest ability to recover (Ribeiro *et al.* 2008; Zolho 2005), while it is estimated that 5.4-9 million ha of forest burn annually in Mozambique due to human activity (Vasco and Costa 2009) and that during 2000 and 2002, approximately 4.42 million ha in Mozambique were affected by uncontrolled fires (Zucula 2003). The presence of illegal logging activities suggests that forests in Mozambique are being degraded, and that their commercial value is being reduced by the overexploitation of a few species (Mackenzie 2006). Mining activities, the clearing of ground to open access roads, houses and/or other infrastructures are also considered important in deforestation (Sitoe *et al.* 2012). Finally drought, floods or other natural calamities can also promote deforestation. For instance, naturally occurring fires account for 0.6-1.0 million ha burned by accident in Mozambique (Vasco and Costa 2009) and the floods in 2000 also contributed to a loss of more than half of the mangrove area in the mouth of the Limpopo River (Sitoe *et al.* 2012). Besides this difference in impact and relative geographic distribution the factors for deforestation can interact in mutual reinforcement. For instance opening an area for agriculture might generate wood for, e.g. dry tobacco, while WF production could promote the establishment of agricultural fields. The transporters of WF producers might open roads to access forests, and thus favouring the degradation of forest. Under “environment” in TOPB there is a box “thousands of people have poor access to energy and alimentation”, which is, in the author view, more of a socio-economic consequence than environmental.

In brief, and following an observation already implicit in §5.2.3, deforestation should be seen more as a symptom of a deeper underpinning complex socio-ecologic dynamic processes. Analysing over 140 economic models on deforestation, Angelsen & Kaimowitz (1999) found that, actually, policy reforms in economic liberalization and adjustment efforts (which in Mozambique are an ongoing process since mid 1980s) may increase the pressure on forests, and question the results of many models for weak methodology and poor-quality data. As Sitoe *et al.* (2007a) puts so nicely, “Little is known about land-cover changes at the national level, and even less is known about more disaggregated levels and the influence of various production sectors”.

Finally TOPB addresses the socio-economic and cultural aspects of the WF production (orange boxes). Remarkably (and not mentioned in the TOPB) is the fact that charcoal is referred in historical documents since 1840, and ever since is always associated with complex socio-economic tensions between who owns, who works and who gets the profit of that labour (Penvenne 1985: 185-188). In recent studies (§5.2.2) these power issues are again referred to from a gender perspective where women are normally portrayed as carrying all the burdens of household energy management while being absent on energy related decision making Regarding the burdens, there is evidence that men also participate in the firewood collection, which takes mostly 2 to 3 times per week, taking in average 30 minutes to 3 hours each time and covering distances around 2km (interviews and e.g. Convery 2010). In relation with the perception of the energy burden on health (see also above) in the rural areas interviews for this work, when asked to list the drawbacks of WF the common issues were the impossibility to cook on rainy days, damage in the pans and while hard work, smoke or risk of burning were listed at last or not listed at all. However, once the smoke problem was suggested a wave of complaints emerged. This late "acknowledgement" was usually explained by "we are used to it, it comes with the job". Therefore, this research found that women, at least the ones interviewed, did not have a "lack of basic knowledge on the effects of smoke on health", especially if "of basic knowledge" means "something hazardous".

What women might have is high levels of endurance and resignation in face of the daily difficulties. On the decision making side the results contradict most research. For instance, when asked to list which household devices they would buy if they had the money and all the conditions were in place, women very seldom listed kitchenware or cooking technology. In fact, the preferences went for fridges to conserve food or TV sets for relaxation, for the kids or information. Remarkably, particularly in areas with access to electricity like Inhaca, despite the cooking being made by women exclusively on firewood (assisted by the occasional low consumption lamp), there was all sorts of audio devices and even TVs, all bought by mail members in the family (similar events are also reported in, e.g., Clancy *et al.* 2003). When confronted with the possibility of buying an electric stove, the answer was the high cost and low quality of the wiring that "cannot support such intensity". While the infrastructure is indeed very bad, TVs were always more expensive that electric stoves and this caused much admiration among women. Therefore, it is not clear if women carry the pains of WF use, or if they do not see it as a problem or if this is only the result of poverty and associated lack of information and options. On the decision making aspect of WF, it is relevant to point that most of the charcoal makers are actually taking the WF as a business, or a survival strategy, and therefore actively run small enterprises or cooperate to make that business. This perspective is confirmed both by WES design elaborated by charcoal makers (all women) in the course of this work (see Annex 5E-I), as well as, in the studies carried on gender and WF production in Mozambique (Chicamisse 2005; Furvela 2004; Maúse 2013; Saide 2001).

Despite being carried in different areas at different times, the results are remarkably consistent with the image of women (some household heads) actively engaged in the WF business as major entrepreneurs. In conclusion, it is not at all clear that women do not take a lead on WF management and decision making, which defy some of the assumptions established (§5.2.2).

Still on the socio-economic aspects in TOPB, aside from the gender aspect, basically all the problems are related with income diminution: reduction of household income; difficult access to forest resources; and increase in expenditures on health and energy. Apparently the designers of the tree of problems focused on vulnerability (see also Eriksen & Silva 2009) rather than business opportunities, or barriers to entrepreneurship. However, in the literature a number of studies do address WF as a viable business in Mozambique (MINAG 2001) or evaluates the impact WF have or could have in the national economy (Alberto 2004; Chitara 2005; Lichucha 2000) and in the rural communities (Mabote 2011; Zibia 2013). Mozambican researchers appear to agree on the predominance of WF as a reality that cannot be contradicted, and generally in their analysis there is no real environmental (which could also be seen as ethical or moralistic) judgement towards the communities or the several informal actors in the WES.

As it was repeated so many times, “charcoal is the only way communities have to get money”. Indeed, the existing data suggests that apparently, despite increased pressure and visible destruction of the woody resource base, WF is still relatively easily available and accessible to a still growing and dynamic WF market. Availability is explained by the abundant forest (tab. 5.1), end of the civil war and opening of farms. Turning the analysis to the urban consumers, it is argued that high poverty rate and low household incomes are behind the increasing use of WF in Mozambique (Nhete 2007; Cumbe *et al.* 2005).

With such an income it is impossible to afford cost-reflective prices of electricity and fossil fuels. Additionally to the high poverty rate, the emphasis on market-oriented economic reforms by the government in the energy sector (and all other sectors) have potentially further decreased the already low levels of access to modern sources of energy (Cumbe *et al.* 2005). For example, the introduction of privatisation and implementation of cost-reflective tariffs in the electricity market have potentially decreased access to electricity in the urban and rural areas, and contributed significantly to the increasing consumption of cheap WF (Cumbe *et al.* 2005; Nhete 2007). There is also a cultural dimension that could explain, for instance, the high consumption of WF by high income households or in bakeries (Brouwer and Falcão 2004).

Finally the last problem left in the tree “deterioration of poverty, illiteracy, health and underfeeding”, which might as well be a portrait of the entire Mozambican reality. Regarding this matter there are literally hundreds of documents and researchers. While interesting these will not be reviewed here since, for the purpose of the thesis (§3) the identification of underpinning aspects that experts consider *relevant*, *concerning* or *basic*

in WF analysis is enough. These aspects will be the initial seed of the design elements of 2MW (§D). For instance, by now, from the reading of this analysis on the TOPB in conjunction with the rest of §5 among other aspects the reader could identify: technological aspects (e.g. concerns with fuel wood conversion technology); Consuming aspects (e.g. high demand from urban areas of a specific WF); Institutional aspects (e.g. the network of power and social relations around WF); Contextual aspects (e.g. history and socio-economic dynamics affecting WF); Legislative aspects (e.g. the laws, regulations, authority).

To conclude the TOPB, by eliciting and integrating in a simple and visual format the wealth of (tacit) knowledge of experts, was inspirational for this work and a valuable source of insights for the design stage of the 2MW (§D). However, the tree of problem served also as a warning sign of how an inspiring idea with a lot of explanatory potential represented exactly what this research was so keen to avoid (§7.1).

6 WOOD FUEL MODELING & MODELS

Being this a research on WF modelling (§2-3) it is relevant to complement §5 by reviewing the models and modelling approaches produced on/for the study of WF in DCs with a dual objective. First, illustrate how models defined within the field of WF in DCs have supported some of the analysis done in §5 or could support the implementation of initiatives in WF design. The second is to show these models as design artefacts, as objects (§9.1), with a formal aspect or format (how they look like), a purpose (what they intend to do) and a design paradigm (the perspective or conceptualisation the designer has on the domain of interest, §9.1). The aim is not, thus, to make an intensive and exhaustive identification and criteria based analysis of the performance of those WF models (§10), but rather to complement the analysis made in §5 presenting and describing relevant models and modelling approaches designed on/for WF in the context of DCs, particularly Mozambique. The most relevant WF models have been, for ease of analysis, divided in three main modelling purposes: to produce a theory that explains why WF consumption in DCs is the way it is (§6.1); describe the WF production and consumption (§6.2); support planning and decision making on WF using mathematical models (§6.4).

6.1 THEORISING TRANSITION: LADDERS, STACKS AND LEAPFROGGING

The relation between income (a proxy for poverty and economic development) and energy consumption patterns can be formalised in the “energy ladder” (or “fuel ladder”) model, where each rung associates a given income level with the predominantly amount and quality of energy used (Boardman 2010; Hosier & Dowd 1987; Leach 1992), fig. 6.1.

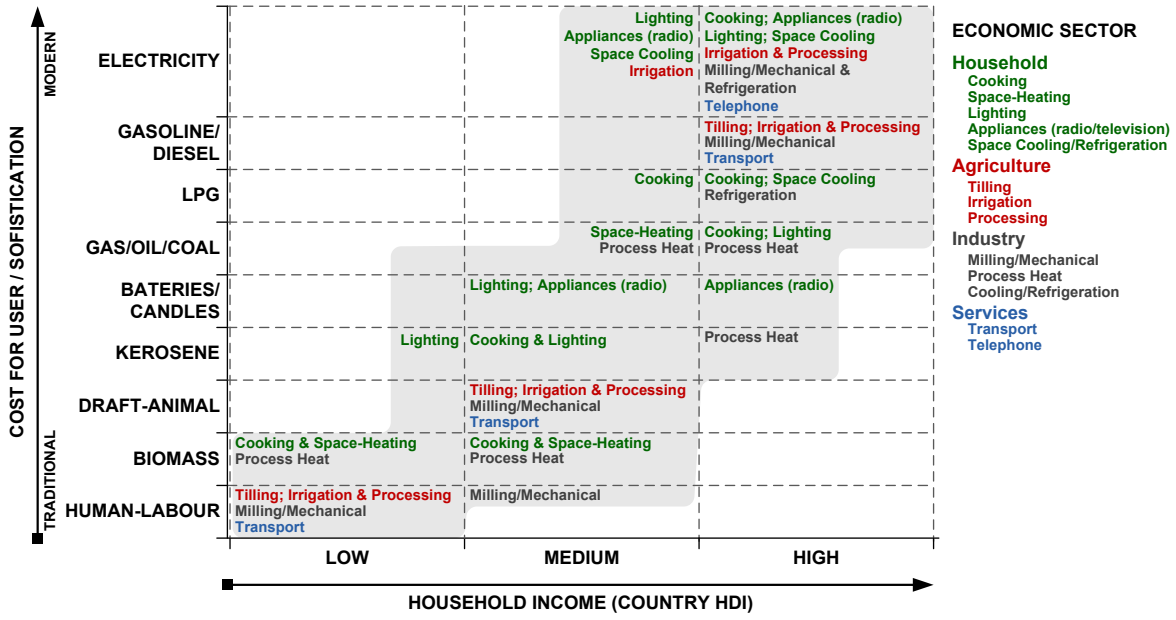


Figure 6.1| An integrated version of the energy ladder linking energy source, technology and economic sector to household income and country HDI [Source: the Author after Ramani & Heijndermans 2003; WB 1996].

According to this model, at the bottom of the ladder are the low-income households using money-free "traditional fuels", i.e., biomass. Progressively higher income allows users to ascend in the ladder consuming increasingly more expensive, efficient and modern fuels, being electricity the top limit. The ascent in the ladder also tends to correspond to more efficient, productive and clean technologies, with higher capital costs and typically centralised production (Holdren *et al.* 2000; Toman & Jemelkova 2003). For instance, compared with traditional WF cook-stoves electric hot plates are 4-5 times more efficient (Reddy 1999) and LPG stove reduce IAP up to 90% (Warwick & Doig 2004). Conversely, the "energy ladder" further theorises that people would move to more modern fuels and technologies replacing traditional ones as their income and/or urbanisation increases (e.g. Holdren *et al.* 2000; Hosier 2004; Leach 1992).

Later developments of the energy ladder (e.g. WB 1996) besides household energy use patterns included other economic sectors, (see colours in fig. 6.1). In this version, for the same set of economic sectors and activities, lower income would have a narrower range of services and technological options, while ascending the ladder (i.e. increasing its income) households would have access to a wider range of services and technology with increasing degree of sophistication and reliance on modern fuels, fig. 6.1. For instance low income households would use human labour or, at best, animal traction for irrigation in agriculture, while higher income could use a diesel pump for the same activity and use the telephone for assistance.

In the limit the "energy ladder" would describe and explain the global energy situation, fig. 5.1, in terms of energy and level of development (e.g. HDI). The explanation worked both ways, DCs countries are poor because they use mostly traditional, inefficient and dirty energy and, conversely, because DCs use traditional, inefficient and dirty energy they are poor. This kind of mutually reinforcing dynamics between energy and development (economic at least) and the direct link between energy fuelling (literally) development resulted in a number of associated concepts, including energy poverty, vicious circle of energy poverty and leapfrogging. As it is argued, unable to afford/access modern energy services because they have a low income (i.e. because they are poor), and unable to generate more income because they cannot afford/access modern energy services (i.e. because they are energy poor) poor people in DCs are not just the poorest; they are also energy poor, trapped in a vicious circle of energy poverty[12] (e.g. Ramani & Heijndermans 2003; Khandker *et al.* 2012), a WF trap (after Kutsch *et al.* 2011). Therefore, fuel/technology switching through the ascent of the "energy ladder" have been considered as a valuable strategy to improve the living conditions of poor by reducing IAP, accidents, deforestation and the time spent collecting and processing WF (§5.2.3) freeing, thus, people, especially women and children, for education or income generation

12 The interaction is a bit more complicated, and energy poverty is not necessary equal to income poverty, see Khandker *et al.* (2012) for details.

activities (Boardman 2010; Brew-Hammond & Crole-Rees 2004; UNDP 2005). Notably the ascent to such wealth of benefits can be done by leapfrogging, that is, instead going rung-by-rung, DCs could learn from the experience and mistakes of developed countries and "jumping" several stages of technology adoption to "catch-up" with modern energy (Sauter & Watson 2008).

As an analytical/descriptive framework, the "energy ladder" and "energy poverty cycle" were a relatively successful way to link income with energy consumption patterns revealing, for instance, that (§5.1): income is an important aspect defining choices, affordability, accessibility and use of energy services, fuels and technologies; and access to better services and technologies speed up the transition to modern fuels.

Until mid 1990s most scholarship used the concept of an "energy ladder" to explain how households selected fuels and energy technologies (Elias & Victor 2005). However, in the last two decades a growing body of empirical studies on household energy use reveals that the energy transition does not occur as a series of simple, discrete steps, rather, multiple fuel use in households is common (§7.5.1). Thus, a new model was proposed, the energy stacking model, which assumes that households may switch back to traditional WF even after adopting modern energy. Instead of a linear progression, households adopt a portfolio of energy options based on a range of factors, including the fuel quality, personal preferences, budget, needs (Davis 1998; ESMAP 2003; Heltberg 2004). Yet, the model still considers income as the major determinant of fuel choice. As households get wealthier, the change in energy use can be characterised as an ''accumulation of energy options'' rather than as a linear switching between fuels (Masera *et al.* 2000).

At a fundamental level, energy ladders or stacks, leapfrogging or energy poverty have been designed (conceptualised) under the deeply rooted assumption that WF and associated practices and technologies constitute a problem resulting from poverty and the epicentre of wider socio-ecological problems in DCs. The solution is then to replace WF and its technologies by other energy carriers and technology considered more suitable (e.g. electricity and solar panels). This process defines the "energy transition" and is grounded on a set of assumptions, here referred to as the *energy transition paradigm* (ETP). Conceiving energy in DCs as solvable technological problem, ETP *normatively* defines modern technology, mostly designed in developed countries, as *better* (cleaner, efficient, productive, women-friendly, sustainable) in clear contrast with *the problem*, the *defect* WF, common on DCs (traditional, inefficient, women-unfriendly, health and ecologically hazardous). Consequently, ETP *prescribes* the implementation and adoption of the *better* technology, remarkably RETs decentralised systems, as the viable solution to promote sustainable development (Nouni *et al.* 2008). Based mostly on developed countries experience and history, ETP proceeds to *prescribe* the method for this transition, assuming that by leapfrogging or step-by-step, the right combination of technology, fuels and income would make people switch from WF and energy poverty to wealthy users of

modern and sustainable fuels and technologies. Finally, it is assumed that households (and communities) are homogeneous and passive actors unable to seek access to energy (assuming that such access is wanted) acting only in terms of income and willing to switch from money-free WF (even even when money is paid for the hands in money, time or effort) to the "obvious" advantages of modern fuels and technologies.

6.2 Describing/Framing Wood Fuel: Boxes, Links, Chains & Systems

The models presented here constitute graphical descriptions (conceptualisations) of *what composes* and *how it is processed* the WF consumption/production in DCs. Implicitly or explicitly these models involve a systems analysis of WF as a complex problem. Both a philosophical approach and a collection of techniques, system analysis emphasises a whole view approach to complex socio-technological problems, from which WF is a clear example (e.g. Miser & Quade 1985). Consequently, every model presented here describes WF reality *as if it is* a system (§5.2), i.e., as a set of interconnected elements (e.g. people, processes, activities) interacting within a context (e.g. DCs, Mozambique) for a purpose: the production and consumption of WF. Presented, usually, as a network of boxes (elements) and links (relations), these descriptive models act as *analogues* or *metaphors* of the WF consumption/production, and thus are used as tools to analyse, understand and/or design wood fuel energy systems, WES. All these aspects will become clear by exploring the chain models and energy systems models which are the most representative models used to describe the WF production/consumption. Biomass, WF and particularly charcoal, both in Mozambique and elsewhere, have been analysed through models that use the metaphor of "chains" (e.g. supply chains, commodity chains, value chain). Chain models describe the flow of material, energy, information, meaning and profits as different actors, activities (e.g. Bailis 2005; Ribot 1998; Sepp 2008) and/or technologies (Sharma *et al.* 2013) transform wood into WF consumer goods/commodities. Here two basic kinds of chain models will be presented, commodity chains (also values chains) and supply chains.

WF Commodity chains (WCC) have been created in management and logistics to facilitate market and value creation analysis (e.g. Porter 1985), but also as an analytical tool in political economy and rural sociology in the field of food systems, the "Commodity Systems Analysis" (Friedland 1984)[13]. WCC are always contextual, product centred and comprise a series of relations through which an item passes, from extraction through conversion, exchange, transport, distribution and final use (Ribot 1998). WCC can be used for a number of purposes (e.g. Friedland 2001), but in the research on WF, they have been used to understand WF production/consumption and to study the distribution of power and revenue in the WF business, with particular incidence on charcoal (Bailis 2005; Ribot 1998; Sander *et al.* 2013). In fig. 6.2 is presented WF WCC for Mozambique.

13 see Bailis 2005: 165 for a resumed genealogy.

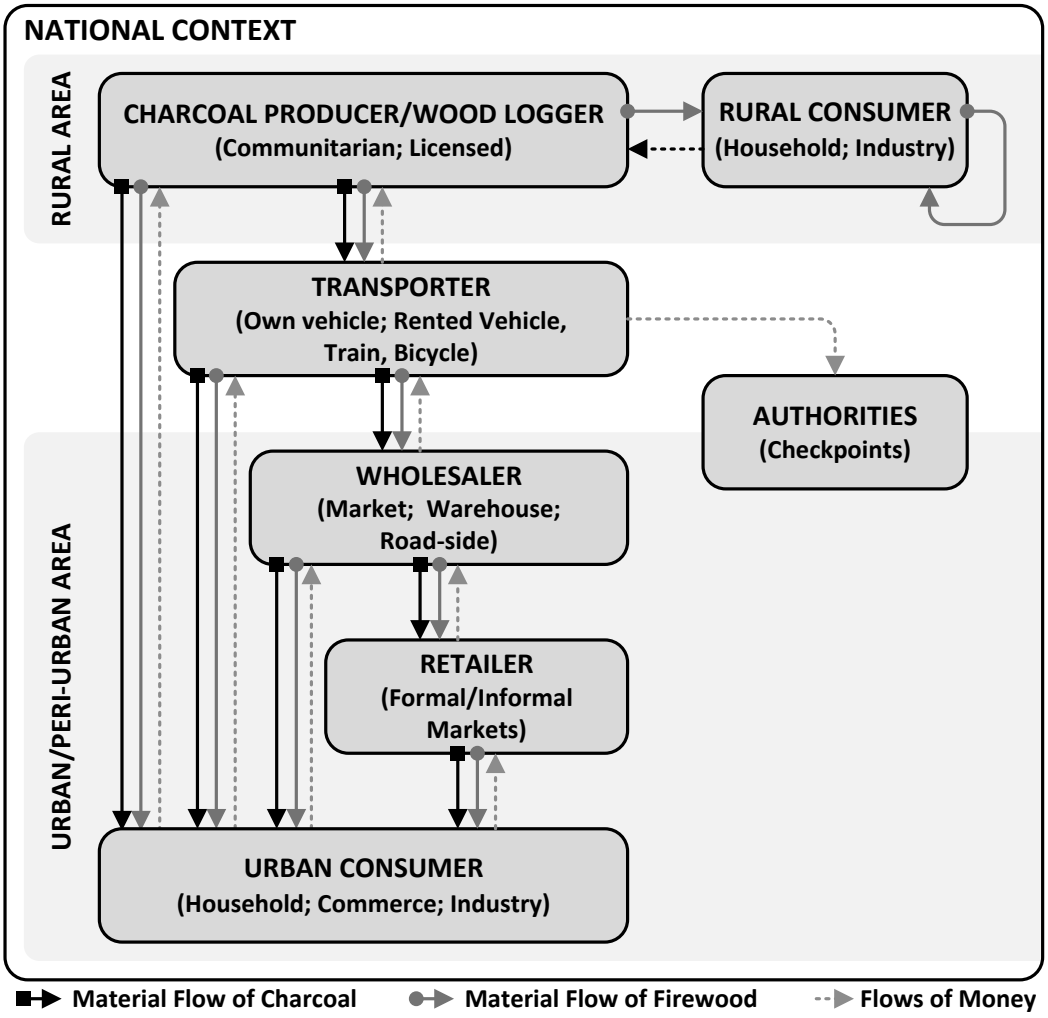


Figure 6.2| The typical WF Commodity Chain for Mozambique including the several actors, flows of money and material and areas of action [Source: the Author based on Bailis 2005; Mahumane & Atanassov 2012; Sepp 2008].

Since charcoal serves virtually only the urban market, while firewood is consumed mostly, but not only, in rural areas, two chains have been considered: a rural chain exclusively composed by a material flow of firewood; and a rural/urban chain comprising material flows of charcoal and firewood. Both the rural and rural/urban chains start in forest areas where wood loggers and charcoal producers work. The firewood can be consumed directly (requires no further processing) therefore unless some rural consumers pay for the firewood the more common situation is where rural households collect and consume money-free the firewood themselves, which is indicated by a return harrow in rural consumers, fig. 6.2. The rural/urban chain is mostly composed by charcoal and aims the urban market, therefore requiring a production process by wood loggers and charcoal producers, transportation to the city (using all sort of means, from bicycles to train, but commonly by truck), where distribution and commercialisation is done by wholesalers (with big storage places) and retailers (small shops at household level) to the urban household, fig. 6.2. This is the most complete indirect route, but all combinations are possible till the limit where the transporter sells directly to the urban consumer. In the

opposite direction goes the flow of money, the exception being the money given by transporters to the police authorities in the road checkpoints in the entrance of the cities as a bribe. Finally, beside link all the actors across the entire chains, the material and money flows are meaningful (and create meaning) within the Mozambican context, marked by specific institutions, regulations and structures (hence the entire chain being enclosed within the national context in fig. 6.2).

Note that fig. 6.2 is a convenient simplification, since chains are not characterised by such linear exchange depicted, since in reality benefits within systems of commodity provision would be better described in terms of networks or webs of actors (e.g. Leslie & Reimer 1999; Hartwick 2001). Moreover, it is quite possible that some actors play more than one role, that payments are made in other values besides money, or that arrangements exist where producers rent the transport, which implies a flux of money from the producers to the transporters, which is not shown in fig. 6.2. Another aspect not represented explicitly in fig. 6.2, is the fact that actors, in their role and site in the chain, exchange knowledge, practices and experiences. As a result, the chain models represent actually institutional arrangements, networks of actors (or group of actors) and institutions connected through relations of knowledge, power, social and economic bounds (Sander *et al.* 2013). This descriptive power of model chains have been used to learn and explore *how* the WF chain behaves, *who* are the main actors, *what* are their interests, perspectives, roles and *how* they interact with each other and with the product/process. In practical terms, fig. 6.2 (or similar) has been used to support the qualitative and/or quantitative design of WF policy an analysis and production systems in several African countries, including Mozambique. For instance, Bailis (2005) used a charcoal WCC to map the flow of resources and benefits along a WF WCC in Kenya to delineate the impacts of WF policy interventions. In Mozambique, fig. 6.2 without the rural consumers and authorities have been used to analyse only the charcoal chain (black arrows with square ends) as a WCC (Brouwer & Magane 1999), a supply chain (Falcão 2008) and a value chain (Mahumane & Atanassov 2012; Sepp 2008). Several of the socio-economic and institutional aspects on WF presented in §5.3.2 have been illustrated or uncovered by theses chain models and analysis, including, e.g.: the structure of the charcoal business composed mainly by poor households; the identification of inefficient production/logging and consumption and corruption as major technological and institutional bottlenecks; the disparities in the distribution of power, knowledge and profit with clear benefit for transporters in detriment to community producers.

Another type of chain model applied to WF is the WF **supply chain** (WSC). WSC are sequences of processes for the procurement of WF from production to consumption (after Fiedler *et al.* 2007) or simply the movement of WF between the source and the end-user (after Sharma *et al.* 2013). In more operational terms, the WSC consists of discrete processes from harvesting to the arrival of biomass at the conversion facility (Becher & Kaltschmitt 1994), which could be represented as in fig. 6.3:

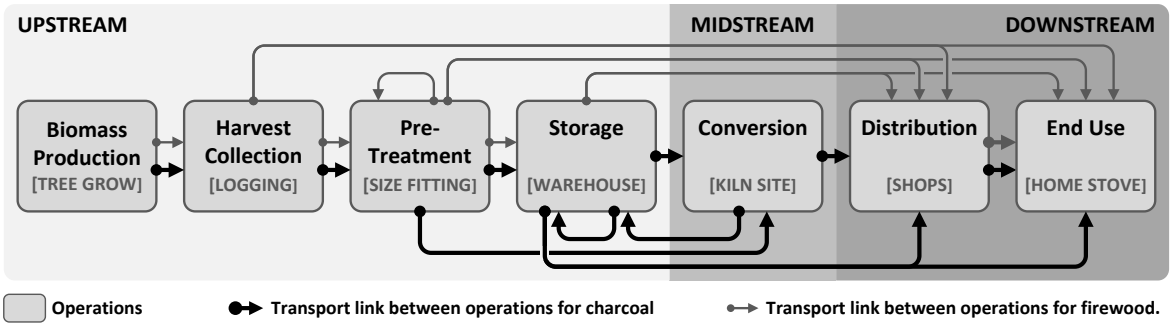


Figure 6.3| A typical WFS for Mozambique, with the operations and transport links from production to end use for charcoal and firewood [Source: the Author based on de Meyer 2014; You & Wang 2011].

The WSC has a strong logistic aspect associated to it. In fig. 6.3, transport (arrows) links all the operations (boxes) showing a flow of WF between specific operational sites being "Conversion" considered as a black box with input of biomass and output of charcoal (or other bioenergy carrier and by-products). These operations are also quite revealing of some important aspects WF as a product, in Mozambique and elsewhere. First they implicitly expose some of the unique attributes of WF as an energy source. Unlike centralised electrical production, for instance, WF is characterised by spatial fragmentation, seasonal and weather related variability, high moisture content, low energy content, low bulk density (e.g. Johnson *et al.* 2012; Shabani *et al.* 2013). Secondly, the possibilities of combinations involving the WF flows also point to intricate interrelationships and interdependences between all operations (e.g. Johnson *et al.* 2012; Shabani *et al.* 2013). Not only upstream decisions affect the later operations in the WSC, but also the type, size and location of conversion technology/facility co-determine the type and sequence of all previous operations. These aspects of WF as a product, revealed by WSC descriptive models are quite relevant modelling issues in WSC (§6.3).

Despite the usefulness for the political, economical and logistic analysis of WF, both in qualitative and quantitative terms (§6.3) chain models are profoundly human centred and socio-economical biased. The entire analysis is done from human-centric perspective within the economic cycle of *value*, which starts when charcoal is produced (wood gains value) and charcoal is sold (the value is transferred to money), missing the fact that WCC and WSC exist within wider realities, all affecting WF "chains" and all with a value. For instance Bailis (2005) includes trees as part of the WCC only because there is a perceived monetary value for trees. This is obviously quite limiting. While being mostly a business for many people, there are other perceptions of WF which could eventually lead to other views on the WF business. Another issue with value chains, particularly WCC, is the consideration of people as part of homogeneous groups, ignoring the distinct motivations, expectations and perspectives that might exist within the groups. In resume, chain models are very useful analytical tools, but cannot assist the integrated and comprehensive design of WES that consider the WF beyond the consumer and the producer and/or with other interested beyond the economic value.

A second type of graphical model describing WF production/consumption as a flow of interrelated processes (boxes and arrows) is the **systems models**. The systems models explicitly use systems analysis (e.g. Gibson *et al.* 2007) and conceptualise the WF production/consumption directly and explicitly in terms of an Energy System (ESy). ESy models are common in energy planning and design where they are used to structure problems and assist decision making (e.g. Nakata *et al.* 2011; van Ruijven 2008). Therefore, energy systems models are not specific to WF and they have not been used much in WF research and never, at least explicitly, in Mozambique. There are many definitions of ESy used in several scientific settings, combining the definition of systems of Gibson *et al.* (2007) (beginning of §6.2) and common definitions of ESy (Goldemberg & Johansson 1995; Løken *et al.* 2009; Nakata *et al.* 2011) adapted to the case of WF, it is possible to define wood fuels energy systems, WES, as:

> *A set of* inter-connected *technological processes and infrastructures joined in regular interaction or interdependence to transform wood resources into desired WF products that satisfy energy services, practices and demands meaningful in a given social and ecological context.*

In fig. 6.4 two possible representations of this definition are provided among many other possible (e.g. Brown 2004, Hall & Ko 2004; Nakata *et al.* 2011; Orecchini 2006).

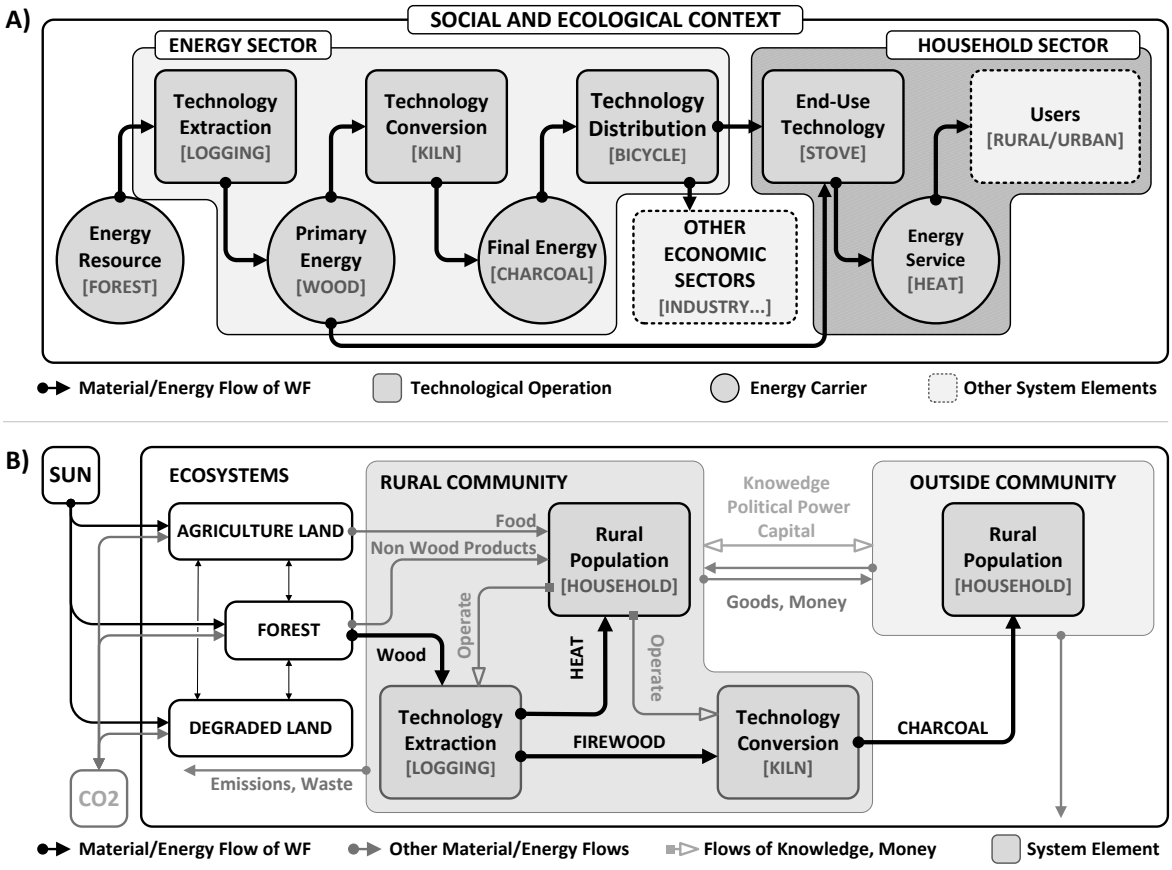


Figure 6.4| Possible representations of a WES for Mozambique considering different aspects, boundaries and perspectives [Source: the Author based on Takada *et al.* 2002 for A); and on Buchholz *et al.* 2005 for B)].

At a first glance in terms of representation, ESy, i.e., WES, are very similar to the chain models, particularly fig. 6.3 and 6.4A, and In fact, other authors referring to similar representations of ESy used other chain denominations, including: production chains (e.g. Gravitis 2008); bioenergy chains (Elia & Floudas 2014; Gavrilescu 2008; Hamelinck *et al.* 2005); unit process chains (Gerber *et al.* 2011); and biomass energy fuel chains or biomass fuel chains (Gavrilescu 2008). However, some differences should be noted. The chain models offer a more socio-political (WCC, fig. 6.2) and logistic (WSC, fig. 6.3) centred perspective, more related with the actual geographical and power and social networks conditions in on specific context, and in this sense is very local and localised. The logic of the ESy is more strategic and focused on energy as an economical sector, with strong bonds to economical and technological dynamics, since the purpose is to identify and represent the structure and dynamic of the networks and links established between different elements (human and non-human) in a wider context social and ecological context (e.g. Hall & Ko 2004; Løken *et al.* 2009). Thus ESy are somehow detached from a specific reality and constitute reference models, i.e., "a pattern on which to base an artefact" (Duce & Hopgood 1990) or a "a standard or example for imitation or comparison […]a framework within which systems may be compared and new systems designed" (Duce *et al.* 1998).

Simply put, different "reference models" generate different references. In fig. 6.4, these ESy modelling aspects become evident by comparing the two offered representations of the same WES in Mozambique (and actually the same as depicted in fig. 6.2-3) in terms of technology selected (kilns, stove, bicycle), resource type (wood from forest) and consumption patterns (firewood and charcoal). It is clear to see that a more engineering or managerial like perspective (e.g. Takada *et al.* 2002; Orecchini 2006) generated the WES model in fig, 6.4A, focused on interaction between infrastructures and technologies as closed systems, which highlight the inter-sectorial interactions and the importance of infrastructures while establishing a technological chain from forest to households and other economic sectors. These models are also very common in engineering and econometric analysis to structure supply and demand, what have also been called "integrated charcoal production system" (Moen *et al.* 1984). The model in fig, 6.4B is more in line with adaptive co-evolutionary views of ESy (e.g. Berkes *et al.* 2003; Holbrook 2003; Manderson 2006) included elements and social interactions in social (people, knowledge and practices), economical (goods) and ecological (ecosystems, emissions) aspects around technology for WF production and use. Therefore, in fig. 6.4A it would be difficult to perceive the differences between rural and urban areas, the importance of agriculture in the WF production or the role of knowledge and practices in WES design, while in fig. 6.4B it would be unspotted the fact that WF could also be used to support industry sector, as well as the need to consider conversion technology in both rural and urban areas. Note that fig. 6.4A is not wrong or less complete than fig. 6.4B, since they are basically reflecting two different perspectives. In fact, one of the more relevant

outcomes of ESy modelling (and systems analysis in general) for this research is the exposure of a seldom forgotten reality: the issue is not on the "correctness" of the model, but rather o on the way boundaries are set, the perspective taken and who make the models and for what (this point will be further explored in §9.2). The different conceptualisation of ESy represented in 6.4A and 6.3 also have consequences on the type and purpose of model they generate as reference models (§6.3) and represent also a widow into the design paradigm of the modeller/designer as explained in §9.1-2.

ESy have been used to conduct a number of analyses on the relation between energy and development (e.g. Goldemberg & Johansson 1995; Takada *et al.* 2000), or to analyse the impacts and benefits of biofuels production in DCs (e.g. Giampietro & Mayumi 2009), However, regarding Mozambique and WF, with the exception of the chain models, and some research that uses the term to refer to energy sector in Mozambique the only known output on ESy modelling is actually the TOPB (§5.3.2), a set of interrelated elements connected around charcoal was defined within a boundary. This fact not only expresses the flexibility of ESy modelling in terms of format (appearance), but also the importance of how, why and by whom are the boundaries set, as it will be seen in §9.2.

Comparatively with the "energy ladder", In terms of design paradigm, *a priori*, chain and ESy models are not normative or prescriptive. There is not any kind of judgement on the elements *within* the systems/chains, the boundaries *defining* the system/chain, or the way these boundaries and elements have been generated. Likewise, chain and ESy models are not prescriptive, since they do not indicate any sort of solution or direct link cause-effect to solve a problem, even if when these models are used to make analysis and propose solutions (§6.3). However, both chain and ESy models prescribe a purpose which is embodied in the model presented as a framework of analysis. The purpose and the process of defining such framework of analysis are, in general, conducted by the modeller. The ESy and chains, as well as their components and relations do not define themselves, instead they are the product of a systemic conceptualisation by the modeller. After all, who defines who is who? And what is a problem? And what is a solution? And why? These are important modelling aspects seldom left available for non-researchers (§9-10). In resume while very useful to conduct analysis, descriptions and design of WES, the chain and ESy models are In fact, planning tools, not design tools (§7).

6.3 QUANTIFYING WOOD FUEL DECISIONS: VARIABLES & EQUATIONS

Deciding between options in quantifying terms, requires mathematical models. Simply, a mathematical model is a set of equations/inequalities that describe interrelations among parameters which, in turn, express measurable or relevant properties of a system. By solving equations describing a model of the system (e.g. the chain models or ESy models), it is possible to mimic the dynamic behaviour of the system and thus explore and understand the systems according to those parameters for predefined purposes. In this

sense the mathematical models integrate and complement the previous models (§6.1-2) facilitating decision making and the understanding/exploration of WES. To follow the sequence used in the descriptions of the previous models, fig. 6.5 provides a graphical image of what could be a typical WES mathematical model and modelling sequence.

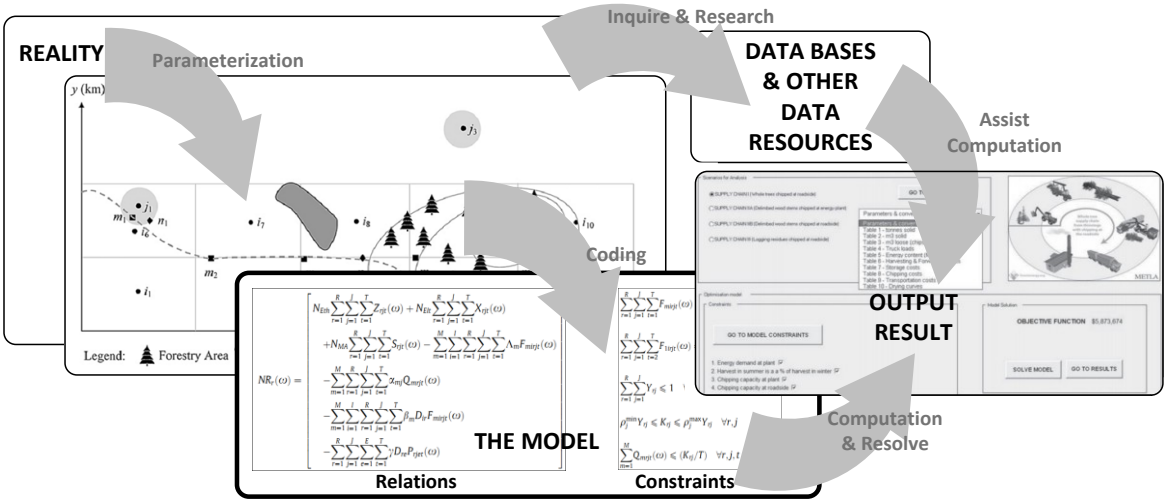


Figure 6.5| Representation of a mathematical model and modelling process [Source: the Author using unrelated images from Acuna *et al.* 2012; Čuček *et al.* 2012; Osmani & Zhang 2014].

Note that fig. 6.5 is only a simplistic representation of what could require feedback and interactive steps. Likewise, the results could be presented in other more or less "user friendly" (like graphics or spreadsheets), but at the backbone of any mathematical modelling process there is a highly abstracted "image" of what the modeller perceives as important aspects (parameters) in the reality to be "simulated". Another issue is the people involved in the process. In general the coding, computing and construction of the "user interface" are tasks conducted by the modeller/expert. Other relevant or knowledgeable actors or stakeholders might be invited to participate in parameterisation stage, in the construction of the data bases as data/knowledge providers and/or in the assessment of results or quality of the interface (§10). However, the actual design of the model is done by the modeller using a number of mathematical techniques, approaches and purposes. In this regard, there are literally thousands of mathematical models with relevance for WES research which could be organised in dozens of classifications (e.g. ref. in tab. 6.1). Since the purpose here is not to analyse in close detail these models, but to expose what are the design purposes and paradigms behind their conception a strategy was devised to achieve such objective scoping efficiently and comprehensively the literature on mathematical models dealing with WES. This strategy is, in a sense, very similar to the process depicted in fig. 6.5 and was conducted in 3 stages:

1| Since WF is a kind of lignocellulosic biomass, bioenergy and a forestry product (§5.3), identify recently published mathematical models of/for WES and supply chains involving: bioenergy production/consumption; forest, lignocellulosic or biomass energy. consider only the references that fulfilled simultaneously two requirements:

1.1| The models selected should cover all WES in fig. 6.3-6.4, bypassing standalone technologies, processes or production/consumption stages[14], but considering firewood transportation.

1.2| The models selected should consider only wood as the energy source, or a mixed source that includes wood since this is what happens in Mozambique (§5.3). Hence, feedstock exclusively composed of herbaceous biomass (e.g. miscanthus), agriculture residues (e.g. corn stalks), dedicated agriculture energy crops (e.g. cassava) or other biomass (e.g. manure) were not considered.

2| Grouping of the results according to emergent issues and properties in the literature with relevance for this thesis.

3| Critically analyse the outcomes in connection with previous results from §5.

Starting from the available sources of data, and in accordance with the key words described in 1| above, besides the individual research of a total of 18 relevant reviews produced between 2006 and 2017 were identified and organised in tab. 6.1:

Table 6.1| Relevant literature reviews on WES mathematical modelling since 2006 in decreasing order of publication year and in alphabetic order of author within the same year. [*Continues in next page*]

REFERENCE	TITLE, BRIEF DESCRIPTION AND RELATION WITH THIS WORK
Cobuloglu & Büyüktahtakın (2014)	***A Review Of Lignocellulosic Biomass And Biofuel Supply Chain Models***- Provides a short, but very focused and updated review on models developed for supply chain and production of lignocellulosic biofuel and biomass from energy crops including, naturally, woody biomass and WF.
De Meyer *et al.* (2014)	***Methods To Optimise The Design And Management Of Biomass-For-Bioenergy Supply Chains: A Review***- Overviews of the optimisation methods and models on the design and management of the upstream segment of the biomass-for-bioenergy supply chain, including many forest based models, which links directly with WF.
Elia & Floudas (2014)	***Energy Supply Chain Optimisation Of Hybrid Feedstock Processes: A Review-*** A very recent article with a full range of supply chain mathematical models up to September 2013, focusing on the production of bioenergy from a number of feedstocks, including WF.
Yue *et al.* (2014)	***Biomass-To-Bioenergy And Biofuel Supply Chain Optimisation: Overview, Key Issues And Challenges***- A very updated and comprehensive overview of the existing of mathematical models and other, addressing biofuel/bioenergy supply chain Optimisation and design from a number of biomass resources as WF.

14 For the interested reader: generic biomass conversion to bioenergy (Ghatak 2011; Görgens *et al.* 2014; Meyer *et al.* 2011); stand alone gasification (Gómez-Barea & Leckner 2010; Puig-Arnavat *et al.* 2010); thermo-conversion (Panwar *et al.* 2012); Pyrolysis (Bridgewater 2012); torrefaction (van der Stelta *et al.* 2011); wood to liquid transportation fuels (Wei *et al.* 2009 Galbe & Zacchi 2002); improved stoves (Kshirsagar & Kalamkar 2014; Kumar *et al.* 2013); charcoal kilns (Mohod & Panwar 2011; Nturanabo *et al.* 2010). For management of forest with energy purposes (Murray 1999; Martins *et al.* 2005; Gunn & Richards 20; Goycoolea *et al.* 2005; Constantino *et al.* 2008; Kinoshita *et al.* 2009; Gallis 1996).

Table 6.1| [*From previous page*] Relevant literature reviews on WES mathematical modelling since 2006 in decreasing order of publication year and in alphabetic order of author within the same year [*Continues in next page*].

REFERENCE	TITLE, BRIEF DESCRIPTION AND RELATION WITH THIS WORK
Shabani *et al.* (2013)[1]	***Value Chain Optimisation Of Forest Biomass For Bioenergy Production: A Review***- Reviews both deterministic and stochastic mathematical models to optimise forest biomass (mainly WF) supply chains used to support a wide range of design decisions.
Shahi & Pulkki (2013)	***Supply Chain Network Optimisation Of The Canadian Forest Products Industry: A Critical Review***- Makes a critical review of the relevant literature on forest supply chains considering also the biomass for energy supply chains, which is central for WSC.
Sharma *et al.* (2013)	***Biomass Supply Chain Design And Analysis: Basis, Overview, Modeling, Challenges, And Future***- Systematically describes energy needs, targets, feedstocks, conversion processes in a comprehensive review of mathematical programming models developed for Biomass Supply Chain (which includes WSC) design.
Sunde *et al.* (2013)	***A Environmental Impacts And Costs Of Woody Biomass-To-Liquid (BTL) Production And Use- A Review***- A very focused on woody and forestry biomass, i.e., WF, to energy resources from the life cycle assessment perspective, complements the remaining reviews with an ecologic take on WES.
Yilmaz & Hasan (2013)	***A Review On The Methods For Biomass To Energy Conversion Systems Design***- Include review studies about energy systems, the studies about design of biomass to energy conversion systems and the studies about design of hybrid renewable energy systems that include biomass and WF as an energy source.
Floudas *et al.* (2012)	***Hybrid And Single Feedstock Energy Processes For Liquid Transportation Fuels: A Critical Review-*** Provides a detailed account of the key contributions to energy supply chains with specific emphasis on thermochemically based hybrid energy systems for liquid transportation fuels from a number of resources, notably, WF.
Scott *et al.* (2012)	***A Review Of Multi-Criteria Decision-Making Methods For Bioenergy Systems***- Focus specifically on multi-criteria, multi-objective, multi-attribute methods, but also covers biomass supply chains which is well within the orbit of this work.
An *et al.* (2011)	***Biofuel And Petroleum-Based Fuel Supply Chain Research: A Literature Review***- Provides a literature review of research on the biofuel Supply chains (which include WSC).
Baños *et al.* (2011)	***Optimisation Methods Applied To Renewable And Sustainable Energy: A Review***- Presents a review of the state of the art in mathematical optimisation methods up to 2011, applicable to renewable and sustainable energy including WES.

NOTE: 1- Johnson *et al.* 2012: *Methods For Optimally Locating A Forest Biomass-To-Biofuel Facility*, provides an update, but this document was inaccessible.

Table 6.1| [*From previous page*] Relevant literature reviews on WES mathematical modelling since 2006 in decreasing order of publication year and in alphabetic order of author within the same year.

REFERENCE	TITLE, BRIEF DESCRIPTION AND RELATION WITH THIS WORK
Bazmi & Zahedi (2011)	***Sustainable Energy Systems: Role Of Optimisation Modeling Techniques In Power Generation And Supply- A Review***- Covering the literature until 2010 , analyzes the role of modelling and optimisation in the energy sector as a tool for sustainable energy systems, including forest supply chains, that is, WF.
Zeng *et al.* (2011)	***A Review On Optimisation Modeling Of Energy Systems Planning And GHG Emission Mitigation Under Uncertainty***- One of the few recent reviews on optimisation and model-based decision support tools supporting ESy planning that considers some WF examples.
Iakovou *et al.* (2010)	***Waste Biomass-To-Energy Supply Chain Management: A Critical Synthesis***- A critical synthesis of the literature until 2009-2010 is provided on the multiple design and management perspectives about the value chains of waste biomass, including also forestry residues and other woody biomass used as waste.
Hiremath *et al.* (2007)	***Decentralized Energy Planning; Modeling And Application- A Review-*** Complies research on WF is related with rural energy and decentralised energy systems, as this reference overviews different decentralised energy models used worldwide, their approaches and their applications along with a few emerging energy models.
Jebaraja & Iniyan (2006)[2]	***A Review Of Energy Models***- A very comprehensive attempt to collect, organise and classify research on ESy modelling including emerging issues, some WES are also commented.

NOTE: 2- There is a more recent review on this subject (Bhattacharyya & Timilsina 2010: *A Review Of Energy System Models*) however, surprisingly this work has no reference to biomass, wood or WF.

Based on the review articles (tab. 6.1) and further research in specialised websites with the keywords suggested in stage 1| a total of 105 models presented in 115 papers were identified as relevant, tab. 6.2. Besides the criteria used stage 1|, this number only considers the most relevant and/or complete accounts for each author, and therefore, does not include similar work with slight differences in content (different site for case study, different technology, and different mathematical technique within the same class of tools) or similar work from different authors with the same research group.

To group these results, stage 2|, an interactive and reflexive process was conducted involving the research purpose (§2, 3), existent classifications and analysis (tab. 6.1) and assertions already exposed in §5. Consequently, 3 main interrelated conclusions emerged on the principles underpinning the WF mathematical modelling. First, the overarching objective of WF mathematical modelling is to support decision making in the context of energy planning and/or management which, for the case of DCs, is guided by the principles of ETP, expressed in the constant endorsement of technological sustainability and efficiency both as a target and a political justification for research. Second, such WF energy planning and management is conducted systemically virtually only within two

major conceptual frameworks provided by the ESy models and chains models (§6.2). Thirdly, the contribution that mathematical models are almost exclusively provided in the form of computational based platforms that simulate or optimise the ESy or supply/value chain. In this regard, mathematical models integrate theoretical (§6.1) and descriptive models (§6.2) and can be used to optimise or simulate the entire WES and WSC as well as sections or subsystems of those, in a number of complex operational, tactical and strategic tasks. Usually, these platforms come in more or less complex software packages (an example of interface being the OUTPUT in fig. 6.5) and are designed by experts to inform and assist decision makers (e.g. planners, managers, policy makers) in a coherent manner, to build insight and to explore and understand possible future changes in ESy on the local, regional and global scale.

However, while there is a difference between simulation and optimisation, there are also differences between how optimisation is made in WES and in WSC. Optimisation models aim to maximise or minimise parameters (e.g. cost or profit) of the system (the ESy or the supply chain), considering a set of constraints. The systems are considered to be in "equilibrium", i.e., operated at the lowest overall value of that parameter, from a technological perspective (after van Ruijven 2008), i.e., the system is working optimally and as expected. Simulation models, on the other hand, describe the development of the systems with a predefined set of rules that do not necessarily require optimality (after van Ruijven 2008), i.e., the system is operating like reality would, if it was a system. With simulation models the user can explore and compare options, but will never know if they are optimal, with the optimisation model, the user gets only the optimum. In this sense, WES and WSC simulation models are very similar, since their description of the systems is also very similar (§6.3-4). However, this is not the case for the optimisation models. ESy optimisation starts from a representation of the system (similar to fig. 6.4A) with all the processes (technology operations in fig. 6.4A) producing, transforming, and consuming energy as a network and then applies mathematical methods (e.g. linear programming) to select the best combination of technologies based on economic data and performance for each process and/or user defined environmental and policy restrictions[15]. The biomass supply chain optimisation starts also with as a network structure (like fig. 6.3) in which nodes are specific site operations (boxes in fig. 6.3) like collection sites *at the forest*, while arcs (arrows in fig. 6.3) quantify the product flow and transport operations through actual roads (e.g. de Mol *et al.* 1997). With this network formalised, mathematical methods (e.g. mixed integer linear programming) are used to optimise both the network structure and the flux of biomass according to a specified economic, energetic and/or environmental objective with the mass balances, capacities and demands as restrictions (e.g. de Mol *et*

15 In fact, this is only a bottom-up approach to ESy optimisation, very technological driven and the mostly used in WF contexts. Another option is the optimisation with top-down models which describe macro-economic structures in a consistent general equilibrium framework, with producer/consumer behavioural equations but aggregate factors for technology development (van Ruijven 2008).

al. 1997). Therefore, while WES optimisation is mostly concerned with Optimise technological/resources options to assist strategic macro-economic decisions, WSC optimisation is concerned with optimising technological/logistic/resource options to assist strategic, tactical and operational decisions (see Elia & Floudas 2014; Iakovou *et al.* 2010) related with providing an efficient and economic chain structure (e.g. Sharma *et al.* 2013)[16]. Hence, WES optimisation allows the identification of the most cost-effective pattern of resource use and technology deployment over time and quantifies the system wide effects of those choices, while the WSC facilitates the definition of the number, location, type and capacity of facilities, production rates, flow of material between operation sites, as well as choosing suppliers and markets (e.g. Mansoornejad *et al.* 2010).

Despite these differences, on a practical level, WF simulation and optimisation use the same mathematical methods classified as: mathematical programming; heuristic; stochastic; multi-criteria decision analysis/aid (MCDA) [17]; and hybrid. Mathematical programming methods are deterministic. i.e., assuming the parameters are known and fixed with certainty, and calculate selected decision variables to optimise a pre-defined objective function in accordance with its constraints (de Meyer *et al.* 2014). Heuristic methods find satisfactory, but not necessarily optimal, solutions for complex problems adapting meta-heuristics to specific problems to reduce or make possible calculations (Alba 2005; Gendreau & Potvin 2010). Stochastic methods assume that parameters are random and uncertain and use probabilistic approaches to define intervals of reasonable variation. MCDA incorporate multiple objectives and/or criteria, often conflicting, in order to facilitate the judicious decisions (e.g. Roy 1996). MCDA is also a valuable modelling tool and, as such, will be discussed in more detail in stage 3| bellow. Finally hybrid methods combine elements of two or more of these methods. Besides these methods assessment techniques can be coupled with mathematical models, like geographical information systems (GIS) (e.g. Calvert 2011) or life cycle assessment (LCA- Sunde *et al.* 2011). In accordance with these differences and similarities the WF mathematical models reviewed where organised in three distinctive classes, each applying one of mathematical methods described above both in developed and DCs, tab. 6.2:

1| Optimisation models based on the chain models (OSM)- models that Optimise the WSC or similar supply/value chains considering wood resources;

2| Optimisation models based on the ESy models (OEM)- models that Optimise WES or similar ESy that consider wood resources;

3| Simulation models for WES (SM)- models that simulate WSC or WES, or similar ESy or supply/value chains that consider wood resources.

16 Again, this is also an upstream optimisation view of the problem and also the only considered by the majority of the models on WSC optimisations assessed. A Downstream Optimisation would start from the demand and incrementally optimise the supply chain till the source.

17 There are also Multi-Criteria Decision Making and Multi-Objective Decision Making, and both could be used in OSM, SEM and SM for details see (Braune *et al.* 2009).

Table 6.2| Classification of references using mathematical models on WES, according with purpose, feedstock, location, and mathematical methods used. (■ Mathematical programming; ● Heuristics; ◆ Stochastic; ▲ MCDA; ❖ Hybrid; References in **Black** are for DCs and references in **Light Gray** for Developed Countries; References **Underlined** refer specifically to WF).

	OPTIMISATION		SIMULATION
	CHAIN MODELS [OSM]	ESY MODELS [OEM]	[SM]
WOOD-ONLY FEEDSTOCK	■ Acuna *et al.* (2012); ▲ Alam *et al.* (2012); ■ Alidi (1988); ■ Cambero *et al.* (2014); ▲ Daugherty & Fried (2007); ■ Elia *et al.* (2012, 2013); ■ Freppaz *et al.* (2004); ■ Han & Murphy (2012); ■ Kanzian *et al.* (2009); ■ Kim *et al.* (2011a, b); ■ Leduc *et al.* (2008, 2009, 2010); ■ Marti & Gonzalez (2010); ■ Natarajan *et al.* (2012); ■ Panichelli & Gnansounou (2008); ■ Rauch & Gronalt (2010)[2]; ● Reche *et al.* (2008)[2]; ■ Shabani & Sowlati (2013); ■ Stasko *et al.* (2011); ▲ Steubing *et al.* (2014); ■ van Dyken *et al.* (2010); ● Vera *et al.* (2010); ■ Wetterlund *et al.* (2012); ▲ Zhang *et al.* (2012)	■ **Arrocha & Villena (2012);** ■ Börjesson & Ahlgren (2010); ■ Chinese & Meneghetti (2005); ■ Frombo *et al.* (2009a, b); ▲ Gassner & Marechal (2009a, b)[2]; ■ Gunnarsson *et al.* (2004); ● Hamann (2008); ■ Keirstead *et al.* (2012); ■ Lehtilä & Pirilä (1996); ■ **Luhanga *et al.* (1993);** ◆ Svensson & erntsson (2011); ■ Yu *et al.* (2009)	■ **Bormann *et al.* (1991)[1];** ■ Caputo *et al.* (2005)[2]; ◆ **Falcão *et al.* (2007, 2010);** ■ **Fernandes (2013);** ■ Gan & Smith (2006)[2]; ▲ **Ghilardi *et al.* (2007, 2009);** ■ Hacatoglu *et al.* (2011); ■ Heller at al (2004); ■ **Heltberg *et al.* (2000);** ◆ Higo & Dowaki (2010)[4]; ▲ Jäppinen *et al.* (2013); ▲ Jovanovic *et al.* (2010); ■ **Kumar *et al.* 2003);** ❖ Mobini *et al.* (2011); ■ **Onoja & Idoko (2012);** ▲ Ridolfi *et al.* (2009)[2]; ▲ Sacchelli *et al.* (2013); ■ Schulz *et al.* (2007); ▲ Svanberg *et al.* (2013); ▲ Tahvanainen & Anttila (2011); ■ Tsalidis *et al.* (2014); ❖ Wolbert-Haverkamp *et al.* (2014)
MIX FEESSTOCK INCLUDING WOOD	■ Aksoy *et al.* (2011); ■ Alfonso *et al.* (2009); ❖ Ayoub *et al.* (2007, 2009, 2012); ● Chen & Fan (2012); ◆ Chen & Önal (2012); ▲ Čuček *et al.* (2010, 2012, 2013)[2]; ■ de Mol *et al.* (1997); ■ Ekşioğlu *et al.* (2009; 2010); ■ Fiedler *et al.* (2007)[2]; ❖ Gebreslassie *et al.* (2012); ❖ Giarola *et al.* (2012); ■ Jenkins *et al.* (1984)[2]; ◆ Osmani & Zhang (2014); ▲ Palander (2011); ■ Papapostolou *et al.* (2011); ❖ Rentizelas & Tatsiopoulos (2010); ◆ **Suwanapal (2010);** ▲ Xie *et al.* (2014); ▲ You *et al.* (2011); ▲ Yue *et al.* (2013)	■ Bruglieri & Liberti (2008); ■ **Heran & Nakata (2012)[1];** ■ **Hiremath *et al.* (2010);** ■ **Iniyan & Sumathy (2003);** ■ **Joshi *et al.* (1992);** ▲ **Kowero *et al.* (2005);** ■ Nagel (2000); ▲ **Nhantumbo *et al.* (2001);** ▲ **Parikh (1985);** ■ **van Ruijven (2008)[1, 2];** ▲ **Santibañez-Aguilar *et al.* (2011)**	▲ **Alam (1991);** ■ **Amatya *et al.* (1993);** ■ **Bala (1997);** ■ **Batidzirai *et al.* (2006);** ■ Clark *et al.* (2013); ■ **Edelman (2000)[1];** ▲ Hamelinck *et al.* (2005); ■ Havlík *et al.* (2011)[3]; ■ Mantovani & Gibson (1992); ▲ **Matsika (2012);** ▲ **Pokharei & Chandrashekar (1998);** ■ **Sitoe *et al.* (2007b);** ■ Smeets *et al.* (2007)[3]; ■ Thornley *et al.* (2009); ■ Tittmann *et al.* (2010); ■ **van den Broek *et al.* (2000);** ■ **Zhen (1994)**

NOTES: 1- Generic for DCs; **2-** Generic for Developed Countries; **3-** Global model; 4- Conducted in Japan and Papua New Guinea.

Before entering the analysis of the data on tab. 6.2, it is relevant to explore some quantifying aspects of this literature review on WF mathematical models. Indeed, using the number and focus of the reviewed articles as a proxy of the interest and focus of the academic community, a number of analyses were performed, fig. 6.6. Note that the purpose here is not to conduct a profound analysis, but rather to confirm some previous assumptions and identify some trends.

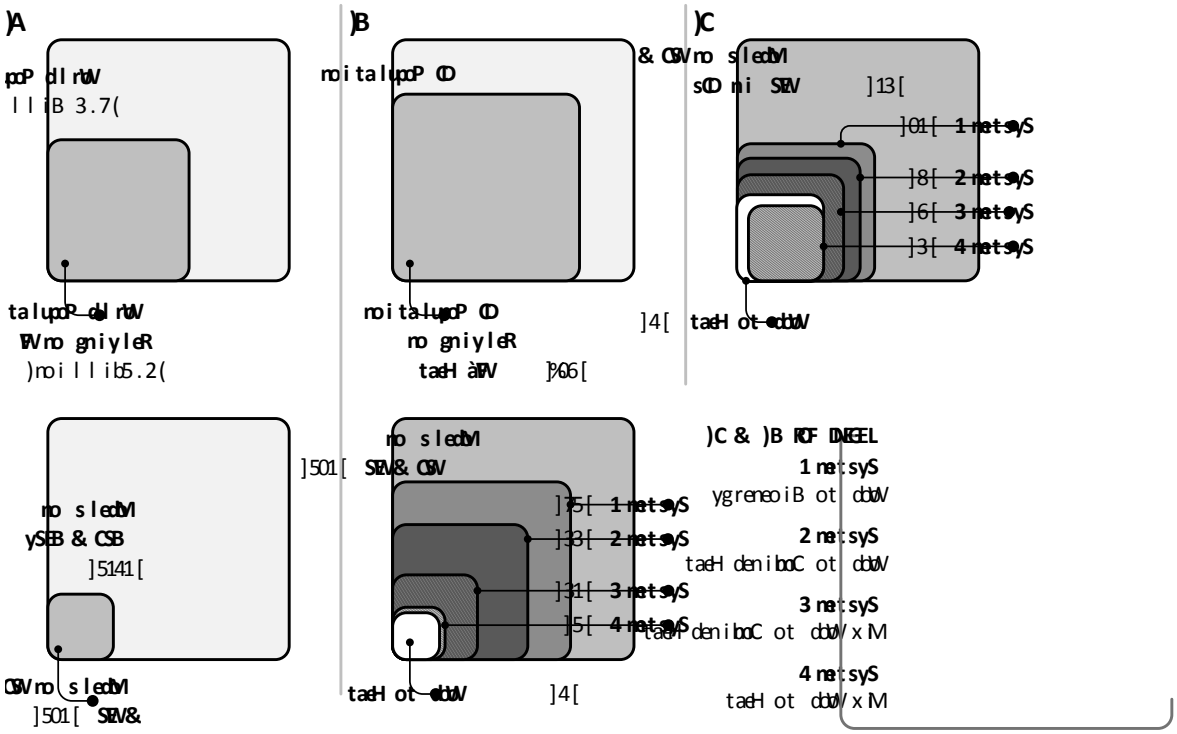


Figure 6.6| Relative proportions of papers published in relation with the modelling of biomass and WF energy issues and the social dimension of the energy problem (§5.1) (Numbers is straight brackets refer to number of papers and the population estimative are explained in the text) [Source: the Author].

One of the assertions advanced in §A, and further in §5, was the relatively lower position of the WF research in the political and academic agenda. Considering the dimension of the problem, already explored in §5.1, it would be expected that some more research, In particular, that useful models would be available by now.

A number very often repeated, but never confirmed, refer to 2.5billion people relying on WF for survival (e.g. WB 2006) which corresponds to more than 30% of the world population, however, in the universe of energy modelling, not only biomass occupies a small niche, but furthermore, modelling on WSC and WES represents a real small portion of research, at least if measured in number of publications. As fig. 6.6A shows, from the total amount of articles mentioned on the reviews on mathematical modelling, only around 8% referred to WF modelling in the terms defined in stage 1|. However, this gap between research and relevant social issues, is not just confined to the quantity of modelling conduct, is also a question of content of those models. From the data and analysis in §5.1 (see fig. 5.1), it was possible to conclude that most people in DCs,

particularly in rural areas relied on WF, mostly from forest or farming areas, on a great extent for cooking (heat). The numbers advanced ranged from 60% to 80% (sometimes even more), however, for the sake of argument, even if the conservative lower limit of the interval is considered, i.e. 60%, it would be expected that research would be concentrated on modelling wood to heat using ESy or chain models, i.e., be concentrated on modelling WES and WSC. That is not the case. As fig. 6.6B illustrates, the wood to heat WES/WSC comes last in the preferences with only 4 models in 105 possible.

Considering a mixed feedstock of wood and other materials (systems 3 and 4 in fig. 6.6B) only 5 models consider exclusively the production of heat (system 4), and only 8 more consider the production of heat in combination with, e.g., electricity and/or biofuels (system 3). While the majority of the wood for bioenergy WES/WSC is dedicated to the production of heat combined with other bioenergy (33 models system 2 in fig. 6.6B), there are 24 models that still consider wood for other purposes.

Nevertheless, this number of wood to heat WES/WSC, even if not in exclusivity, could indicate that some models are available to Optimise and/or simulate the production of heat from wood in DCs. Again, judging from the available models in the literature, this is not case. From fig. 6.6C it is possible to conclude that most modelling efforts are concentrated in “Developed Countries”, since out of 105 models, only 31 deal with DCs. This was already visible in tab. 6.2, particularly for the optimisation models, where the work on/for DCs (black references) is virtually non-existent. This can be the result of an extensive work on forest and woody biomass supply chain optimisation carried in developed countries with rich forest resources. Indeed, Finland, USA and Canada together also produced 31 models and represent 57% of all supply chain optimisation models made in DCs regardless of the kind of feedstock, Within these 31 models developed in/for DCs, it is also clear from fig. 6.6C, that wood is not the preferred feedstock, since only 10 models consider wood for bioenergy (system 1), neither is heat a preferred output envisaged by modellers, since from the 31 only 14 models consider that option (system 2 and 3 added in fig. 6.6C). Therefore, what the incidence and topic of the models seems to indicate is the use of mixed feedstock to supply processes that generate electricity and biofuels. While these results are in close agreement with the crescent interest on the use of WF alone or mixed with other biomass to produce biofuels, it can also be understood as yet another sign of the ETP in action, i.e., the promotion of new and “modern” technologies for energy.

Returning to the tab. 6.2, two interlinked aspects deserve further considerations. First, is the absence of OEM compared with the OSM and SM. With only 20 models in total, OEM represents about 21% of all models identified. Since the definition of ESy, and In particular, WES, has been taken as a planning activity (e.g. FAO 2000), it would be expected to see more OEM in tab. 6.2. This “absence” is even more surprising considering the number of powerful software developed specifically to support ESy 0ptimisation, like

the MARKAL family (Loulou *et al.* 2004), TIMER (van Vuuren *et al.* 2006) or DICE (Nordhaus 1993). Indeed, some authors use these models, like Börjesson & Ahlgren (2010), Chinese & Meneghetti (2005) and Schulz *et al.* (2007) who used MARKAL to optimise and test WES based on forest residues and/or dedicated plantations to produce electricity and/or biofuels, or Lehtilä & Pirilä (1996) who used EFOM (Energy Flow optimisation Model) to optimise a biomass ESy in Finland for the production of bioenergy from wood. In DCs a recommended optimisation model for WES (FAO 2000) is LEAP (Long-range Energy Alternatives Planning System) was used by Luhanga *et al.* (1993) to assess optimal alternatives to charcoal. Bala (1997) and Kumar (2003) also used LEAP in DC contexts, but to assess and simulate rural ESy. More recently, van Ruijven (2008) introduced WES in a global ESy model based on MARKAL/TIMES. Moreover suggestions have been made to combine chain models with ESy models, like MARKAL in order to incorporate biomass supply chain networks can also be incorporated into a larger scale, regional, renewable energy planning (e.g. Floudas *et al.* 2012). Nevertheless these continue to be exceptions rather than the rule, apparently because MARKAL, and other similar tools, are not suitable to deal with the logistic and geographical nature of biomass supply chains and, likewise, WSC (Sarica & Tyner 2013).

As several authors throughout the reviews in tab. 6.1 mention the cost of producing biofuels is strongly related with location, access and availability of sources, something OEM do not account very well. in other words, OEM generally consider that all the operations are in place and a clear and well run market exist, which is seldom the case. However, if OSM manages with efficiency geographical, operational and logistic aspects of the WES, relatively few studies have been able to address uncertainty related to generic biofuel supply chains (An *et al.* 2011).

Deterministic models are necessary and helpful but cannot capture all aspects of forest biomass supply chains. Most of the parameters and events in forest biomass supply chains, such as wood quality, market situation, prices, and yields, are uncertain. Uncertainty makes this industry volatile and long term planning difficult. Even in the short term, variations in raw material quality can impact the performance and efficiency of forest bioenergy production. On this regard, Shabani & Sowlati (2013) defend that despite the interest and much effort in extending deterministic models, only few studies considered uncertainty in optimizing forest bioenergy supply chains. An option would be to use more stochastic methods however, there is still a lack of research that addresses multi-period, multi-layer, stochastic models, since most papers deal with a single-period and assume a deterministic environment (Melo *et al.* 2009, Scott *et al.* 2012).

Amidst this concern with uncertainty Iakovou *et al.* (2010) claims that that there is a lack of research tackling systemically biomass supply chain network design, specifically, they add, few papers address the critical issue of designing sustainable biomass supply chains in which both profitability and environmental impact are balanced. Along these lines Gold

(2011) and Gold & Seuring (2011) highlight the importance of actors and coordination among them for a well managed supply chain. Moreover Scott *et al.* (2012) consider that alongside technological choice, policy decisions were the most notable problem in OSM. de Meyer *et al.* (2014) also relates the importance of social aspects in the design of supply chains, criticising the usual and simplistic quantification of social objective by measuring the number of local jobs created, when social sustainability also covers the integration of human rights, labourer's rights and corporate governance.

These critics find and suggestions for new trends on the way supply chains and ESy are modelled might also be extensible to the way WSC and WES are designed. A proof is given in tab. 6.3 where criteria, objectives and parameters that emerged from the reviewed articles are organised by type and modelling approach.

Table 6.3| Criteria, objectives and/or parameters identified in the review literature in tab. 6.2 (OSM- optimisation models based on the chain models; OEM- optimisation models based on the ESy models; SM- Simulation models for WES).

EMERGENT CRITERIA, OBJECTIVES AND/OR PARAMETERS	OPTIMISATION		SIMULATION	% TOTAL
	OSM	OEM	SM	
ECONOMIC	43	22	37	97%
ENVIRONMENTAL	17	15	25	54%
SOCIAL	0	3	7	10%
TECHNOLOGIC	15	14	24	51%
LOGISTIC	43	4	16	60%

Not surprisingly, economic aspects are clearly the main concern in the mathematical modelling of WES (used in 97% of all models) while social aspects (considered in 10%) of all models considered) are the least concern. The term "aspects" or "concerns" is used here instead of "criteria ", "objective" or "parameter", since each of these roles can change in modelling and normally do. Economic *aspects* can be used to define the function objective, or be a parameter of the equipment or criteria to be considered.

Note also, that some numbers should also be seen with some care. For instance while scoring high values of use, environmental aspects are normally reduced to emissions accounting and very few papers including other aspects like, for instance, land usage or water quality. Likewise technology appears in many such models as a black box or brief technical considerations. Social aspects are, like de Meyer *et al.* (2014) referred above simplistic reduced to "job creations". On this regard, economic and logistic aspects are far more clear and identifiable, probably because they compose the, *de facto*, nature of the models considered. Nevertheless, the objective was not to conduct a precise examination of a toxicology of concerns or aspects, but rather to identify the *dimensions* considered by modeller in the design of WES. These dimensions will be very useful in the further ahead to define the 2MW (§D).

Relevant for now is the fact that conciliating these dimensions in a coherent model is a considerable challenge. A challenge that have prompted various studies to simultaneously consider multiple factors to maximise the supply chain profitability and sustainability using optimisation frameworks to examine trade-offs between different strategic decisions. The general description of the problem (and solution) seems to be straight forward: uncertainty is ubiquitous (Nikolopoulou & Ierapetritou 2012), *thus* sustainability must be incorporated in decision making on supply chain, (Awudu & Zhang 2012).

The need to incorporate multiple perspectives and promote sustainability in a context of strong uncertainty brings to the discussion the second aspect implicit in tab. 6.2 and already addressed above: MCDA. While the mathematical programming, expectedly remains the first preference for modellers being used in 65 models (24 OSM, 16 OEM and 25 SM) representing 61.9% of all methods used, MCDA comes in second applied in 24 models (9 OSM, 4 OEM and 11 SM) accounting for 22.9% of all methods used.

Indeed, the progressive need to incorporate environmental and social considerations in energy planning resulted in the increasing use of multi-criteria approaches. Alongside new policy measures a new conception of energy planning procedure emerged to include different actors in decision making (Haralambopoulos & Polatidis 2003; Pohekar & Ramachandran 2003). MCDA comprises a collection of formal approaches which seek to take explicit account of multiple and probably conflicting criteria (e.g., technological, economic, environmental, risk, social) in helping individuals or groups to get involved exploring decisions that matter (Belton & Stewart 2002). Fundamentally, MCDA has inherent properties that make it appealing and practically useful, namely (Belton & Stewart 2002):

1| Provides explicit account of multiple, conflicting criteria;
2| Helps to structure the complex problem;
3| Provides a model that can serve as a focus for discussion;
4| Offers a process that leads to rational, justifiable, and explainable decisions;
5| Can deal with mixed sets of data, quantitative and qualitative
6| Facilitate compromise and collective decisions and provide a good platform to understanding the perception of models and analysts in a realistic scenario;
7| Facilitates negotiation, quantification and communication of priorities and course of action

MCDA had proved a valuable contribution to various types of energy planning problems such as renewable energy planning, energy resource allocation, energy project planning, and support in a number of Decision Support Systems in, e.g.; utility planning, technology selection, site selection, investment planning, evaluation of alternative energies (e.g. Alarcon-Rodriguez *et al.* 2010; Lahdelma *et al.* 2000; Pohekar & Ramachandran 2004; Wang *et al.* 2009). While MCDA seems to be well adjusted to complexity and uncertainty, the evolution of decision-making is likely to continue to lead to the emergence of ever

more diverse complexities which challenges the simplistic approaches of current decision aid methods (Sinclair 2011; Zeng *et al.* 2011). These complex systems have emergent properties that depend on the interactions between their constituent parts, and that "lead to an approach to decision-making, with MCDA [and other decision aid processes] being an example" (Elghali *et al.* 2007). Scott *et al.* (2012) seem to reach a similar conclusion, claiming that currently, MCDA do not "fully address the problems faced by the bioenergy industry"

To finish this review of mathematical models it is relevant to analyse briefly the models developed for Mozambique and/or WF. There is no model that deals with the optimisation of the WSC, the models identified included only SM (12 models) and OEM (5 models).

Starting from the SM, probably one of the first attempts to model the WES in mathematical terms was conducted by Bormann *et al.* (1991). They constructed a parameterised model of a generic charcoal production from a tree plantation to urban household cooking analysis in the process emissions, volumes, energy, demand and supply. Amatya *et al.* (1993) proposed an end-use/process analysis approach developed on a on a spreadsheet to simulate WF scenarios in Nepal. Pokharei & Chandrashekar (1998) built a multi-objective model to analyse the energy situation of a rural area and examined the tradeoffs between energy supply (mixed biomass), investment for energy programs, and employment generation, which makes this the only model with social consideration from the ones reviewed. Bala (1997) had presented projections of rural energy supply and demand and assess the contributions to global warming. The output of the dynamic system model had been used in the LEAP model and overall energy balances are compiled using a bottom–up approach. Almost ten years later Batidzirai *et al.* (2006) assessed the potential for Mozambique to became an exporter of wood pellets in strict respect for food security and sustainability criteria by analysing the supply chain as a WES.

Still in Mozambique, Falcão *et al.* (2007, 2010) constructed a dynamic game theoretic model to simulate human population and forest dynamics, harvesting costs, household consumption and prices of forest products. Using WF data from field surveys were used allowed the analysis WF management regimes. In the same year Sitoe *et al.* (2007b) proposed a model to relate the deforestation with the charcoal production in the North of Mozambique. In Mexico a similar approach was conceived by Ghilardi *et al.* (2007, 2009), who constructed a model to relate the consumption and production of WF based on GIS data and socio-economic profiling of the charcoal ESy. A similar technique was also used by Matsika (2012) to assess the spatio-temporal dynamics of woody biomass supply and demand as a result of human exploitation of the forest in South-Africa. More specifically in relation to charcoal Onoja & Idoko (2012) identified the variables influencing WF demand in rural areas of Nigeria by analysing eighty households and used to calibrate a simulation model of demand and its effects on the forest. Using a linear-

programming method, produced a model that simulates the sustainable production of charcoal to supply Beira in the centre of Mozambique. Finally, Wolbert-Haverkamp *et al.* (2014) proposed an agent-based model able to consider market competition and the whole value chain of wood chips to generate energy in order to analyse the producers' behaviours in Germany. This study is both one of the few conducted outside the DC and not considering economic aspects.

On the OEM side, Joshi *et al.* (1992) also simulated an Indian village with a simple linear model to minimise the cost of mixed biomass supply to fulfil household demand. Luhanga *et al.* (1993) also supported energy planning in Tanzania using the LEAP models applied to charcoal production through the use of optimisation models in combination with a forecasting model. In a first model the optimum mix of energy resources at minimum cost is defined and in a second model the optimum number of end-use biomass devices and hectares of land to be afforested is minimising the wood fuel deficit. Nhantumbo *et al.* (2001) developed a weighted goal programming to reconcile the goals of food security, improved incomes and woodland conservation in households from selected sites in Mozambique and later in Malawi and Zimbabwe (Kowero *et al.* 2005). The models optimised the supply with the demand defining which area can be used or not. With the same purpose, Arrocha & Villena (2012) defined a bio-economic model that relates charcoal production, household consumption and slash-and-burn agriculture.

From these descriptions, it is possible to perceive that a relatively wide array of simulation and optimisation approaches have been employed to enhance the understanding of the WES, mostly in DCs, including analytical and statistical equation-based, mathematical programming, agent based modelling, GIS. However, apart from the limited levels of complexity that can practically be built into them, these models have all focused on planning and none actually supports design of WES.

7 ENERGY TRANSITIONS: THE CRITIQUE

As exposed through many lenses in the previous sections, the energy reality of DCs is complex and problematic. Numerous technologies, approaches, perspectives and models have been considered to address that complexity, however, they all seem to find root on the energy transition paradigm (ETP). ETP is a set of normative and prescriptive assumptions that perceived that energy problems in DCs are caused by a vicious mix of poverty and the (so considered) dirt, hazardous, inefficient and traditional WF; and thus, endorse the switch to the (so considered) clean, efficient and modern energy carriers and technologies as the solution to sustainable development. Pervading almost all political and research agendas and initiatives related with energy in DCs, ETP basic and related set of assumptions will be critically explored here highlighting the importance of perspectives, how they vary and how they express a source of complexity. The purpose is to ground the need for a new approach to energy in DCs as a situated design problem requiring not prescribed solutions or normative framings, but design tools that support people with their own perspectives in the contextual exploration and definition of their own problems/solutions. The insights built here will serve as the philosophical design fundaments of the tool 2MW to be developed in §D.

Therefore, in the remaining of this chapter, several approaches and realities will be questioned regarding their ability to be questioned. The purpose is to show that few tools actually perform participatory design, while being quite good to produce planning, assess the quality of designs and theorise on the energy transition.

7.1 REVISITING THE TREE OF PROBLEMS AND FIND A TREE OF SOLUTIONS

In §5.3.2 a tree of problems for WF in Mozambique, mostly focused on charcoal, was presented as an expert outcome promoted by SNV at Maputo. Despite all the potential and usefulness of the “tree of problems” in §5.3.2, a deeper view of the layout reveals that this is, indeed, a “tree of solutions”. By defining what are the identified problems, the problem tree also expresses what the designers were looking at, that is, reveals what the their focus is: to define a road map to the predefined destination- change. This reverse logic can be implemented using the mechanical and simplistic cause-effect connection between the several problems (boxes) reversing the adjectives, e.g., instead of the problem “weak coordination” there is the prescriptive solution “need for a strong coordination”. Explored this way, the “tree of problems” is easily converted into a “tree of solutions” exposing the experts views and perspectives, more than the actual problems.

It is interesting to see how different perspectives interact in this tree of problems. From the “root” to the “top” the range of problems presented interestingly mixed two perspectives on WES that are apparently conflictive, but on second look share a number of characteristics. On one side there is the perspective that WES can be “modernised”

which is achieved by implementing good forest management associated with sustainable, modern and efficient production technology and formalising the market, the agents and the institutions. These ideas are in line with "WF is sexy" approach in §5.2.3 which defend a revamp of the WES, towards a more sustainable production of charcoal with benefits for the state, environment and charcoal makers. On the other side, there are those who defend a complete reconfiguration of the WES into some other energy systems doing the same as the WES, only "better". In the tree of problems this perspective is represented in "problem" like "lack of incentives for importing alternative equipment and technologies". This perspective could be further divided into those, like the international agencies and NGOs, who tend to defend the "small is beautiful" solutions, that is, modular autonomous renewable technologies (e.g. solar panels) and those, notably the DCs Governments, who prefer centralised grids macro-infrastructures (Zerriffi 2011). By presenting both approaches, the "tree of problems" defends an integration which normally is achieved in the two ends of the WES, revamping the production in rural areas, less wood is spent, changing, or promoting changing in the urban areas it is possible that people consume more effectively, i.e., less or with other alternatives. Therefore, while describing what would be the problems of a generic WES of Mozambique, the "tree of problems" is also imparting an idea of change, and how that change should look like, of energy transition towards something "better".

The relevant point raised with this small analysis is not to criticise a political agenda, or minimise the problems identified. Rather the aim is to show how the Mozambican expert discourse aligns with the global trends of "sustainable development" and "renewable technologies" while keeping the approach very "technical". In fact, this tree is not unique in energy analysis, and remarkably similar schematic representation in terms of contents can be found, for instance, in Escobar *et al.* (2002), always in relation with sustainable development and renewable technologies. Moreover, this analysis indicates that how the problem is seen influences how the problem is solved. In other words, structuring the problem is not very different from solving it, which, in turn raises the importance of design knowledge, purposes and paradigms. Assuming change as the design paradigm from an expert perspective will produce ESy designs for change, hindering other options and knowledge. Within this line of reasoning, this review of the SNV tree will serve as the departing point to a similar line of questioning to other assumptions associated with the ESy design, particularly relevant for the WES design.

7.2 TRANSITION TO MODERN TECHNOLOGY IS THE SOLUTION… OR IS IT?

The argument is always the same repeated in almost all energy paper on development field. Broadly the transition strategy argues that the absence of modern energy critically hampers the prospects of 2 to 3 billion people (like mentioned in §6.3, a number several times repeated but never confirmed) to escape from poverty, whereas its availability

offers a range of benefits capable of triggering wider transformations in their living conditions and livelihood opportunities. Modem fuels and electricity play a critical role in releasing the poor from their bondage to land-based, labour-intensive drudgery for sheer survival and, in its place, usher in a host of opportunities for their self-improvement (e.g. Modi *et al.* 2005). Within this broader energy context, alternative energy technologies, in general renewable energy technologies (RETs) provided in modular decentralised equipment (e.g. small-scale hydropower, solar PV systems and wind power), serve the needs of the poor effectively in many situations where the cost of providing modem energy through conventional means is prohibitive (Nouni *et al.* 2008). Poverty will be broken only, it is argued, by combining improved energy services with end uses that generate cash income (Brew-Hammond & Crole-Rees 2004; Cecelski 2008; Luca *et al.* 2003; Ramani & Heijndermans 2003), efficiently and sustainably (WBGU 2004). Moreover, it follows form this argument that suitable policies, models and initiatives should be created along the technological lines described above to fulfil overall principles such as efficiency or sustainable development. This is a strategy that reflects most of the history of energy in the development of the most developed countries, and as such seems quite natural and obvious for most researchers from those countries. After all who would not be happy with a clean technology that is the state of the art in term of electricity productions?

7.2.1 Results Are Mixed, But The Tendency Is For Failure

With several decades already of energy technology implementation in DCs, the balance is far from positive or optimistic. Indeed, most of the attempts to implement energy technology in DCs have either failed or only met with moderate success (Hudnut *et al.* 2006; Mabuza *et al.* 2007; Mapako 2006; Morgenstern 2002; Vedavalli 2007). The list presented here is not exhaustive, but will illustrate this point.

In the 1980s in India, from a total of 30.9million improved stove (chulhas) installed by the Government only 55.6% units were actually in use in 1992 (Neudoerffer *et al.* 2001). Similarly, from the early 1980s to the mid-1990s about 14000 units of firewood stoves were installed in the poor families in rural Zimbabwe and 95% of them had been abandoned by 1997 (Mapako 2004). A Philippine government program for biogas-powered water pumping in the 1980s saw only 1% of the gasifiers in use after some years, while 16% went unused and 80% needed repair (Bernardo & Kilayko 1990). In 1998, the government of South Africa spent around 1.7million pounds and installed photovoltaic units for 582 rural households in Folovhodwe, to find only 13 operational in mid-2004 (Bikam & Mulaudzi 2006). In the high profile multifunctional platform project for rural electrification in Mali, 40 % of the systems were non-operational after five years (PTF-Mali 2006). In Mozambique, as part of an international congress on RETs held in Maputo (Mozambique), participants went to an “exemplar electrified village” just to discover that only a few panels actually worked (interviews). The same result occurred again with the

author in a workshop in Mozambique held in 2013, a visit to a biodigester, considered unique in Mozambique, ended up in the description of a process next to a broken infrastructure. Experience shows that most RETs installed in rural areas become "cemeteries" of sophisticated equipment after foreign or government technicians left or when maintenance needs increase (AUSAID 2000; Jung 2007).

However, there are also histories of success (Barnes & Foley 2004): In Thailand, over 80% of rural people acquired it in the last decades; in Costa Rica, cooperatives and the government electricity utility provide electricity to almost 95% of the rural population; in Tunisia, 75% of rural households already have a supply. Since, 1984, there has been a successful private household market for PV in Kenya (Jacobson 2004) amounting to more than 3MWp of installed capacity (Byrne 2009) and recent estimates of the Tanzanian PV market suggest it has reached 1MWp of total installed capacity for solar home systems (Hankins *et al.* 2009). Mapako (2006) estimates that between 60% and 80% of the 85 000 solar systems in Zimbabwe are functional, while 16 PV water pumping sites and 650 wind pumps have been installed successfully. However, too often the success of dissemination projects is determined by the number of new technology ''adopters'', which has statistical value for the project, but tells little about the sustainability of these technologies or the efficacy with which they are utilised (Murphy 2001). Other approaches might reveal that success is relative. In a well researched study concerning Kenya, Jacobson (2007) shows that: the major beneficiaries were in the rural middle class; there are few links between solar PV and economically productive and education related activities; and solar PV is more closely tied to the increased use of TV, radio and cellular phones than to income generation, poverty alleviation and sustainable development.

In Mozambique, and more related with biomass energy production two major failures are worth mentioning. The Pro-Cana project, a mega project of 30000ha and over 500 million US$ set up to produce ethanol from sugar cane and launched in 2007 in Gaza Province (south of Mozambique) by private foreign investors among criticism of land grabbing (Borras *et al.* 2011). The project was an utter failure and eventually cancelled by the government in 2010 (Verdade 2010). Around the same period and even before, Mozambique was also engaged in the "Jatropha fever". Jatropha can grow in dry areas and poor soils and the oil produced from its seeds is considered a valuable biofuel. In Mozambique it is known as *Kala-Maluco* and serves as fence for latrines and farming fields, since the seed is poisonous and keep the wild animals away. Jatropha was (is) considered almost as a "miraculous" tree able to address poverty, climate change and green energy, with low financial, land and technical input (e.g.de Jongh & Nielsen 2011).The government provided funds for small farmers that allocated farm land to Jatropha, and there was the promise of high prices in international markets for Jatropha oil. Once those prices did not come true, almost all farmers were faced with great losses and no food crops to eat or sell. Eventually the damage was reduced by the Government that bought the production at a minimum price only to let it rot in huge piles (interviews).

On the success side an example is a factory in Dondo, Sofala Province, fully operational and producing ethanol (actually a kind of gel fuel) from cassava, to fuel a special stove. This new system, the *ndzilo* (Literally "flame" in one of the Southern Languages, ndzilo.com) is experiencing some level of success in urban areas, particularly Maputo, but how much is it replacing WF is still unknown.

7.2.2 Developing Countries Realities Are Complex And Dynamic

As it turns out, the reality is far more complex and difficult than the ETP depicts in its simplification and linear discourse. In fact, a number of factors contribute to make implementation of technology in DCs an impressive challenge. The first is the socio-economic background of many DCs, already exposed in §5. DCs are, in general: agrarian societies, possibly itinerant; essentially non-monetary with null, uncertain or variable cash-income; remote and/or dispersed; with very low energy demands; and very vulnerable to natural disasters and market fluctuation like the increases in food and fuel prices (Kaygusuz 2011; Masera *et al.* 2000; Zerriffi 2011). Moreover, there is a weak performance of utilities in DCs (§5), poorly managed, with limited finances, or with the lack of clear, well structured energy policies and strategies. Another factor to consider is that the number and nature of decisions to be made is very high, and particularly constrained by scarce, ambiguous and incomplete data. In these conditions, creating and sustaining energy markets and services is quite a challenging, complex, and ill-structured problem, requiring considerable investment, diversified knowledge (e.g. technical, social) and the involvement of many actors (from governments to local entrepreneurs).

7.2.3 Technology And Positive Impacts Are Not A Given

Despite these challenges not considered by many advocates of technological solutions, a basic unchallenged assumption of ETP is the positive role that energy has on development in general and in DCs in particular. Technology is considered to play an important role in poverty reduction through their contribution to growth, their use of factors of production, their environmental spillovers, the social relations associated with production and the characteristics of the products which they produce (Mulder 2005; Rohracher 2008). In particular, electrification is considered pivotal to achieve the MDGs (Modi *et al.* 2005; Mustonen 2010), promoting, directly and indirectly, social improvement, income generation opportunities, better education and health services with added environmental benefits (e.g. Ramani & Heijndermans 2003; World Bank 2008; Zerriffi 2011). However, a growing number of accounts have questioned this assumption. This is more relevant, when some of the critics come from reports that, ultimately, endorse energy transitions. In the World Bank report on energy, poverty and gender, Ramani & Heijndermans (2003: 9) state that: "awareness of [energy] impact on poverty has been confined largely to abstract conceptualisation and anecdotal experience to date". In another World Bank report (WB 2008), it is estimated that only "7% of dedicated RE projects and energy

sector projects have an explicit poverty-reduction objective", and Deichman *et al.* (2011) assert that the connection between rural electrification and local revenue growth remains "largely anecdotal". In conclusion "[…] it does not automatically follow that electricity is unequivocally benefits the poor. In fact, most studies on the subject conclude that rural electrification benefits higher-income populations more than if does the lower-income ones, and that it often exacerbates rural poverty gaps and gender inequities" (Ramani & Heijndermans 2003: 19). Notably, this conclusion is not applicable just to privatised or market-based approaches, but also a reality in public grid extension to rural areas, where high connection costs and monthly charges tend to accentuate the demarcation between the rich and the poor (Nygaard 2009; Ramani & Heijndermans 2003). However, in grid connected areas, the majority of the poor can benefit from electricity services in public places (e.g. schools, clinics) (Modi *et al.* 2005), while in decentralised systems those public spaces tend to lag behind basic household electrification or be ignored in rural energy objectives, making integration of electrification into larger development goals difficult (Zerriffi 2011). Moreover other "benefits" of electricity have also been questioned. The effect of electrification in reducing deforestation, via reduced use of wood as fuel for cooking has been contested (Balachandra 2011; Lachman 2011). Regarding the "women-friendly" description of electricity, a survey of PV users in Kenya found that lighting systems probably create more time in the day for women to complete household chores (van der Plas 1998). Considering the fact that most rural women's workdays begin prior to sunrise, one has to ask whether or not lighting systems will actually add to the workload of many women.

7.2.4 Technology Is Contextual And Contextualizes

Considering that energy transition implies the deployment of an energy technology in a given setting to provide a given energy service in accordance with perceived social needs and conditions, highlights the importance of the Innovation and diffusion/adoption processes as part of wider socio-ecological dynamics. In this regard, research on Innovation systems (Clark 1990; OECD 1997; Spielman 2005) has highlighted technological innovation as a complex system phenomenon involving a network of actors to produce and use new knowledge. In this sense, innovations and the social context are interdependent and each can effect change in the other. Subjacent to the systems of innovation is the importance of social learning. Innovation requires an interactive learning process among a variety of agents, but learning can also generate much interaction and evolution to take place in innovation processes and approaches (Hall *et al.* 2004). Likewise, similar conclusions are produced by the social and political analysis of the innovation process as an economic process. Ficher *et al.* (2004) claim that investing in technology is a complex matter, since it is not possible to predict the effects, it is rather complicated to associate political decision with technological performance, and there are dynamic social and market effects that shape efficiency, cost and acceptability of

technologies. Zerriffi (2011) also states that electricity in the context of DCs involves complex and context dependent factors such as: technology; subsidies; and institutional capacities. For instance decentralised RETs are not optimal for remote areas *per se*. Technological innovation that reduce costs will increase the area where decentralised systems are competitive, while technological innovation in the utility system that make it able to expand further into rural areas, or in the institutional framework (e.g.; the provision of subsidies to the utility) will favour grid connections.

In this regard, a clear example of the importance of contextual nature of energy innovations, policies and, ultimately, designs is the prevailing dichotomy between two idealised views in energy transitions in DCs. Indeed, the energy policy agenda of developed and DCs diverge (Birol 2007; Pandey 2002). Developed countries have no electricity supply problem (fig. 5.1) and, therefore, focus energy strategies around sustainability problems, climate change, energy security and impacts of energy use. DCs have urgent developmental priorities and thus, tend to concentrate on fuel subsidies and electrification to fulfil basic needs and increase welfare (Reddy 1999). The refocus of global climate policy in poverty reduction (Goldemberg & Johansson 1995) towards a higher partnership with DCs (Metz & Kok 2008), had refocused energy policies (and development aid) for social development and the integration of social concern in ESy design (Nygaard 2009). However, in practical terms, the discussions are always marked by the split between recapitalized DCs interested in funds for centralised fossil-fuel power generation, and developed countries interested in funding only decentralised renewable WES (Kok *et al.* 2004; Modi *et al.* 2005) through climate change related mechanisms (e.g. emission trading, the clean development mechanism and REDD+) (Winkler *et al.* 2008). Since Sub-Saharan Africa have a rather low level of per capita emissions (fig. 5.1), sustainable development and climate change tend to rank low in policy concerns, but are increasingly being considered as funding opportunities. Zerriffi (2011) refers to this dichotomy as two idealised visions of electrification for development: the governmental image of the high-voltage transmission line reaching into the countryside; and the NGO and international donor vision of "the small is beautiful" solar home system providing clean electricity for a remote household. However, as Zerriffi (2011: 2) explains, the problem with these images is that "they are idealised visions of a much more complicated reality and fail to convey the complexities of solving the rural electrification problem".

As a consequence of this dual vision on the same reality, DCs might endorse RETs because that is a way to get funds to energy projects[18] (Zerriffi 2011), while there is also a great deal of pressure from developed countries over DCs to implement energy transition based on RETs as "green technology" (e.g. Barnett *et al.* 1989; Wilkins 2002). Incidentally, developed countries are also major players in R&D and commercialisation of RETs. This

18 An example is provided in the report "Energy and The Millennium Development Goals" produced by Forum of Energy Ministers of Africa (FEMA 2006). "Sustainable development" is mentioned twice in the entire document and "climate change" only to justify the *financing options*.

political game is also followed in the academic world, being energy related research in DCs mostly conducted according with the availability of funds form donor, mostly interested in "small is beautiful" options, as referred explicitly by many academics interviewed in Maputo. Therefore, technology suppliers end up selling engineering services and capital goods, that "may not reflect adequate analysis either of the real needs and demands for such changes or of the alternative ways in which those needs and demands might be met" (Barnett *et al.* 1989: 37).

A good example of the pressure of developed countries over DCs is given by the dissemination of solar PV systems. It is estimated that during the last 30 years, half a million PV systems have been installed in Sub-Saharan Africa (Nygaard 2009). Despite this apparent success, PV has been criticised for being donor driven, expensive, fragile and unfitted for cooking and heating, the two basic energy uses in DCs (Villavicencio 2004; Wamukonya 2007; Zerriffi 2011). During the 1980s and well into the 1990s DCs represented more than 3.5 % of the annual world market for PV modules, and 10 % of the annual European production (FEM 1999). Most initiatives were included in developed aid, but were implemented and commissioned to foreigner companies as tied aid (Nygaard 2009). The installation of solar PV systems when the less expensive small diesel grids were available (Drennen *et al.* 1996) was considered a typical case of "finding problems to fit the solutions" (Naudet 2000). In recent years, a marked increase in the number and dissemination of PV systems over the globe, a decrease in cost and the escalating oil prices changed this reality (Nygaard 2009). Nevertheless, a consumer in Uganda pays twice as much as an Indian consumer for an equivalent system (Moner-Girona *et al.* 2006). Moreover, within the off grid domestic sector, applications in rural areas drives the markets in DCs "despite the mismatch between the cost of delivered electricity and the willingness and ability to pay by the target user group" (Chaurey & Kandpal 2010). This reality assumes that the diffusion of PV has been driven by government and donor-supported projects aimed at serving specific needs for electricity while at the same time creating a national niche market for PV. From this general trend in sub-Saharan countries, the market-based diffusion of PV in Kenya was the only exception (Hansen *et al.* 2014). However, recent years witnessed the creation in DCs of enabling frameworks comprising innovative financing schemes, exemptions from taxes, standardised power-purchasing agreements and feed-in tariffs, which had favour a change towards more market-based diffusion and private-sector involvement (Hansen *et al.* 2014). Moreover, China is also playing a relevant role as producer of RETs changing the balance of transactions and price (e.g. Dincer 2011). Mozambique, however, is still concentrated on government based projects to meet energy demands and, in line with funders sustainability concerns, to promote "environmental friendly" energy, like improved stoves, or solar PV systems in rural areas, schools and households. This situation is actually accentuated by the "lack of incentives for importing alternative equipment and technologies" as "root" problem in the tree of problems/solutions in §5.3.2.

7.2.5 Technology Might Be Part Of The Problem

In the face of a not very successful list of energy projects implemented in DCs (§7.2.1), extensive research has been devoted to identifying the challenges and barriers to technology implementation in rural areas of DCs (e.g. Holland *et al.* 2001; Mirza *et al.* 2009; Reddy & Puinuly 2004; Valencia & Caspary 2008). While these studies vary in focus and approach this research and analysis offers important insights to the present research:

1| The barriers identified cover practically all spectrum of human society, from policy making to consumer behaviour, explicitly recognising the complexity associated with ESy and the importance of contextual factors other than just energy in the success of technology transfer, adaption and innovation.

2| There is a prevalence of a project focus and an almost invisibility of people, local contexts, including institutions, knowledge and dynamics. Local entrepreneurship involvement and Indigenisation of technology are mentioned, but only mostly for the benefit of project success.

3| Technology is considered a given, something that people would accept immediately due to the "inner benefits", forgetting that technology can be difficult (or impossible) to manufacture, purchase, operate, and maintain cost-effectively, safely, and efficiently in DCs.

4| The emphasis is on technologies that only provide lighting to households barely benefiting house heating and cooking, the bulk of DCs household energy consumption (§5) and may leave women further out of energy making decision processes.

In conclusion, financial constraints, organisational and managerial weaknesses, lack of technological capabilities, adverse political, economic and environmental contextual factors, and moreover, the multiple and dynamic interaction between all these elements seem to compose a framework where energy is not a "switch" between success and failure as it is presented by ETP, but rather another element affecting and being affected by others elements embedded in a socio-ecological context.

Another major conclusion from these barriers and previous analysis is the notion that ESy failures in DCs are indeed the result of a design mismatch. Energy policies, projects and technologies seem to be unfit to DC socio-ecological. In other words, ESy are not designed "for the people, with the people, by the people" understood in their ecological context, but instead for the sake of project success or technological dissemination and fix (see §7.4). The access to energy, development and the environment are related through highly dynamic, complex and mostly unknown, unpredictable and interdependent links. In this sense, energy is a necessary but not sufficient condition suggesting that increased access to modern energy will not, in itself, result in development and/or environmental benefit (e.g. Cabraal *et al.* 2005; Reddy 1999).

Finally, a meta-analysis of these barriers also describe, like the “tree of solutions” (§7.1) did, the institutionalised presence of the ETP. Note that the criticism is not for *what* is the energy transition process as a whole, but instead to *how* the process is conducted. For instance, classify in derogatory terms WF (or traditional biomass) or not even question why and how people use it, fails to perceive that WF might be a very effective and probably cleaner resource than many “modern” technologies. WF can be obtained locally and easily converted into fire for cooking, heating and small business or farm activities (e.g. dry tobacco), the core energy uses in rural areas. These advantages have served human communities since ancient times (Deforce *et al.* 2013; Oliver 2003), which already constitute a proof of “sustainability”.

7.3 DEVELOPMENT SHOULD BE SUSTAINABLE… OR SHOULD IT NOT?

Closely related with the RETs issue, another important, and for the most part unquestioned, assumption is the linkage between rural energy and sustainable development. DCs governments might introduce this linkage in order to get the needed funds for rural energy projects (Zerriffi 2011). However, sustainable development is a rather controversial concept[19] (e.g. Kane-Köhn 1999; Lélé 1991; Meadowcroft 2000; Reid 1995; Robinson 2004;) that tries to integrate desirable, but probably conflicting, goals (e.g. everlasting economic growth, ecological conservation, social equity) which lead sustainable development to be labelled as a “political fudge” (Richardson 1997), an “oxymoron” (Thring 1990), a "truism" (Redclift 1987) or a “contradiction in terms” (O'Riordan 1988). However, this conceptual flexibility (Bell & Morse 2003) might be essential for tradability (Pieterse 2001; Schuurman 1993), i.e.; to create a discourse playing field where different perspectives can be debated (Bell & Morse 2003; Redclift 1988; Robinson 2004).Other authors prefer to think in terms of sustainability, defined as a co-evolutionary adaptive and resilient process, inherent to all socio-ecological systems (e.g. Köhn 1999; Norgaard 1988). In practical terms, thus, rather than an objective yardstick for development sustainable development is gradually being perceived as a conceptual guideline (e.g. Bagheri 2006, Drummond 1996; Hettne 1995) strongly influenced by ideology, ethics, social contexts, specific agendas and perspectives (e.g. Redclift & Sage 1994; Schuurman 1993; Vogler 2007). Sustainable development is used to simultaneously justify and find grounds for certain technologies and ideas lacks any sort of metrics, clear operational rules of engagement and/or implementation and even clear definition from where to extract those indicators, parameters or rules.

In conclusion, sustainable development is more a convenient, political driven and locally defined term, rather than a global trans-cultural political objective to justify and promote specific ESy designs, technological options and perceived needs and expectations.

19 For an idea of the number of different possible representations of sustainable development see http://computingforsustainability.com/2009/03/15/visualising-sustainability/

7.4 ENERGY PROJECTS SERVE COMMUNITIES… OR DO THEY?

With very rare exceptions, energy initiatives in DCs, as well as the design of ESy happens in the context of projects implemented by, or with the support of, governments, international organisations and NGOs. Therefore, projects and project planning, i.e., the way energy projects are designed, become the "practical face" of energy transitions, that is, ETP. Energy projects comprise a set of activities managed by experts to achieve objectives within a cost and time frame (after Bell & Morse 2007). A general assumption is that energy projects provide communities with an opportunity to assess better technology in very protected and accessorised conditions, which also carry some sort of knowledge transfer to the community.

However, in practice most project practice is framed by the, so called, rational comprehensive planning model, which defines a linear progression from situation analysis; strategy design; implementation; and evaluation (Bi 2011). Considered objective and easily translated into quantifiable indicators for success assessment, this planning model is also criticised for being too expert-driven and "insensitive" to less tangible socio-ecological elements (Bi 2011). Nevertheless, this continues to be the prevalent project design model, producing *blue-prints* where time, resources, principles and 'deliverables' are established before the project onset. In this context, energy projects are taken either as a technical set of decisions or a political process to implement energy technologies which is planned, designed and managed *for* the rural community and not by the rural community. Even if the intended user of the technology participate in the situation analysis stage, seldom do that participation extends to a role in the definition of criteria or assessment models and even less the actual definition of strategies (e.g. Bi 2011; Birch-Thomsen & Kristensen 2005).

Besides ignoring or bypassing local knowledge and expertise, projects aiming towards the energy transition also tend to assume communities as a static, homogeneous entity that consensually will support the project based on its clear advantages (Woodhouse *et al.* 2000, §9.4.1). However, communities are in continuous flux, receiving and loosing members which establish different bonds at different level, for different reasons (e.g. Theodori 2005). Moreover, community decision-making mechanisms are not mandatory consensus-making devices as conflict is an intimate part of "community" life (Woodhouse *et al.* 2000). As a result, the "energy project" and the technology associated will enter the network of options that households have to manage in their livelihoods strategies and within their social and ecological context (e.g. Bolwig 1999; Ellis 1998; Preston 1992).

Critics to this rationalist way of doing energy planning and projects, point that this planning approach in reality follows donor agendas and schedules which favours: short term cyclic interventions while technology based on local knowledge requires time, effort and resources; fails to recognise the sheer diversity of knowledge systems; and suffers

from interpretation problems (Sillitoe & Marzano 2009). To overcome these shortcomings, it had been suggested that it should be institutionalised in "a set of agreed ways of going about technology development" (Platt & Wilson 1999), some overarching theory to give some coherence and structure to what is essentially localised and fragmented (Sillitoe & Marzano 2009). Other perspective would be to institutionalise collaborative planning or adaptive planning (e.g. Healey 2003, 2006). This would provide a generic framework to apply in multiple contexts, but would also require teachers of technology to become learners themselves. However, such endeavour could also be ethnocentric, imposing certain views over others, or the interpretation of the interpretation problem (how well could a different cultural referential be understood by an outsider?) (Sillitoe & Marzano 2009)

Therefore, an important aspect that emerges from this brief critical analysis is an implicit aspect of energy transitions: the idea that "superior technology" is accompanied by "superior" knowledge. As already mentioned regarding the energy poverty concept (§6.1), projects tend to assume that experts know better, that technology benefits "speak for itself". This idea is so deeply rooted that government officials responsible for energy projects and/or programmes interviewed in Mozambique went to the point of "blaming" the people for "not changing for something that would be better for them". Associated with this logic comes the power issues that evolve around knowledge, who produces it and who decides which is valuable and which is not (see Cline-Cole 2006; Foucault 1972).

By providing a close box of objectives, time and frames, closely linked to political accountability and metrics of success, projects provide little space the "project view" obliterates all other perspectives, and becomes, in fact, a cultural barrier leading to inappropriate technology choices (Barnes & Foley 2004; Valencia & Caspary 2008). As a result, local realities, knowledge and perspectives are not considered and participation looks more like an institutional stage than a crucial design element.

7.5 TECHNOLOGY USERS MAKE RATIONAL DECISIONS… OR DO THEY?

A basic tenant of the ETPis the idea that (§6.1) once the technology is provided at affordable prices and/or the people raise their income level, the choice would be for modern technologies. That is, users (consumers) would make decisions based on utilitarian, economics and rational grounds. This principle of "rational decision" is clearly expressed in conceptualisations like the leapfrogging or the energy ladder (§6.1) and is, accordingly, also incorporated in the OSM, OEM and SM (§6.3), which are In fact, decision support tools (DST). Therefore, this fundamental assumption will be critically contested here addressing three perspectives: the theoretical model of energy ladder and energy stacking and associated leapfrogging concept (§7.5.1); the decision making process in general (§7.5.2); and finally the DST, from which the models in §6.3 are clear examples.

7.5.1 Users Do Not Climb Stairs, They Live With Them

For the last two decades a growing body of empirical studies on household energy use has criticised energy ladder, energy stacking and leapfrogging (§6.1) for being too deterministic and simplistic failing to express the complexity and dynamism of energy decision making at the household level. Specifically, empirical work found that "people do not climb the "energy ladder" naturally" or based simply on energy consumption (Peters *et al.* 2009), but rather rely on a net of interacting factors, including: the consistent availability, ease access and delivery frequency of different fuel options (Brook & Besant-Jones 2000; Kammen *et al.* 1994; O'Keefe & Munslow 1989); the energy demand (Foley 1995; van der Horst & Hovorka 2008); social and household power relations (Cecelski 2002; Thom 1994); sense of energy cost controllability (Peters *et al.* 2009); contextual and cultural preferences (Barnes & Qian 1992; Brouwer & Falcão 2004; Leach & Gowen 1987); collection time, fuels characteristics and different end use efficiency (Convery 2010; Leach & Gowen 1987; van der Horst & Hovorka 2008). At a global level, the relationship between income-energy, use-quality of life is also not linear, contradicting even more the descriptive capacity of the energy ladder model (§6.1). According to Smith *et al.* (2012) population metrics such as infant mortality and life expectancy improve until levels of ≈2000-3000 kgoe/year per capita, then remain steady, although with much variation.

For the Mozambican context, the apparent distortion or inversion of the energy ladder at the household level was also measured (Arthur *et al.* 2010; Atanassov *et al.* 2012; Brouwer & Falcão 2004). In particular, Arthur *et al.* (2010) clearly demonstrated that consumers actually spend more money, time and resources acquiring WF that using readily available electricity in urban areas. While some of these critiques were considered in the stacking model, (Davis 1998; ESMAP 2003; Heltberg 2004), this continues to be a "income decides all" model. Moreover, as Wilson & Heeks (2000) point out, stacking could be risk aversion, a strategy common for poor people to avoid risk. Hence, based on the knowledge of risks and opportunities, the acceptance of new technology and innovative solutions by households is always a balanced decision between potential to improve livelihood and the associated risk, which might also limit knowledge acquisition, and technological development, due to over-conservative decisions (Wilson & Heeks 2000).

Therefore, fuel stacking could also be an energy strategy to reduce: insurance against supplier failure (ESMAP 1999); vulnerability to modern energy price fluctuations (Leach 1992; Thom 2000); inflexibility of cooking methods and preferences (ESMAP 2003; Masera *et al.* 2000); high costs associated with using modern energy sources (Davis 1998); costs to purchase modern energy conversion technologies (Elias & Victor. 2005). Therefore, what might be happening is not stacking, but rather an opportunistic strategy of households to use, if available other energy carriers (e.g. electricity) even in small quantity while satisfying their bulk of demand by lower ranked fuels (Victor 2002).

Regarding leapfrogging, it is also considered as too technology-driven and ignorant of the social, cultural, and economic conditions prevailing in rural areas and their role in the technology diffusion process (Peipert *et al.* 2008). Altogether, leapfrogging might actually be a misconception since in the household level, "energy technology leaps […] are incremental process" (Murphy 2001). Technologies are absorbed when they are compatible with the technological capabilities of the people using them. These capabilities are manifest in individuals' capacity to adapt to new technologies, their ability to take economic risks, and in their desire to modify their behaviour (Murphy 2001). The conclusions presented by Murphy (2001) are in concordance with empirical research which determinate that energy transition at the household level are neither linear, neither definitive (Heltberg 2004; Hosier & Dowd 1987; Masera *et al.* 2000).

Hence, based on their knowledge of risks and opportunities, the acceptance of new technology and innovative solutions is always a balanced decision between potential to improve livelihood and the associated risk, which might also limit knowledge acquisition, and technological development, due to over-conservative decisions (Wilson & Heeks 2000). In more common terms, the issue is not what ladder exists, but which ladders to use, when, for how long, with whom, and why, since different contexts generate different ladders, and different ladders offer different opportunities and risks.

7.5.2 Rationally Speaking, Decisions Are Not Rational…

Being a positivist approach, ETP assumes that a causal link exists between intention, decision and action. However, this causal link has been proven empirically dubious (e.g. Mintzberg & Waters 1990; Spellman 2010; Starbuck 1980, 1985), instead, research indicates that "decisions" are In fact, post-rationalisations of non-rational decisions (e.g. Starbuck 1985; Weick 1995). Following the constructivist perspective, decisions are social driven, emerge from social interactions (e.g. Harrison & Singer 2006; Perroux 1964; Skitka 2009; Sonis 2009) and are, thus, affected by power relations (Gazon 2008; Tainter 1988) and reflect desires, beliefs and available social constructed knowledge (Elster 1986; Green & Shapiro 1984, Harrison & Singer 2006). Therefore, decisions' should be judged in relation to specific social aggregations (Harrison & Singer 2006) and considering the challenges posed by complexity to the "habits of though" of most decision-makers (Richmond 1994; Sterman 1989). Consequently, "technical rationality" favour analysis and the possibility to substitute analytical results and computations for judgement, failing thus to address social and personal perspectives required to implement decisions (Courtney 2001; Rosenhead 1989)[20].

In the very core of this vision of humans as purely rational decision-makers is the idea that humans have access to all the needed information and act on behalf of their best self-interest,

20 These results have also been corroborated by the work of many economists, like Maurice Allais, Daniel Ellsberg, Karl Polanyi, Amos Tversky and Daniel Kahnenman.

taking an opportunistic advantage of situations. This vision is conceptualised by the metaphor of the *homo economicus*, which uses utility maximization principle (including factors of rational expectations) to decide upon different technologies, innovations or social choices (Sonis 2009). This concept of man as a decision-maker in social contexts has been confronted by several researches. Perroux (1964) proposed the concept of *homo socialis* which defends that humans rely on social interaction mechanisms (e.g. learning processes, imitation, knowledge share) with other agents of the social system to make decisions (Sonis 2009; Skitka 2009). More recently the concept of *homo moralis* has been advanced (e.g. Alger & Weibull 2013) as an alternative to the predominately "wants" and "desires" based approach defended by the the *homo economicus* and *homo socialis* metaphors (want to maximize their self-interest or to be socially valued). The *homo moralis* metaphor grows around the "ought" and "should" instead. The "outcomes come in different flavours, and to predict the relative importance of outcome considerations reasoning, one needs to know which flavour one is dealing with" (Skitka 2009). In other words, culture defines the "ought" and "should" visions and guiding principles, which shape the "wants" and "desires". These metaphors or theorizations of decision-making are not opposed or self-excluding, since they might co-exist and be "incorporated" by the same individual (or group of individuals) depending of the situations, risk/opportunity evaluation, social pressure and amount of intelligence available. In any case, what is relevant for this research is the overwhelming amount of research that clearly indicates that decisions are not purely rational, individual and taken out of context.

Specifically on the realm of energy, reviewing research on energy consumption patterns, Kowsari & Zerriffi (2011) and Howells *et al.* (2010) independently identify energy transition as a household decision process, and include research on different dimensions of the phenomena, including: technological; economical; psychological; anthropological; sociological. From a behavioural and social sciences point of view, there is an agreement that energy use involves complex behavioural, cognitive, and social processes (Keirstead 2006; Laitner 2007; Lutzenhiser 1993; Stern 1986; Wilhite *et al.* 2000).

Sociological and economical analysis indicate that energy transitions are also a complex process involving dynamic interrelations between economic, technical, social and cultural issues as well as the physical environment (Masera *et al.* 1997). Together, these two conclusions, suggest that people, do not take energy/technology decisions rationally or exclusively with a "maximising benefits/minimising costs" perspective (Cogoy 1995; Fernandez 2001; Frederick *et al.* 2002; Kooreman 1996) but, instead, are influenced by non-economic factors and social contexts (Stern 1986; Lutzenhiser 1993). In this sense information (Howells *et al.* 2010) and social learning (Kowsari & Zerriffi 2011) are relevant mechanisms, drivers, or factors that influence decision-making, attitudes, customs and aspirations (Schiffman & Kanuk 1997). Unfortunately, there are very few integrated perspectives and there is a huge knowledge gap regarding household energy use patterns in DCs (Elias & Victor 2005; ESMAP 2003; Farsi *et al.* 2007; Heltberg 2004; Leach 1992; Masera *et al.* 2000; Pachauri 2007).

From the discussion above, it seems that the fundamental assumption of rational decision making that supports most of the ETP is, at least, doubtful. The conclusion is not that humans are irrational, but rather that rational decision making requires the complete knowledge, both in time and space, of the consequences of the decisions, as well as, of the mind frame of all involved, something clearly impossible in complex realities. Therefore, humans decide with the best information available and all the package of previous experience, which is also not constant, and change with time (Gilbert 2011). Nevertheless this "reduced reality" created for practical life is still too complex to be captured by rational models, which raises serious questions on the way models and the modelling process in energy are conceived and implemented.

7.6 WOOD FUEL SYSTEMS COMPLEXITY CAN BE SOLVED… OR CAN IT?

Probably the most fundamental principle of the ETP is the assumption that the WES can actually be solved, that is, reduced to a set of relations and constraints to be optimised. Consequently, as already mentioned (§6.3) energy mathematical models are mostly conceived as DST in energy planning and management. Most DST and associated planning and design activities are positivist and rely on "technical rationality" (Schön 1983) or "comprehensive rationality" (Rosenhead 1989) as its epistemology of practice. Essentially technical rationality is a rigorous problem-solving approach based on linear, rational, deterministic, mechanistic and finite decision-making processes (Capra 1983; Cucuzzella 2011; Guba & Lincoln 1989; Rihani & Geyer 2001; Schön 1983). Reality is simplified to unambiguous problems suitable to be solved through rational and sequentially selection of means to achieve clear, verifiable, predefined design objectives. Consequently, positivist DST responds well to hierarchical management structures, equilibrium models, and to reductionism, rather than integrative, evolutionary and open-ended methods of analysis (Rihani & Geyer 2001; Scoones *et al.* 2007). However, developments in complex sciences and systems thinking, among others, indicate that prescriptive equilibrium models and goal oriented DST are unsuitable to address wicked problems such as the energy systems (WES) design (§3.3) for a number of reasons exposed below.

7.6.1 Equilibrium, Balance & Optimal State Are Concepts *Not* Reality

None of the systems that integrate WES (fig. 3.2, 9.2-3) exhibit stable, equilibrium-type properties. Systems (e.g. DeAngelis & Waterhouse 1987; May 1977, 1986; Rohde 2006) and natural resources management (e.g. Ludwig *et al.* 2003) may be better understood in terms of multiple stable states and shifts between stability domains. Likewise, industrial ecology (Jelinski *et al.* 1992), ecological modernisation (e.g. Mol 1995; Spaargaren & Mol 2000) or socio-technical transitions (e.g. Bijker 1997; Geels 2004; Smith & Stirling 2006) show that technology transitions do not evolve to reach a "stable equilibrium", but are rather highly social dynamic processes embedded in continually evolving socio-ecological contexts (Scoones *et al.* 2007).

7.6.2 Goal-Seeking And Decision Support Tools Restrain Creativity

The goal or criteria that will serve as term of comparison in DST is also, and ultimately, an expression of the assumptions, knowledge and paradigms of those building the DST. Therefore, while useful in certain controlled contexts, goal-seeking DST are limited and limiting when applied to real contexts. Reducing WES design to a set of variables, from which optimal solutions are sought according to pre-established assumptions, disconnects WES from reality by overlooking the inherent complexity of WES limiting thus, the range of design options to explore on the design problem (Bohm 2007; Herring & Roy 2007; Hertwich 2005; Morin 1977; Schön 1983).

Paradoxically, goal-seeking perspectives aim to improve technical innovation in complex realities (Spellman 2010; Cucuzzella 2011), but could overlook creative and innovative options outside the solution space defined by that goal (e.g. Garvin 1964). Within this perspective, design outcomes are strongly dependent on whom and what defines the goal leading to a process where design is disconnected from reality to fulfil predefined goals, which, like a "self-fulfilling prophecy", compromise seriously creativity and innovation. In other words, the design to address complexity is developed away from complexity. In resume, with technical DST the creative generation of alternatives is replaced by presumably objective feasible and optimal alternatives (Rosenhead 1989).

7.6.3 Goal-Seeking Decision Support Tools Misunderstand Participation

While many DST, and In particular, MCDA, have been integrated with participatory methods to address energy and natural resources management decisions (e.g. Catrinu 2006; Wang *et al.* 2007), the prevailing utilitarian precepts and the need to frame quality aspects of decision-making may lead to misunderstanding and misrepresenting the reasons and motivations for actors involvement (e.g. Rosenhead 1989; Pries-Heje & Baskerville 2008). Indeed, goal-seeking DST assume that numbers, intervals, or the same set of decision trees, hierarchy of criteria can represent and compare decision makers preferences and decision alternatives (e.g. Wang *et al.* 2007; Xu *et al.* 2006). However, in real situations, alternatives are so essentially different that analytical comparisons will not judge the ones that are "best" but only those that adjust better to the set of selected analytical criteria (Pries-Heje & Baskerville 2008).

Acknowledging the gaps and problems described above, several authors (e.g. Churchman 1971; Courtney 2001; Mitroff & Linstone 1993) argued that a new paradigm for decision-making is needed within DST. In the context of design, such paradigm requires a new DST perspective, which integrates organisational and personal perspectives, decision-making styles and knowledge across all stages of decision-making process, promoting, thus, a continuous dialogue between actors and reality, which is the same to say, a learning process involving diverse knowledge and mental models and the act of design/make decisions. Therefore, decision-making has been evolving to embrace knowledge

management concerns (Courtney 2001) with DST serving as knowledge management tools connecting decision-makers with diverse sources (Churchman 1971; Courtney 2001; Holsapple & Whinston 1996).

It should be mentioned that other models exist that try to bypass deterministic formulations of problems and some like agent based modelling have actually been used in modelling with relevance for the WES design (Wolbert-Haverkamp *et al.* 2014). However, these are marginal and limited attempts in a field overwhelmingly dominated by the rationalist planning and decision-making or the expert driven deterministic models. Note, however, that this thesis does not hold that these are all useless models. On the contrary, as exploratory devices any coherent model is a useful tool to produce insights. The purpose here was to openly question the normative and prescriptive ETP to open therefore space for novel approaches in the WES design.

7.6.4 Energy Models Do Not Reflect Developing Countries Realities

One last critic on the way that optimisation and simulation models based on the ESy framework (OEM and SM) deal with DCs reality and WF is given by Urban (2007) and van Ruijven (2008). According to these authors, while helpful for exploring the future of ESy in DCs, OEM and SM do not adequately reflect the condition on DCs. As the majority of these models is designed in industrialized countries, they mainly focus on issues which are important for developed ESy systems, which are characterised by full access to modern energy forms, high welfare levels and a minor role of agriculture in the structure of the economy (van Ruijven 2008).

Consequently OEM and SM are biased towards DCs, neglecting main characteristics of DCs, e.g. the informal economy, supply shortages, poor performance of the power sector, structural economic change, electrification, traditional bio-fuels, urban–rural divide (Urban 2007). In modelling terms this means that a unsuited characterisation of the ESy and economies of DC countries can lead to only sub-optimal and/or distorted solutions regarding the energy and emissions predictions (van Ruijven 2008; Urban 2007). These shortcomings seem to affects both simulation and optimisation models with respect to DCs. Optimisation models assume perfect market conditions and adequate centralised decision making which tend to be, and in the case of Mozambique definitely are (§5.3). Simulation models claim to be more realistic, but the relationships used are often from DCs data and experiences (van Ruijven 2008). In resume Urban (2008) concludes that “A ‘universal’ model which will solve all tasks equally well and which will represent all main characteristics of DCs is also illusory, because of technical restrictions, data inconsistencies, limited purposes of the models an d the complexity of the system”.

8 SUMMARY: THE MISMATCH BETWEEN REALITY & MODELS

In this section a critical, exploratory and comprehensive analysis on WES in DC and particularly in Mozambique, was conducted to: provide a rich description of the work produced so far on the subject; ground some arguments for the next sections; and make a preliminary identification of elements that will be incorporated in the design tool to be developed in this work (§D).

Considering the utmost relevance of WF in the life of billions (§5) and the possible implications that WF has on deforestations and global ecosystems, human health, women's living conditions, poverty and well-being (§5), the amount of research produced on the subject is relatively scarce (see fig. 6.6). While WES are still involved in controversy two main results emerged from the critical review. First, WES are complex, dynamic, uncertain and unpredictable entities (§5) deeply embedded in socio-ecologic contexts. Secondly, in the near decades, Mozambique, a least developed country with one of the highest economic growths on the Planet, will continue to export electricity, natural gas and coal, but will survive on food and hot water provided by WF from Mozambican forests (§5.3).

Therefore, the WES complexity embedded in complex socio-ecological contexts makes the task of planning and decision making both in Mozambique and elsewhere remarkably challenging. While there are not many tool that address systematically WES design, theoretical (§6.1), descriptive (6.2) and mathematical models (6.3) have been devised to assist decision making and energy planning on WES. In particular, based on systemic analysis of ESy mathematical models (§6.3) employing a number of methods have been conceived as DST assisting energy planners and managers to (tab. 6.2): optimise WSC; optimise WES; and simulate WF flows. Based on ETP most of the models assume that WF constitutes a solvable problem in deterministic terms, consider actors as rational decision makers in economic terms and have been developed within mono-disciplinarity expert perspectives and do not consider socio-ecologic contexts (§6.3). However, the high degree of complexity, uncertainty and non-linear behaviour prevailing in WES (§5) cannot be described or calculated by predictive equilibrium models and short-term optimisation based on closed systems, reductive science and reversibility prevailing in these models (§7). Thus, it seems that most DST used to support the complex WES use paradigms, descriptive frameworks and methods developed for non-complex and controlled realities resulting in equilibrium models biased, incomplete, unable to understand the complexity they address.

The main outcome of this section is exactly the identification and description of this **modelling mismatch**. Considering the multiple difficulties that mathematical models have to address complexity, uncertainty and intangible issues (e.g. sociological phenomena, tab. 6.3), a gap, mismatch or even conflict between comprehensiveness and complexity is

inevitable. A way to deal with this modelling mismatch is to consider participatory modelling with enhanced communication between different knowledge and perspectives. This is a route is increasingly being considered both in modelling, as the use of MCDA (§6.3, tab. 6.2) shows, or as the political economy/ecology also suggests (§5.2.3). In fact, the modelling mismatch can be translated in terms of perspectives. Spreading from rural areas to urban centres and involving a number of different actors (fig. 6.2) with different and conflictive perspectives the WES is a kind of problem that cannot be solved because **there is no objective rational measure of success accepted by all involved**.

The purpose would not be to identify all the perspectives, but rather to aggregate *kinds of perspectives*, through *some sort of meta-analysis*, something that will be done in §D and was already attempted here, for instance in the *aspects* identified in the last paragraphs of §5.3.2, or the left column of tab. 6.3. However, MCDA is still confronted with the basic nature of most WES modelling, which is governed by ETP. In this sense, more than look for a way that addresses and integrates multiple perspectives, as it was repeatedly emphasised in this section, the entire ETP should be contested as the main conceptual framework for modelling.

This search for a new paradigm for WES modelling implies the exit from the planning realm and **entering design creation**. The models presented here (§6) support planning, not design, even when they say they do. The difference is subtle, but real. These models support design within the conceptual framework they provide for design, which included the basic paradigms, purposes and methodologies. Design is an inherently creative activity which cannot be addressed by a specific method (§9). The questions now are: what kind of model supports this kind of design? What would it look like? How would it be built and tested?

The next section will provide some theoretical background to address these and other questions.

SECTION **C**

THE CASE FOR PARTICIPATORY CONCEPTUAL DESIGN METAMODEL

***Words do not only define reality, they create it. Hence, to speak true words is an act of transforming the world*.**

Paulo Freire, in: *Pedagogia Do Oprimido* (1970)

***We have seen how it is originally language which works on the construction of concepts, a labour taken over in later ages by science*.**

Friedrich Nietzsche, in: *Truth and Lies in a Nonmoral Sense* (1873)

…Where design thinking and systems thinking are used to reframe wood fuel energy systems, design criteria for the 2MW is defined and metamodels and meta-modelling are defined and presented as valuable tools to support the participatory conceptual design of wood fuel energy systems…

9 REFRAMING THE PROBLEM: SYSTEMS & DESIGN THINKING

This chapter describes the exploratory process taken to address the definition of the model and modelling approach that could bridge the modelling mismatch identified in §B, or better said, to go beyond the normative and prescriptive ETP, and consequently, outside the energy planning framework. For this purpose models are and modelling are defined (§9.1) and systems thinking (§9.1) and design thinking (§9.2) will be presented as two "thinking styles" valuable to address complexity in the presence of multiple perspectives. The result is a new representation of WES as a mutually embedded socio-ecological system (§9.2), the reframing of WES problem into a complex WES design problem (§9.3), and a reorientation of modelling purpose from solving the problem to support participatory design of WES conceptual design (§9.3). In the process, model and modelling criteria are also defined and used to compare the approach presented here with the relevant models and modelling approaches available (§10).

9.1 On Modelling And Models

Since the objective is to define a model and modelling approach, it is relevant to start with the definition of what is understood by those two concepts.

A useful definition of model is provided by Baumgärtne *et al.* (2008: 389) as:

> "An abstract representation of a system under study, explicitly constructed for a certain purpose, and based on the concepts within a […] community's basic construction of the world […]".

According to this definition, a model is located in the interaction between purpose, format (an explicit representation of an abstraction) and paradigm (Kuhn 1972), i.e., the set of norms, notions and mechanisms (e.g. causal relationships), that represents the individual's perception of the world. Paradigms are historically, socially and culturally contingent (Gergen 1994; Kuhn 1972), which implies that models are situated, dynamic and interact with the surrounding socio-ecologic context.

Therefore, being models representations of an abstraction, depending on how the designer (the maker of the model) abstracts the concept, the model will be different. In the opposite direction, a model could give insights on how the designer abstracts the concept, that is, how the designer *thinks up the concept*. This logic also works the other way around, that is, depending on how the designer perceive what is a model and what modelling entails the paradigm, purpose and format will also change. Linking all these elements is the process of making the model, that is, *modelling*, and the executer of the model, the *modeller* or *designer* (in this context). Through action of the modeller in the modelling process, the mode embodies, encapsulates and gives form to the purposes, paradigms and creativity of the modeller. Therefore, this thesis, anticipating the results from §9.3, consider modelling as a complex design process, where designer create model,

taking part simultaneously of the process (modelling), the outcome (model) and the socio-ecological context (time & space). Integrating this definition within a visible format (that is modelling this definition) fig. 9.1 illustrates the dynamic and continuous interactions (double arrowed lines) between the several elements of the design process. Note that, from the definition, this is dynamic and situated process, i.e., evolve with time (time arrow in the bottom) and interact with its context (dotted lines). The modeller is presented as participating simultaneously on the socio-ecologic context, modelling and model.

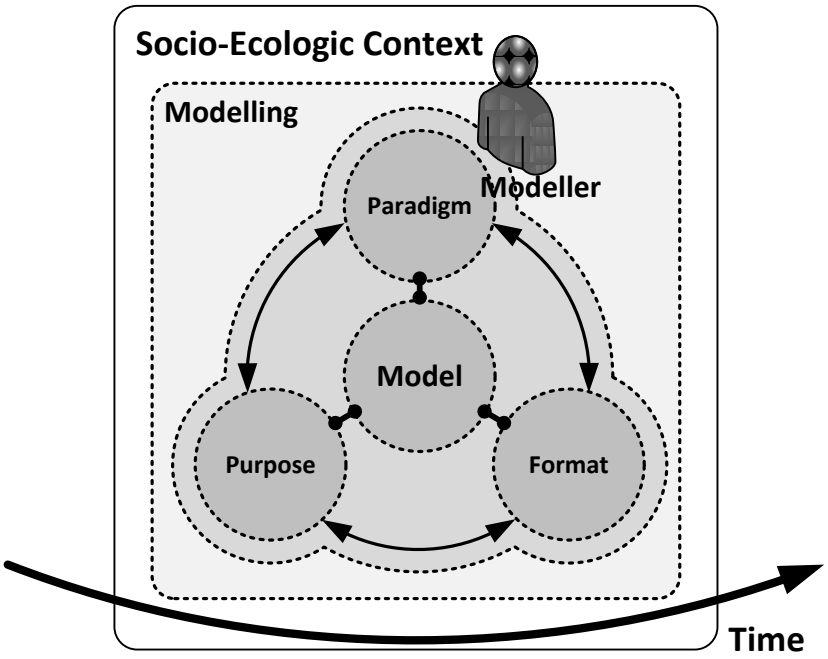


Figure 9.1| Representation of the modelling and model concepts integrated in a socio-ecological context with the modeller [Source: the Author].

In the following, systems thinking and design thinking will be explored as useful approaches to define in more specific terms each of the elements in fig. 9.1, including the modeller.

9.2 SYSTEMS THINKING: REVISITING THE WOOD FUEL ENERGY SYSTEMS

As already defined in §6.2, a system is an organized set of interrelated components determined by a boundary and ground by a common purpose and/or functionality (after Gibson *et al.* 2007).

With this starting point a new representation of WES will be presented here. Defining this representation is fundamental because it will act as an expression of the author design paradigm an aspect fundamental to guide the definition of model purpose, format, modeller and modelling elements of the modelling approach (§9.1, fig. 9.1). Therefore, fig. 9.2 is not important per se, it is just a representation, what is important is what it conveys in philosophical terms with relevance for the reframing of the WES design.

In simple terms the systems approach concentrates on the analysis and design of the whole, as distinct from the components or parts (Ramo 1969). Systems thinking highlights connectedness, relationships and context, considering the essential properties of an organism, a society or other complex system as properties of the whole, which none of the parts has in itself. Interactions and relationships among the parts generate the systems behaviour which can be understood only in the context of the larger whole, since the whole can't be analysed fully in terms of its parts. The focus is on basic principles of Organisation rather than on building blocks (Checkland 1981). This is a useful property to deal with complex, multidisciplinary, dynamic, social and open problems (e.g. Checkland 1981; Gibson *et al.* 2007; Langefors 1995). In the sense WES, as mentioned before (§5-7) is a complex system exhibiting (de Meyer *et al.* 2014; Remedio 2009; Sanser et la 2013):

- *Structural complexity*: High number and diverse elements, including different kinds of actors, knowledge, technologies, interests and perspectives (e.g. conservation, production) regarding WF and WF design. Besides there are also a number of possible combination of this elements, like the OSM in §6.3, tab. 6.2 demonstrates.
- *Behavioural complexity*. WF and WES encompasses and is networked with other complex systems (e.g. technological, natural) often related through dynamic, non-linear processes across multiple scales and with many inherent uncertainties;
- *Cognitive Complexity*. WF, WES and the knowledge generated in them, can be seen as an open system exchanging information, material, and energy with technology and the biomass as a natural resource.

Using the "ideal type" grouping of Problem Contexts (Flood & Jackson 1991, p. 35) that relates the kind of system with the most appropriate system thinking approach, the research is identified as complex-pluralist, that is, a context where there is a lack of agreement about goals and objectives among the participants concerned, but where some genuine compromise is achievable, which is expected in a sustainability discussion among actors. For this context properties, soft-systems methodology (SSM, probably the better know and stable systems thinking approach so far) (Annex 2) is considered to be the most appropriated, since it stresses the idea that system "exist within our minds as perceptions which we throw out into the world as a means of describing and understanding it" (Bell and Morse, 1999, p. 86). Indeed,. As Koestler (1971) advises, “[“wholes” and “parts”] just do not exist anywhere, either in the domain of living organisms or of social organisations. What we find are intermediate structures or a series of levels in an ascending order of complexity”, likewise Attenborough (2006: 76) also reminds that “Systems don’t define themselves, people define systems”. Consequently the choice of boundaries is crucial in ESy modelling, because it drives *what* (or *who*) is considered for analysis and *what* (or *who*) *is not*. Consequently it also defines the interaction between the identified elements, that is what or who is affected/affects what or who. Therefore, depending on what is seen particular interactions will be easier to spot, while others will be overseen because of the systems elements they interact with (are

affected/affect) are absent or are overlooked. On the other hand, depending on *how* the analysis is done different elements would be identified (*what* or *who*), In resume, *how* ESy boudareis are set, defines *what* is (and what is *not*) inside the ESy and, conversely, *what* is considered to compose the ESy, constrains *how* the ESy reality can be analysed (e.g. Cilliers 1998; O'Brien *et al.* .. 2013; Midgley 2003). Another aspect is what kind of boundaries are considered, if open allowing the continuing exchange of information, energy and mass controlled by the environment, or closed, indicating self-contained and controlled entities.

A system could be built by very structured methodologies or systems analysis (e.g. *Bots & van Daalen2008; Enserink et al. 2010; Gibson et al. 2007; Jackson 2003*), However, in essence a systems is a model (Miser & Quade 1985: 19). Therefore, for the purpose of this chapter, the WES will be built here as simple representation of the description done throughout §5-6 departing from the representation presented by fig. 6.4B (the one with a more evolutionary perspective close to the one followed in this work). Moreover, as a model, and considering the definition in §9.1 (fig. 9.1) a modelling paradigm, purpose and format were define from the outset.

Accordingly, the modelling paradigm was defined in accordance with the research paradigm (§1-2- what was expected for a question of philosophical coherence in the research), that is, the WES is conceived as socio-ecological system mutually embedded in the wider system and equally composed of mutually embedded systems, each one representing a certain dimension of the overall WES. Each system is defined according to the interaction established with the other systems, which mean that boundaries are transitory but real, and systems do not occupy a place, rather it is the interaction of the systems that creates the temporary notion of place. This paradigm is derived from the observation that no element is strictly *one thing*, but rather the interaction of others (e.g. Ingold 1986; 2001). The purpose of the model is to represent the main elements that emerge from the WES description as provided by the literature for Mozambique and DC (§5) with some additional information from the interviews conducted in the field work in respect with the paradigm defined. Finally the format, fig. 9.2, was defined considering both the design purpose and paradigm. Therefore, as a descriptive model it should be a simple arrows and boxes scheme, composing a reference model in line with those described in §6.2. Considering the mutually embedded paradigm the system elements are represented by dotted lines, to express that elements have open boundaries and are not actually confined with a strict border. Moreover, between the elements and through the open boundaries, flows energy, mass, information, knowledge and capital. The arrangement of the elements was made in order to represent all systems interacting with all systems, being the human beings in the middle not because they are the centre, but for pure graphical convenience. Note that each element in the WES is *multi-dimensional*, that is, can assume different "aspects" in each system. For instance, can be seen as a mode condensed form of knowledge, which flows. Likewise, Human beings are as much

biological as social, economic or technological (bearing knowledge). Technologies, people, institutions and natural resources interact through input, throughput, output and feed-back loops of energy, matter (e.g. residues), information, knowledge (e.g. to use, design, manage and/or operate the ESy) and capital, fig. 9.2. Since the WES and all the composing elements are open, WES can undergo transformation, adaptation, present properties that cannot be explained by the sum of the components (emergent properties) and can be controlled or managed (Manderson 2006; Berkes *et al.* 2003; Dale 2001). This dynamic aspect is represented in fig. 9.2 by a time line bellow.

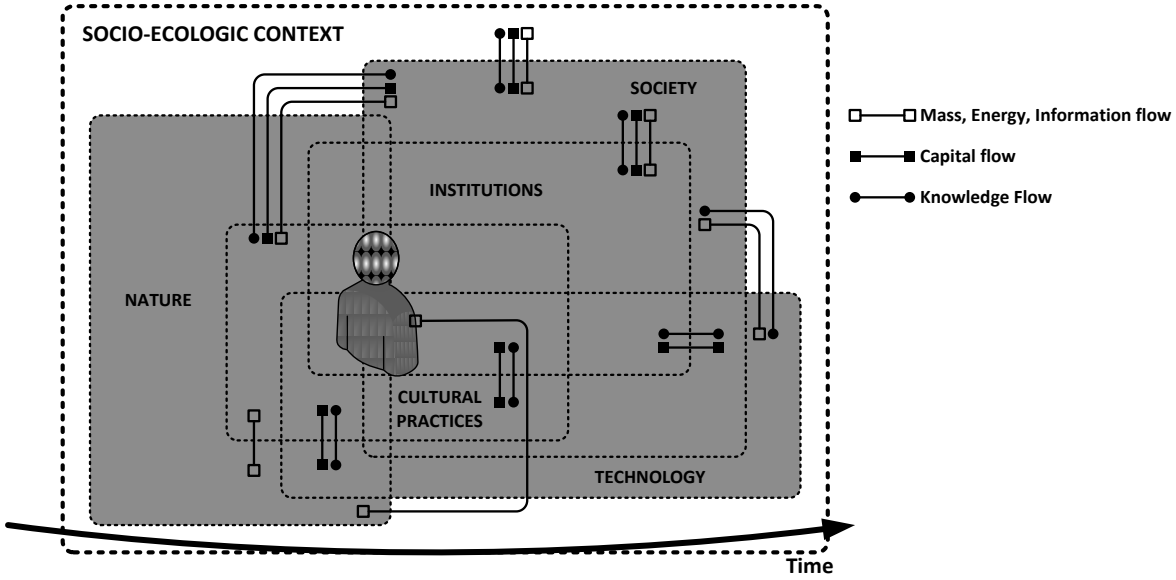


Figure 9.2| The WES defined as set of mutually embedded systems and interacting with each through flows of energy, mass, information, knowledge, capital [Source: the Author].

This representation, while quite abstracted is not very uncommon to represent ESy from a non-strictly-economic perspective, like the one presented in fig. 6.4B.

With these design elements identified it was possible to define WES as:

> *A set or assemblage of technological processes, knowledge/skills, practices & behaviours, capital, actors and institutions joined in interdependence with the nature and natural resources to produce a set of energy products, process or services that satisfy perceived social demands within a given socio-ecologic reality*

From fig. 9.2 and definition above it is possible to represent, WES as a biophysical reality since it relies on natural resources and is affected/affects the ecological reality in wich it is embedded as well as, a cultural reality only meaningful within a given social context, since resources, technology, and services are only valuable if people acknowledge their energy potential and know or learn how to explore/use it. An automobile in the middle ages would probably be pushed by horses, if there were horses available. In resume, the WES is shaped in the interaction between all the systems.

On a more schematic representation, less concern in represent the systems as mutually embedded realities, is presented in fig. 9.3:

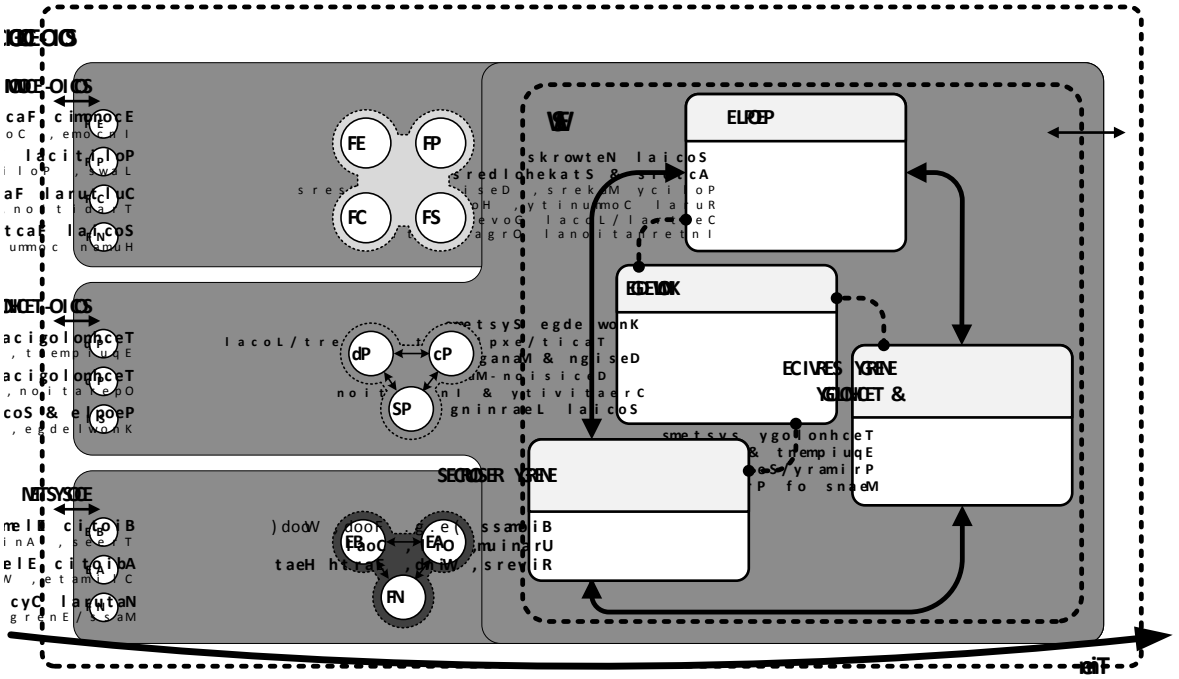


Figure 9.3| Energy systems as a network of people, energy technology/services and resources, shaping, and shaped by, knowledge/learning and expressing both the integration of ecosystems, socio-economic and socio-technical systems and the effect of external factors [Source: the Author].

In fig. 9.3 the WES is, like in fig. 9.2, perceived as the interaction among different complex systems. In fig. 9.3 However, the emphasis is in the composition and nature of those elements, trying to establish a middle ground between the design paradigm (mutual embeddedness) and the purpose (a descriptive reference model). These systems are:

- *Ecosystem* (also ecosphere or natural/biophysical system). Includes biotic (living organisms) and abiotic (non-living) components interacting in a particular area through a network of mass, energy and information cycles and flows provides the space and resources for life (Campbell 2009; Kabata-Pendias & Mukherjee 2007; Odum 1971; Schulze *et al.* 2009; Smith & Smith 2012; Tansley 1935;).
- *Socio-Technical Systems*. Comprise technological products/processes and people, that is, the interaction between technical systems and social participation in terms defined by interests, concerns, knowledge and social institutions/organisations or social networks (Rechtin & Mayer 2002; Summerville 2003).
- *Socio-Economic Systems*. Define the group of people interacting with each other (e.g. social networks, communities) within characteristic social, cultural, economic and political factors, institutions and/or structures (Messerli & Messerli 2008). Includes, thus, the set of commonly accepted norms and characteristic pattern of relationships and behaviour that bound the group together (Wordnet) and the relations with ecosystems and/or technology (Berkes *et al.* 2003; Chapman *et al.* 2009, Young *et al.* 2009;).

According to fig. 9.3, more than a linear sequence of technology between energy resources and services (like in fig. 6.6A) the WES is a network of people, technology,

resources and knowledge. Notably knowledge acts like a "currency", connecting, giving meaning and facilitating WES management. The three systems integrated in fig. 9.3 are, in fact, three main perspectives over WES and each of its elements, maintaining this way the *multi-dimensional* properties referred in fig. 9.2. Therefore, people could be understood as biotic elements of an ecosystem, operators, designers or innovators in a socio-technologic system or an economical factor, a political agent or a social actor in a socioeconomic system. Conversely WES can also be regarded as the result of a co-evolutionary dialogue (Durham 1991; Lalland *et al.* 1999; Norgaard 1994; van Valen 1973), between environmental, socio-economic and socio-technical systems, that is, as a complex adaptive system (Arthur *et al.* 1997; Janssen 1998; Levin 1998; Ramos-Martín 2003). Therefore, like in fig. 9.2, fig. 9.2 considers WES a socio-ecological system where both the dynamic and structure change with time, which means that some WES may become obsolete while other emerge at different times in different points of the globe.

9.2.1 Systems And Learning

Also implicit in fig. 9.2-3, is that a *system* is as much an "idea" about the real world as a physical description of it (Williams & Iman 2006). The systems described here can also be used as tools to understand the real world in a more profound way, i.e., treating a situation *as if it is a system* (as the models in §6.2). In this perspective, the systems described are not regarded as representations of reality, but as mental constructions to enable learning (Burns 2006).

These constructions are usually built from exploring and considering multiple perspectives. The role of models as learning devices was also identified in the relevant field of natural resource management (e.g. Brugnach & Pahl-Wostl 2007), from which WF is an example. According to Brugnach & Pahl-Wostl (2007), not just the model, but particularly, the whole model building process, supports a process of social learning and reflection in design groups. In practical terms, the use of model/modelling as learning devices implies an extreme shift in the role of experts from guiding external observers to facilitators participating in a process of co-production of knowledge (Checkland 2000; Pahl-Wostl 2007; Sterman 2000; Vennix 1996).

In resume, when used for participatory learning purposes, the differences between model and modelling process dissolve as the model becomes the vehicle to engage individuals in a dialogue. In particular, participatory model building approaches can be used to make explicit mental models and frames (Vennix 1996) which is of major importance for social learning processes (Bouwen & Taillieu 2004; Pahl-Wostl & Hare 2004). Still in relation with the learning purpose, models are also useful communication tools (Baumgärtner 2008; Brugnach & Pahl-Wostl 2007) when they reduce complexity to the few salient characteristics of the system modelled which are most important to the actors for whom the model was constructed (e.g. Walker *et al.* .. 2006).

9.2.2 From Revisiting To Building: Systems Thinking In This Research

Constructing the systems models in fig. 9.2-3 revealed to be a valuable exercise for two reasons. First these two models will have a practical use in the definition of the design tool to be build in §D. Secondly, as advanced in the previous §9.2.1 the modelling process in itself, revealed to be, a *learning-by-doing* experience. Indeed, while the definition of the systems models in fig. 9.2-3 seems to be a linear and straightforward process, from design elements (fig. 9.1), to descriptions (§5-6) and then to produce the representations (fig. 9.2-3) and definition in §9.2, the reality was far more interactive and reflexive, providing, nonetheless, an opportunity to explore, learn and understand the WES.

Cumulatively, in relation to the objectives stated in §9, this experience provided three useful and interlinked insights into the kind of tool to be developed and the modelling process to achieve it. The first insight comes from the use of the mutual embeddedness paradigm. By establishing that each system element defines itself in the process of being defined by other, and vice versa, the mutual embeddedness paradigm highlights simultaneously the importance of interaction over border definition, as well as, the importance to facilitate that interaction in terms co-created by the intervenient elements.

Translating to design contexts, this implies that, instead of designing models, solutions or optimisations, the purpose now is to facilitate the process of interactive creation (participatory design, §9.22, §9.3.4) through an equally interactive process. In more simple terms, use a participatory design process to construct a tool that facilitates participatory design. This insight is in close agreement with the systems models defined in participatory approaches that simultaneously function as leaning devices (§9.2.1).

Therefore, the second insight is that, as a participatory tool, the model to be developed (the 2MW, §D) should support learning and dialogue, that is, support knowledge exchange. The design tool is then envisioned as a medium to pass message across different actors, which is also a suggestion already identified in this research (§5.2.3). A third insight is related with modelling. All systems approaches have a stage where the situation/problem is *modelled* by the participants (§9.2.1). Notably, SSM involves a stage where individual perspectives and tacit knowledge are made explicit through a rich picture of the situation/problem at hand (Annex 2). This *rich picture* is indeed a participatory pictorial model of the conceptualisations/perspectives and their relations the participants hold on the situation/problem. This is also a method to structure the problem, a systems approach to complexity that will be further addressed in §9.3.5. The rich picture might then be used to produce a "good solution" by the group (Annex 2).

Here this thesis adapted the SSM initial stage of rich picture creation through conceptualisation and visualization, but truncated the process by not proceeding to *find solutions*. Instead, considering the problem analysis conducted in the SSM and design process from which solutions emerges this thesis focused on the design thinking to make it explicit. This truncated SSM methodology process will be also used in a participatory

manner to construct the 2MW (§13.2), providing this way the theoretical and practical background for the participatory design process in this research, as proposed by the previous aspect.

Therefore, reframing the WES through a system thinking approach to WES as defined in §9.2, provided a new focus on interaction, which conducted to the objective of create or find participatory methodologies to construct a participatory tool that should promote leaning and communication. Furthermore, a truncated version of SSM, a well known and widely used systemic methodology (Checkland 2000) demonstrates the utility of using visual processes to make explicit tacit knowledge and/or perspectives in the modelling of that participatory tool. Furthermore, this thesis, in a novel approach to complex problems, combines the systems thinking with design thinking using approaches and theoretical perspectives from both to produce the 2MW. Those design thinking approaches and perspectives are presented in more detail in §9.3.

9.3 DESIGN THINKING ON WOOD FUEL: REFRAMING THE WOOD FUEL PROBLEM

If WES is complex, the design of WES adds a wicked dimension to that complexity. Notably, design thinking is being promoted as a tool particularly suitable to address this kind of wicked problems (e.g. Brown & Wyatt 2010; Buchanan 1985; Jones 2010) due to a specific cognition style, mode or process (Boland & Collopy 2004; Buchanan 1992; Buxton 2007; Gedenryd 1998; Jones 2010), known as “designerly ways of knowing” (Cross 1982) or “design thinking” (Rowe 1987). As already discussed in §6-8, currently, defining WES is a planning task assisted by DST which optimise costs based on deterministic modelling. The result is expert and disciplinary biased designs and few room for creativity and *actual design* (§8). By focusing on WES and the definition of WES as a design problem, opens a new door to the creativity and exploration.

However, in line with the insights produced by the systems thinking (§9.2), the focus will be on the process of design. A tempting approach would be to define design methods, based on a description of how skilled practitioners do their work in order to prescribe how others ought to work. Besides being a prescriptive approach to design, something already criticised in ETP (§7-8), this was already tried by the design method movement in the 1970s (e.g. Alexander 1971) just to be abandoned by the promoters of the idea themselves (see Gedenryd 1998). Therefore, the proposal here is rather different. Identifying design thinking as a suitable approach to address the complexity of WES, and identifying the definition of WES as a design problem, the research will critically inquire the body of knowledge on design thinking to derive the principles, ideas and insights that could help the definition of the modelling approach and model to be designed (2MW). This inquire will start with definition of design (§9.3.1), will proceed for current approaches to design (§9.3.2-4) to finally propose a problem reframing (§9.3.5).

9.3.1 From Design To Design Thinking

Design is a controversial concept (e.g. Buxton 2007; Edder 1981; Kimbell 2009; Love 1998, 2000). Indeed, behind its "general intelligibility" (Pobiner & Mathew 2007) design is susceptible to be understood in many ways, such as:

- A process- the human ability to conceive, create and change the future as part of planning, construction and problem-solving in general (e.g. Simon 1969);
- A product- the end result and object of the design process or design profession, Tangible or intangible objects or artefacts created with a specific end in view (e.g. Attfield 2000);
- A subject- the body of work dedicated to systematically understand, describe and theorise design and design knowledge inherent to design objects, processes and profession (e.g. Alexander 1964; Archer 1979; Asimow 1962; Buchanon 1982; Cross 2001; Jones 1970; Julier 2006; Simon 1981; Squires & Byrne 2002).
- A Thinking style or professional activity- the practice of design where the specifications of an artefact are decided and abstracted by people trained to solve complex problems, visualise and materialise results defined by a user in a socio-ecological context (e.g. Schön 1983)

Far from being consensual, there is an ongoing design thinking debate on the design process, practice, activity and knowledge production (see Cross 2001, 2006; Figueiredo & Cunha 2006; Love 2000). Chronologically this design thinking debate has shift from the design method movement mentioned above (§9.3) towards a reflection on how designers in social contexts make sense of reality in order to provide insights or a generalized design thinking applicable to virtually any problem (Cross 2001; Figueiredo & Cunha 2006; Gedenryd 1998; Kimbel 2009). More recently, inspired by sociology and anthropology (e.g.; Hutchins 1995; Suchman 1987), some authors propose design as a distributed social accomplishment (e.g. Margolin 1995; Julier 2006; Shove *et al.* 2007). This theoretical shift in design thinking from "methods of practice to solve problems" to "reflection-on-practice to manage wicked problems" is also mirrored in cognitive terms. Initially perceived as an individual cognitive style to solve problems (e.g. Simon 1969), design was then viewed as an intellectual approach to problem formulation/solving within a social context (Buchanan 1992) and finally as a combination of intra-mental processes, action and the physical world (Gedenryd 1998). Consequently, the practice of design is also increasingly change from a linear, individual, rational, systematised process to an organic, socially-mediated, creative activity, rather than (Bucciarelli 1988, Minneman 1991).

The theoretical, cognitive and practical interrelated shifts in design thinking highlight the central importance of reflective-practice (e.g. Schön 1983), stakeholder participation (e.g. Ehrenfeld 2008; Cross 1972; Kensing & Blomberg 1998) and social learning (e.g. Jones 2010; Bazjanac 1974; Dorst 2010). In the following each of these fundamental elements could shape design supports tools, particularly the metamodels for WES design.

By "supporting design" this research intends to assist potential users of the design tool built in this research which include, e.g., rural communities, entrepreneurs, NGOs or local governments, in the process of designing a WES. Moreover associated with that purpose, the users should be able to jointly define a specification of the ESy, i.e., a conceptual model of what should be, and what should be in, the ESy as a design product. In this sense the design support tool envisaged resembles a decision-support tool. However, instead of the usual normative prescription of a solution the option for a mutually embedded reality (§9.2), drives the design tool more in the lines of a support to the thinking process of users engaged in designing WES. The idea is not, thus, to develop more efficient or sustainable WES, or improve the design decision-making (although this could eventually happen if that is the purpose of the users), but to support users as potential designers, that is, to assist those users to better enact their design knowledge. This perspective is derived from the notion that "we are all designers" (Norman 2004; Willem 1990), but also that not everything is design (Jonas 2010; Hjelm 2005; Ulrich 2011; Wildavsky 1973). In other words, all can creatively solve problems or create objects (Simon 1969), but design is expressed through a specific practice, thinking and way of knowing. Consequently, design and design support tool, are, in this research, more related with the "design profession" and could, hence, gain much insight from the design theory and research on design, i.e., from design as a subject. In particular, research on design could highlight which stage of the design process offers more opportunities for local/expert knowledge integration, and what properties should be present in such design support tool.

Simultaneously, the design support tool is, in itself, a design product (the research goal) achieved through a design process (the research process) conducted by a designer (the researcher). It follows that, for coherency, the insights provided by design as a subject are also valuable for designing the design tool. For instance, since theory on design highlights the relevance of "participation" in design thinking, the research design should also be undertaken in a participatory mode (also a consequence of systems approach as concluded in §9.2). This kind of coherency is not always followed and constitutes an identified gap in the literature.

9.3.2 Reflective-Practice: How Designers Design

Based on the theories of practice (Bourdieu 1990; Giddens 1984; Reckwitz 2002; Schatzki *et al.* 2001), a number of authors (Barley & Kunda 2001; Hutchins 1995; Orlikowski 2000; Suchman 1987) sustain that practice is fundamental to understand the nexus people, technology, knowledge and context. Practice is what people do and how they interact with other people, objects, knowledge, discourse, structure/process and agency within a given context (Reckwitz, 2002). In these terms, artefacts are fundamental to promote experimentation, feedback, redesign and innovation (Shute & Torres 2011, Knorr Cetina 2001). Moreover, since a single designer cannot grasp all the possible meaning and

interaction produced around the artefact, it is important to keep a continuous and dialogical interaction between the different actors in the design life-cycle, the artefact itself, and the context where design is enacted through a learning spiral of experimenting and reflection. Accordingly, design thinking also highlights the central importance of practice (e.g. Kimbell 2009; Wright *et al.* 2006) and social learning (e.g. Bazjanac 1974; Dorst 2010; Jones 2010) as a strategy to enhance design.

A central author in this movement is Schön (1983) and his "reflection-in-action", which further claims that designers, besides being involved with practice, are also continuously reflecting on that practice, reframing and restructuring the design problems according to their experience and contextual aspects. In other words, designers act according to know-how, tacit knowledge, beliefs and perspectives, reflects upon those actions made, and new circumstances emerge from what is learnt and the situation continues to be shaped through a kind of reflective conversation (Weis 2010: 19). In reflection-in-action, design is an interplay between conceptualisations (individual or collective), creative action, bias, values and contextual constraints from the socio-material world (e.g. time, market, culture) to produce tangible and/or intangible artefacts (Hjelm 2005; Kimbell 1999).

In practical terms, design thinking does not follow a recognised prescribed method or methodology, but a set of overlapping activities or principles generally emphasise learning, collaboration/participation, visualization of ideas rapid concept prototyping (Brown & Wyatt 2010; Buxton 2007; Dorst 2010; Jones 2010; Kraaijenbrink 2006; Love 2000). Thus, while the design process could be normative, i.e., guided by a predefined idea of what the object should be, the final object itself is normally generated through non-deterministic ways as a continuous dialog and interplay between action (designing), successive designs (artefacts), designers (participants) and design contexts (networks, environments, methods) (Gasson 2003; Nakashima 2009).

9.3.3 Design, Knowledge And Learning

A significant, but implicit, result of conceptualising design as a reflective-practice is that designing also becomes a knowledge process. In the process of reflect, the designer also "interpret", and in a sense, all design elements in the modelling process, fig. 9.1, could be the subject of interpretation or be part of interpretative processes. In this sense design have been linked with hermeneutics (e.g. Jahnke 2012) and phenomenology (e.g. Poulsen & Thøgersen 2011), that is, with knowledge and knowledge processes. Simultaneously, from the Schön perspective of reflective-practice (§9.3.2) design is a cyclical reflective process of search-and-learning, or trial-and-error, where several possible solutions are created, perspectives are developed, insights are gained, and mental models are updated in the process of exploring and documenting the problem in its context (Courtney 2001; Dorst 2007; Mårtensson & Westerberg 2007; Schön 1983; Suchman 1987). In this sense design is conceived as a learning process, a *make sense*, a reasoning process involving

deduction, abduction and induction (Coyne 1990), integrated as a reflection-in-action and reflection-on-action (Valkenburg & Dorst 1998).

Accordingly, design support tools (like the one this thesis is set to build and test) could be considered knowledge management (KM), and design thinking equated with ways of knowing or, appropriately, *designerly ways of knowing* (Cross 1982). The question then arises on the kind of KM tools and/or systems to consider. Hatchuel (2001) advocates the need for learning devices able to support design in expanding and redefining initial concepts and collective action. Recent trends on KM seem to agree on this idea, defending that KM tools should support the emergence of knowledge, providing suitable conditions for that purpose (Alavi & Leidner 2001; Terra & Angeloni 2005; Von-Krogh *et al.* 2000). With such learning devices, people can have a common knowledge platform to learn (using information and experiencing the world) and apply their knowledge (Alavi & Leidner 2001; Terra & Angeloni 2005; Von-Krogh *et al.* 2000). Moreover, this platform should be participatory, that is, support participatory design. Being design social in nature (e.g. Kvan & Kvan 1997), learning in design also occurs through interaction among designers. The idea that interaction between people with different perspectives can lead to the emergence of new insights is generally accepted in literature (Funtowicz & Ravetz 1993; Levine & Resnick 1993; Hoffman 1959; Webler 1995) in what has been referred as "social learning" (Bandura 1971, 1986).

Therefore, when considering from a KM perceptive, design tool should try to conform to 3 interlinked characteristics (after Terra & Angeloni 2005). First is that it should be centred on people and their practices, imagination and strategies. In particular, the design tool should address the energy strategies of the users (i.e., those using the tool) by providing non-normative and non-prescriptive space of creativity. Secondly is the focus on participatory knowledge construction and innovation, which follows directly from the need to stimulate learning and knowledge exchange on the process of doing design. Finally, as a consequence of the previous two, the KM through the design tool is indeed an "act of managing", i.e., focus on the identification of knowledge in people and the interplay between people and design tools to promote the dialogue process between learning and acting. Like design thinking do not aim to the correct design, this perspective on knowledge does not promote the correct use of knowledge measure in some metrics, rather the idea is to support people in what they actually do, think and create.

A last issue on the definition of design tools and KM and learning devices, is concerning the actual physical platform (format in fig. 9.1). While sophisticated information and communication technology (ICT) is, by far, the choice followed to implement KM (e.g. Butler 2002; Hirschheim & Klein 1989), some authors question this option. For this research probably the most compelling argument is the possibility that ICT might cleave are left out of the process (e.g. Swan *et al.* 1999; Galliers & Newell 2001). Designed to be implemented in Mozambique, and aiming to include the widest number of people, both as co-designers and as users of the design tool, this research has to be sensitive to the

high level of illiteracy and structural difficulties (e.g. lack of electricity, hardware, software). In accordance, this research concentrates on non-computer based solutions to support collaborative design as knowledge activity, focusing on the social actions through which this may be achieved.

9.3.4 Design, Conceptualisation & Perspectives: A Call For Dialogue

Despite the semantic dispersion, there is a reasonable agreement that design is a complex social and cognitive human activity requiring the evaluative and creative articulation of technical/non-technical knowledge and skills to generate new tangible/intangible artefacts (e.g. Buxton 2007; Gedenryd 1998; Jonas 2010; Love 1998). In this proposition design is purposeful or teleological (Rosenblueth *et al.* 1943) to address problems, i.e., recognised gaps or deviation from a norm or desired set of conditions (Cowan 1986; Newell & Simon 1972; Watson 1976). In basic terms, design involves the ability to "give form", i.e. to creatively translate an idea (individual or collective) into a tangible or intangible artefact suitable to a given purpose, which might not be obvious or readily understood.

Accordingly, design includes some sort of visualisation, conceptualisation or mental model of: the existing reality and context; of the problem/situation (e.g. Buxton 2007; Gedenryd 1998; Jonas 2010; Kruijf 2007; Simon 1969). Such conceptualisation is dependent on three interlinked factors: The nature of the context where design occurs; the quality of knowledge available; and personal and collective perspectives. Design in very complex environment as the WES (§5) requires abundant and diversified knowledge (Buchanan 1992). However, complexity also implies that such knowledge tends to be highly uncertain, incomplete, ambiguous, unknowable, unreliable or unavailable, which turns perspectives a central element in design. In the face of the unknown, uncertain and unpredictable, in order to design in the real world and for the real world, perspectives, assume a leading guiding role for action, and reflexion.

A perspective is the integrated whole of beliefs, values and presumptions that a person, or group of persons, uses to get to grips with a particular problem (Cuppen 2009). A perspective shapes people's perceptions and determines how someone perceives a particular problem and its solution (Linstone 1989). Therefore, perspectives represents a way of *making sense* of and acting upon reality, provide an "entrance" to understand 'what we are looking at'. Perspectives *frame* the various ways in which actors form conceptualisations of reality, i.e., determine what knowledge is examined, why and how it is considered (Courtney 2001; Cowan *et al.* 2006; Koppenjan & Klijn 2004; Pries-Heje & Baskerville 2008). Accordingly, Schön & Rein (1994: p30) prefer the term "frame" to state that "there is no way of perceiving and making sense of social reality than through a [frame]" (Schön & Rein 1994: p30). Conversely, perspectives are contextually constructed through the interaction between people, personal frames of reference (e.g. experiences, values, knowledge, paradigms) and reality (Cowan *et al.* 2006; Dewey 1933; Kitchener &

Brenner 1990; Kuhn 1972). Perspectives are shaped by underlying value orientations and worldviews, by knowledge and experience, culture and by the interests of an individual. They embrace an individual's beliefs and presumptions with regard to a specific issue. As perspectives often remain tacit and belong to our taken-for-granted world, we are often unaware of their role in organizing our perceptions, thoughts and behaviour (Argyris 1995). Therefore, it is argued that designers' cultural preferences unconsciously influence product concepts, semantics and semiotics. These qualities, being invested in the products by designers, are better communicated to the potential users of the same culture than users from other cultures (Cuppen 2009). In conclusion, perspectives are fluid and in constant dialogue with the context, which affects and is affected by design. Perspectives are dynamic and plural. People can take on multiple perspectives, dependent on the specific situations or role. While different people have different perspectives on the same subject, the same person can have different perspectives on the same subjects in different situation or stages of life, since perspectives can change over time as a result of new experiences or information.

By considering a systems and design thinking reframing of the WES design (in itself a change of frame in the author) the importance of perspectives emerged as central to design. Stretched from rural to urban areas and involving actors with different interests and experiences, and analysis of the WES complexity is above all a multiplicity of divides. There is the divide between the rural and urban worlds (e.g. §6.3), which could be interpreted as: the divide between the forest and the city, the production and consumption; the experts and the lay people; the need to generate income in rural areas, and the need to adjust income with energy needs in urban areas (§5.3.2); the divide between the Ministry of Agriculture (MINAG) that rules the forest and rural world in general, the Ministry of Energy responsible by energy initiatives mostly focused o RETs and based on ETP (§5.3), and the MICOA concerned with sustainability. There is also the already mentioned divide between policy makers, technical staff and social, like the divide between the CBNRM and "WF is sexy" approach (§5.2.3), or even between different disciplinary approaches to WES. These are just some examples on the multiplicity of perspectives or standing points on the problems emerge when a system is considered from a design approach. This standing point geographical sense of these divides was actually conceptualised by AIA/Rush (1986) as "operational islands", fig. 9.4, which are the result of juxtaposing two typical discontinuities in design:

- Design management discontinuities which refer to the different roles and expertises involved in the design life cycle from concept/idea to the end-product; and
- Functional gaps that reflect the different disciplinary, theories, paradigms, roles and trades that had developed independently in design, each holding specific knowledge and ignoring, generally, other design contributions (see also Holzer 2009; Taylor & Levitt 2004).

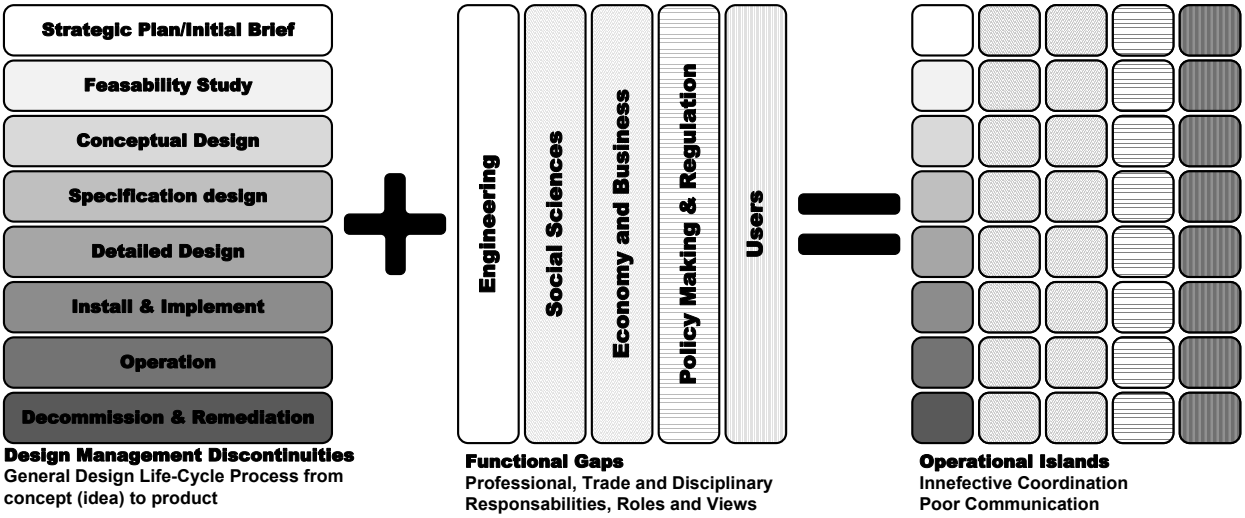


Figure 9.4| "Operational islands" as the result of "design management discontinuities" and "functional gaps" [the Author after from AIA/Rush 1986; BSI 1996; ISO/IEC 15288]

Note that these operational islands are not just "personal perspectives", they exist and are affected, and affect, the wider socio-economic context where they manifest. The "operational islands" reflect the ongoing diversification of "design" specialised profession, the progressing subdivision of professional responsibility and accountability in design projects (e.g. Holzer 2009; Cowan *et al.* 2006; Love 2003), as well as, the market monopoly, professional identity and authority reinforcing social dynamics (Turkle *et al.* 2005; Kuhn 1972).

Thus, while reflecting specific knowledge, information requirements, theories, mindsets and culture, these "islands" also conceptualise the design problem and solution with specific language, semantic idiosyncrasies, notations, and models (e.g. Holzer 2009; Cowan *et al.* 2006; Gann & Salter 2001; Thammavijitdej & Horayangkura 2006). Under these conditions, the communication, coordination and knowledge transfer across "operational islands" is a huge challenge (e.g. AIA/Rush 1986, Baer *et al.* 2008; Cowan *et al.* 2006; Holzer 2009). Moreover, as explained above, the inhabitants of those islands might not perceive they are i9nhabitants of those islands. Actors ins different islands might perceive the existence of these islands, but hold completely different images, geographies and topologies of it. Therefore, when discussing, although each actor from different island might believe that all are talking about the same thing (design) in the same way, that reveals to be an illusion.

The perception that WES design was plagued with these "perspective islands", as well as, that few tools existed to support, in a structured way, the communication, dialogue and knowledge exchange between actors in the process of designing, was one of the greatest motivations to search for such a tool. In fact, supporting dialogue and sense making across these islands sounds a viable, relevant and necessary task, but also a complex one.

9.3.5 Wood Fuel Energy Systems Design A Wicked Problem To Structure

From the analysis conducted above, WES design emerges as a complex artefact (an ESy) developed within a complex socio-ecological reality (WF in DCs) through a complex process (design) shaped by uncertain, ambiguous and incomplete knowledge and conflicting and ever-changing perspectives on the design goals, criteria, requirements and representations. Societal problems with these characteristics are defined as a wicked (Rittel & Webber 1973), ill-structured (Simon 1984), ill-defined (Reitmann 1965) or messy (Ackoff 1974).

Note that, while these terms are native to systems thinking they fit perfectly the situation of reframing the definition of WES in DCs as a complex design problem, a perspective that emerged from applying a systems thinking approach to WES in DCs. Remarkably, wicked, unstructured or ill-defined problems are design problems and vice-versa (Cross 2000; Dorst 2006; Friedman 2003; Rittel & Webber 1973, 1984). In particular, this conclusion is applicable in relevant fields such as energy policies and/or bioenergy systems (e.g. Buchholz *et al.* 2005; Cuppen 2009; Elghali *et al.* 2007) or energy resource management (Afgan *et al.* 2002, 2007; Kranjc & Domac 2007; Weible & Moore 2010).

As a wicked problem the WES design shares a number of interdependent characteristics:

- Design and design decision-making are strongly influenced by natural and social contexts and deeply embedded in societal and organisational structures (e.g. Rotmans & Loorbach 2009).
- The facts and causal/associative relationships are not fully understood or consensual and there is a high level of confusion, ambiguity, uncertainty or knowledge conflicts resulting from diverging perspectives, lack of reliable data or ignorance (e.g. Becker 2007; Mingers 2008).
- What is (the problem) and what should be (desired state) are unclear, poorly formulated, conflicting and value-laden preventing thus the definition of objective and undisputed design assessment criteria (e.g. Becker 2007; Cuppen 2009; Hoppe 2002; Koppenjan & Klijn 2004; Mingers 2008), solutions (Gray *et al.* 1994; Kruijf 2007) or reliable standardized design methods (Alexander 1966, 1971; Jones 1977).
- Rather than a single solvable problem, WES design constitutes a “problematic” or “strategic problem” (e.g. Venters 2003; Mingers & Rosenhead 2004; Mingers 2008), i.e., a collection of interlocked problems constantly changing in response to external and internal socio-ecological and technical factors (e.g. Jackson 2003; Mingers 2008).

A fundamental result from these four characteristics is recognition that design, and In particular, WES design, is too complex to comply with Cartesian sequential synthesis-analysis problem-solving logic. In wicked problems, there is no definitive formulation of a wicked problem, formulating the problem is the problem (Rittel & Webber 1973) and the actual problem is not understood until a solution has been developed (Van Bruggen & Kirschner 2003). In other words the activity of understanding a problem (analysis) is equal

with that of solving it (synthesis) (Popper 1972; Nordström 2010; Hisschemöller & Hoppe 2001), and both are contextual and depend on personal interests, ideologies, perspectives, mental models, rather than on a "linear", "neutral", "objective" or "scientific" translation of facts (Ganapathy 1981; Lawson 2005; Mackinder 1980; Papamichael & Prozen 1993;). In wicked problems the choice of explanation determines the nature of the problem's resolution (Holzer 2010; Kruijf 2007; Rittel & Webber 1973), the understanding of the problem is linked with ideas we may have about solving it (Parham 2003) and each attempt to solve the problem or arrival of new actors affects the judgments on the problem and solution (Becker 2007; Lawson 2005; Marashi & Davis 2007; Märtensson & Westerberg 2007). Consequently, in complex realities "success" depends on the capacity of different actors and groups to communicate, negotiate and reach collective decisions (Cowan *et al.* 2006; Figueiredo & Cunha 2006; Mingers 2008; Pahl-Wostl 2002; Rulye 1973; Schusler *et al.* 2003). While this description indicates once more (§9.2.2, §9.3.4) the need to support dialogue in complex context or problems, another important result emerging from considering the WES design as a wicked design problem is the need to focus on the problem rather than on the solution.

Without a metric of success, or at least a metric that all commonly agree, an uncertain, ambiguous and dynamic nature of the problems, subject to many perspectives, wicked problems, for which design is an example, are considered to "manageable" (Ackoff 1981) or "handled" (Schön 1983), but never solved (Ackoff 1981). This perspective radically changes the deterministic and positivistic approaches to problems, which are basically *solution-finding strategies* (§6.3), to a more contextualised and constructivist approach, where the focus is the problem, the understanding of the problem from multiple perspectives. In this regard, problem structuring (also problem formulation, setting or diagnosis) has emerged in mostly in systems and design related research (e.g. Damart 2010; Mingers & Rosenhead 2004). The purpose is to understand the problem nature and improve strategies to address the problem (Maani & Maharaj 2004; Spellman 2010).

Indeed, a clear and agreed problem definition is as a fundamental stage in problem solving, since it determines the solution space (Einstein & Infeld 1938; Rittel & Webber 1973), provides insights into the problem and its solution, or, at least points to a plausible direction (Büyükdamgaci 2003). Problem structuring assumes that the progressive definition of the problem shapes the solution space (Büyükdamgaci 2003) since "the process of formulating the problem and of conceiving a solution [...] are identical" (Rittel & Webber 1973), and cannot be treated as separately (Hisschemöller & Hoppe 2001), or yet in other words, our understanding of the problem is linked with ideas we may have about solving it (Parham 2003). Hence, a great concern on problem structuring is the need to avoid type III errors, that is, trying to solve the wrong question (Ackoff 1974; Dunn 2001). However, as Büyükdamgaci (2003) acknowledges, the human tendency and the availability of powerful solution search tools encourages the focus on simulation and solution synthesis without proper problem definition (see also Yadav & Korukonda 1985).

In order to support problem structuring a number of methods have been developed, appropriately called problem structuring methods (PSM, e.g. Mingers & Rosenhead 2004). PSM facilitate a space where people could simultaneously expose individual perspectives, while participating in a structured process of investigation and exploring the problem (Damart 2010; Mingers & Rosenhead 2004). The objective is thus to identify causal relationships, connected problems (Damart 2010), as well as, to "converge on a potentially actionable mutual problem or issue within it, and agree commitments that will at least partially resolve it" (Mingers & Rosenhead 2004). Note that PSM still focuses on solving (even if partially) the problem, However, tries to do it from the problem analysis perspective, considering, for instance, the option of doing nothing. In this sense PSM is already an alternative to the deterministic problem-solving and provide a number of relevant principles for this research, in particular, PSM (Mingers & Rosenhead 2004):

- Focus on make explicit several alternative perspectives for jointly analysis;
- Intends to be cognitively accessible to actors with a range of backgrounds and without specialist training, so that the developing representation can inform a participative process of problem structuring;
- Operate iteratively, so that the problem representation adjusts to reflect the state and stage of discussion among the actors, as well as vice versa.

Therefore, PSM aims at the generation of alternative solution through the systematic exploration of the problem as the participants in the process *see it*, while producing a representation of that participatory process equally meaningful for those participants. Problem structuring is also about gaining improved understanding of divergent perspectives on the problem and its solutions. Especially in the case of unstructured problems, actors are often unaware of their own and each other's perspectives (Argyris & Schön 1974; Schön & Rein 1994; Van de Kerkhof 2006). Remarkably these principles have found a strong application in design and management sciences, which deal with complex social and technological situation and require some sort of device to trigger conceptualisation of the problem. In this process of making explicit and trigger perspectives, the role of visualization seems to be appreciated (§9.4.2). Indeed, visual experiments and visualisations (Dorst 2010, Schön & Wiggins 1992) are central for designers to learn from what they see (Coyne 1990) in the jointly construction of meaning, exploration of different solutions, perspectives and complex relations/process (e.g. Buxton 2007; Checkland 2000; Gedenryd 1998; Holzer 2009; Schön & Wiggins 1992).

9.3.6 Reframing Wood Fuel Energy Systems As A Complex Design Problem

Reframing the WES definition as a complex design problem has multiple implication on the definition of a design support tool (§D). This reframing is not just "making the problem a design problem" which, *per se*, is not the equivalent to look to real alternatives to the prevailing positivist and determinist approach to modelling and design, expressed in the WES design as the ETP (§6.1, 7, 8). As the previous critical analysis show, several

authors, notably Simon (1969) while acknowledging the complexity of the problems design has to deal, defended a deterministic approach conceived as “design as problem solving”. Likewise PSM while departing from the problem, also aim at the solution. This utilitarian view of design, in more or less degree, do not diverge much from the “paradigm of simplicity” (Morin 1977, 1990, 2008), which assumes that complexity, which has no limits and cannot be fully formalised or measured, can be fully defined and controlled. Therefore, this research searched for a real and intentional reformulation of the terms in which the definition of WES have been done so far. In this regard, Schön “reflection-in-action” (§9.3.2) design thinking, or *designerly ways of knowing*, *thinking* and *acting*, had frequently been proposed as a particularly suited thinking style to deal with complex societal issues without simplifying them (e.g. Boland & Collopy 2004; Buchanan 1992; Cross 2001).

Build on theories of practice (§9.3.2) which are also linked with the mutually embedded paradigm considered in the systems thinking (§9.2) Schön “reflection-in-action” also provides paradigmatic and philosophical coherence to combination of systems and design thinking considered in this thesis. Finally, Schön’s “reflection-in-action” has been remarkably successful in combining procedural knowledge (know-how), socially constructed perspectives (frames), action (practice/interaction) and reflection on that acting to continuously adapt and evolve design solutions in relation to reality. In this sense, reflection is ”thinking which *looks* at itself” (*Tiensuu 2005: 194*) or meta-cognition, thinking about thinking, (*Weis 2010*).

By focusing on WES definition as a design problem, this thesis reframed the WES definition as a wicked problem, that cannot be solved, but still need to be addressed, managed and worked with. It also revealed that WES in Mozambique (and probably elsewhere) is above all a fragment field of cognitive islands (operational islands in §9.3.4), each expressing a particular perspective and experience, but also, imparting a valuable contribution for the big picture of WES design. This result reinforces the already identified need for a tool that supports dialogue, participation and knowledge exchange processes, that is, learning (§9.3.3). However, has the research on PSM, that tool should provide the means for the participants simultaneously explore the problem and make explicit their perspectives in the process of designing (§9.3.5).

Therefore, the dialogue is not just between participants, but also permanent dialogue between the object, the context and the process of design. In this sense, this is not just a “problem structuring activity”, it is a true design process in the terms defined by Schön (§9.3.2). Moreover, it is a learning experience, a knowledge process and a creative act. Conversely, this result refers back to the relation between systems and design thinking. As the systems thinking already had made clear (§9.2), since problems in real world are unique, complex and uncertain, some sort of representation has to be made and continuously reframed as the designer is gaining sense of the problem, that is, the designer needs to “reflectively” construct a representation of the wicked problem. This is

called problems setting: “Problem-setting is a process in which, interactively, we name the things to which we will attend and frame the context in which we will attend to them” (Schön 1983: 40).

From this analysis a main contribution of design thinking to the definition of the design tool to be built (§D) emerge: the importance of visual tools in the ideation or conceptualisation stage, that is, conceptual design. The problem structuring happens in the ideation stage, and that is why participation from wide number of perspective is so relevant, to avoid solve the wrong problems for the wrong reasons (a type IV error?). Moreover, as the substantial body of practical experience form design and management sciences clearly show (e.g. Buxton 2007; Damart 2010; Mingers & Rosenhead 2004), visual tools seem to facilitate the ideation stage effectively and open to all sorts of perspectives. Therefore, the design tool to-be should address conceptual design stage and be visual (a characteristic that, in Mozambique, will have other advantages (§9.4.4).

Finally there are three implicit results also emerging from the previous analysis, the fact that most of the design support tools are, in fact, tools to make sense of problems, rather than support decision making on problems. Also, in general , these tools tend to blur the distinction between participant and facilitator, since in a design process conceived as an intense and continuous dialogue with the facilitator is not a “conductor”, “director” or “professor”, but rather a co-participant in that process. Finally, and in relation with the previous point, since to keep the design process really open, the condition of the potential users of the design tool should be considered. In this regard, considering the level of literacy, energy related technical skills and the conditions of most rural communities, it was decided that the design should not require any kind of computer support, be simple and visual, and should be focused on conceptual design. In these design criteria (or specifications) will be critically addressed.

9.4 Design Criteria For A Non-Deterministic Design Tool

The insights that design and systems thinking provide in the design of WES in Mozambique (as a DC) have, as §9.2-3 show, an immense impact in this research, since they provide a strong theoretical and practical background to support the use of participatory design, the focus on the conceptualisation stage of design, the preference for visual tools of easy understanding, and, implicit in all, the need to make sense, more than impose a top-down normative, prescriptive and deterministic decision making focused on solutions. In the following these aspects will be considered in more detail.

9.4.1 Participation & Participatory Design

Participation responds to a growing interest felt in a wide range of fields to include knowledge, priorities and perspectives from a number of sources in design, planning and decision-making (see Reed 2008). Due to this dispersion, participation has gained distinct

ideological, social, political and methodological meanings and interpretations, but not lent to a single theory, paradigm of study or approach to practice (Cornwall 2008; Lawrence 2006; Slater 1998). As explained before (§9.2.2) for this work participation links with this research at two distinct stages and with two purposes. Participation is used as the viable and sound *process* to build and test the design support tool (§14-15), that is, the design support tool will be made (designed) not by the Author alone, but in a participatory design process. In a second stage, once produced, the design tool is also intended to support the conceptual design of WES, in other words, the design tool supports participatory conceptual design. Since the use of participation in both stages follows the same argumentative line, these stages will not be addressed differently here.

Participation in the context of this research could be defined as participatory design (PD) or participatory modelling (PM). PD refers to a set of theories, practices, approaches and studies aiming to actively involve, through mutually agreed ways, the knowledge and/or perspectives of those people considered to be relevant in the design life-cycle in order to improve the design process and/or product (after IFAD 2002). PM combines participatory procedures with modelling techniques and/or activities in one or more stages of the modelling process in order to effectively assist collective decision-making or understanding (after Hare 2011; Voinov & Bousquet 2010). Thus, while PD provides the philosophical fundaments underpinning the use of participation in/on design, PM provides a medium to implement participation in design contexts. To avoid future confusion and considering the PD wider semantic range, here, the term PD will be used to study participation in the context f design. In this regard, in line with design thinking as envisioned by Schön (§9.3.2) the purpose with participation in design is to promote a continuous and dialogical interaction between the different actors affected by, or influent in, the design life-cycle, the artefact itself, and the context where design is conducted/enacted. PD might also be seen as a strategy to cope with complexity and uncertainty by enriching design, problem-setting and/or decision-making, with different perspectives, knowledge and values (§9.2-3).

The claims supporting the potential benefits of participation in complex design process can be articulated in 3 interlocked arguments: the cognitive (or knowledge); the normative (or moral); and the pragmatic (also utilitarian, functionalist, substantive or instrumental). The cognitive argument claims that in complex realities, due to the human limited cognitive capacity (Arrow 1974; Newell & Simon 1972; Simon 1955) relevant knowledge/perspectives are likely to be dispersed across multiple individuals (Van Bruggen & Kirschner 2003; Baer *et al.* 2008). Encouraging knowledge share/integration, social learning and innovation (e.g. Bammer 2005; Nuschke & Jiang 2007) participation generates *"*knowledge rights*"* (Leach *et al.* 2002) and *"*collective intelligence*"* (Fischer *et al.* 2005), both important for empowerment (Williams 2004; Hickey & Mohan 2005) and improved decision-making (Chhotray 2004; MacNaughten & Jacobs 1997; Nuschke & Jiang 2007). The normative argument, sustains that for those affected by the problem

and/or carrying out the solution participation is a democratic right (Rosson 2007) that increases empowerment, sense of ownership, social acceptance and legitimacy in decision-making (Bammer 2005; Kruger 2001; Sheppard & Achiam 2004; Weisbord 1989). In this regard, Habermas' (1987) suggests that participation should be *"*fair*"*, representing the full range of relevant stakeholders and equalising power between participants, in addition to being *"*competent*"* (resulting in settled claims). Finally the pragmatic argument focuses on the advantages of participation for outcomes, holding that actor knowledge/views improve understanding of local conditions, reduce conflict and increase people's commitment (Blackstock *et al.* 2007; Siebenhuner & Barth 2005; Susskind *et al.* 1999; Voinov & Bousquet 2010) and are, thus, fundamental for sound design, better technology transfer and improved decision-making at lower costs (e.g. Blackstock *et al.* 2007; Rosson 2007; Nuschke & Jiang 2007; Webber & Ison 1995).

With such number and variety of claims, meanings and interpretations, participation is often assumed as another word for *"*panacea*"* (Bevan 2000; Cernea 1991; Cornwall 2008; King 2003) and, indeed, practical and theoretical work (e.g. Cooke & Kothari 2001; Mansuri & Rao 2004) highlight that PD is subject to several interlinked misconceptions, myths, barriers and dangers. Common misconception on participation includes the idea that Participation is not obligatorily synonymous with equity, social justice or decentralization nor it is clearly linked with environmental benefits (Lélé 1991). However, *"*Being involved in a process is not equivalent to having a voice*"* since people might be hindered to talk or voluntarily decide not to participate at all (Cornwall 2008: 278). Moreover, Participation does not necessarily or automatically lead to legitimacy and support of policies (Korfmacher 2001) or consensus (Blaikie 2000; Nustad 2001). Likewise, Synergies between local and formal technical knowledge are not immediate, but complex and context dependent (Agrawal 1995; Biggs 1990; Biggs & Clay 1981; Okali *et al.* 1994).

On the basis of these misconceptions is the idea that communities are not precise categories, but problematic and pluralist entities (e.g. Woodhouse *et al.* 2000, §7.4). Common barriers to participation with impact on PD can be technical, political or cognitive. For instance, the use of technical terms and language can limit public participation (Kasemir *et al.* 2003). On the other hand, participation might be hindered by political or historical reasons including, for instance: previous bad experiences (Oakley 1995); or specific group dynamics, political manoeuvring, peer pressure, cultural and professional bias (Wittenbaum *et al.* 1999, 2004). Finally, Heterogeneous cognitive structures representational gaps (Chi *et al.* 1981; Cronin & Weingart 2007) and *"*tunnel vision*"* (Boland & Greenberg 1988; Mason & Mitroff 1981) can prevent knowledge share, learning, interaction and communication in PD (Baer *et al.* 2008). Besides the misconceptions and barriers, participation also has well known drawbacks. The most well documents is the fact that, in many occasions, actors are merely informants with a quite nominal engagement and the participatory process is just a means to derive legitimacy and accountability for external decision makers (e.g. Cornwall 2008; Morse 2009; Voinov

& Bousquet 2010). Another commonly mentioned problem with participation, is the absence of visible results and benefits for participants, particularly rural poor. The lack of strong links between participation and well-being leading to disappointment, consultation fatigue, and distrust (Beaulieu *et al.* 2002; Burton *et al.* 2004; Ramani & Heijndermans 2003) that create ambiguity and delay decisions (Bojorquez-Tapia et aI 2004; Vedwan *et al.* 2008). Other less frequent problems include stakeholder categorizations that might raise questions on legitimacy and how people see themselves and to what point they could represent a group (Cornwall 2008; Dryzek 2001), conflict and distrust due to divergent objectives and interests which can narrow and bias the problem formulation (Carnevale & Probst 1998; Pettigrew 1973). Therefore, *"*more is not always better*"*, as different contexts, purposes, resources and capacity for actors to influence outcomes, may define different levels of engagement, participatory models and design strategies (Cornwall 2008; Lynam *et al.* 2007; Richards et aI 2004; Tippett et aI 2007). Additionally, the level of engagement is a major factor to decide on the participatory methods and models that probably would be more relevant.

Analysing the claims and drawbacks of participation, it seems clear that PD, as participatory processes, are complex historical process shaped by contexts, goals, values, knowledge, expectations and related power constellations (e.g. Cornwall 2008; Lynam *et al.* 2007; Reed 2008; Voinov & Bousquet 2010). Ignoring this dynamics can lead to diffuse *"*all-inclusive*"* processes of purely symbolic participation and finally doubt on participatory benefits (Wiesmann *et al.* 2008). On the other hand, understanding these dynamics calls for an approach that regards participation as *"*an inherently political process rather than a technique*"* (Cornwall 2008: 281), a social negotiation between power, intentionality and agency (e.g. Kotari 2001; Rosson 2007). Consequently, the participation focus, with clear relevance for PD, is on whom, when, where, how and why to involve and which participation to consider (e.g. Bots & van Daalen 2008; Cornwall 2008; Voinov & Bousquet 2010).

Integrating arguments, myths, misconceptions and failures, a number of participation typologies based on different participation aspects have been developed both to choose participatory methods suitable for the type of participation required, and/or to assess the type of participation that has occurred (Reed 2008). Accordingly there are typologies based on a continuum of increasing involvement of actors, from passive dissemination of information to active self-motivated engagement. This continuum is generally portrayed through the metaphor of a ladder of participation (Arnstein 1969) with numerous alternative terms for the different rungs (e.g. Biggs 1989; Farrington *et al.* 1993; Goetz & Gaventa 2001; Pretty 1995). Other participation typologies are based on the nature of participation according to the direction of communication flows (Rowe & Frewer 2000). In this typology the progression goes from *"*communication*"* (information dissemination to passive recipients) to *"*consultation*"* (gathering information from participants) till *"*participation*"* (a two-way communication where information is exchanged through

dialogue or negotiation). Another participation typology focuses on the theoretical basis, distinguishing between normative and pragmatic in defined according to the arguments presented for participation presented above (see also Beierle 2002; Thomas 1993). Finally participation can be typified according with the purpose of the participatory exercise, including classifications such as: *"*research-driven*"* and *"*development-driven*"* (Okali *et al.* 1994); *"*planner-centred*"*, *"*people-centred*"* (Michener 1998) and *"*building consensus*"* (Warner); *"*diagnostic and informing*"*, *"*co-learning*"* or *"*co-management*"* (Lynam *et al.* .. 2007); and "inform", *"*design active engagement processes", *"*consult", *"*deliver implementation of management plans", or to *"*monitor and learn from the effectiveness of participatory practice" (Tippett *et al.* .. 2007).

Notably, distinctions between classes in the several typologies are not so clear and different levels of engagement are likely to be appropriate in different contexts, depending on the objectives of the work and the capacity for stakeholders to influence outcomes (Tippett *et al.* 2007). This reality justified the "wheel of participation" as a more suitable metaphor that "ladder" to emphasise the legitimacy of different degrees of engagement (Davidson 1998). Nevertheless common to these typologies seems to be an idea of progression or opposition between participation as pragmatic, project-centred, top-down and conductive perspective and a normative, people-centred, bottom-up, self-motivated co-learning empowerment. This could be the result of the historical genesis of the participatory approaches, liking public consultation over political decision-making, in Developed Countries with more action-orientated, site-specific approach DCs (Lawrence 2006). While this linkage highlights the project, managerial and planning nature of participation, the progression/opposition served to justify different approaches to participatory processes. Remarkably, in an effort to support planning and management of participatory projects, alongside those typologies a number of frameworks have been devised to analyse and describe participation in decision making (e.g. Cohen & Uphoff 1980; Salter *et al.* 2010), PM (Bots & van Daalen 2008; Hare *et al.* 2003; Hare 2011), assessment (e.g. Blackstock *et al.* 2007; Kloprogge & van der Sluijs 2006) among other purposes. Likewise a number of approaches and tools have been proposed for the relevant fields of rural energy or natural resources management, which are more in line with the "bottom-up participation" approach including Collaborative Planning (Healey 2003, 2006, §7.4), Participatory and Rapid Appraisal (PRA e.g. Chambers 1994a, b, 2007), Participatory Ecological Planning (Tippet *et al.* 2007).

In parallel, and surprisingly independently, with these developments in planning and project management, PD in "design field" (e.g. architecture, industrial design, interaction design) also went to similar paths and encounter equivalent progression and/or oppositions. while the 1980s the roles were well defined between designers and costumers or consumers (shoppers and buyers), the late 1980s and early 1990s witnessed the emerging of the "users" as more interactive products were produced (Sanders 2006). This was still a design *for the people*, producing artefacts that were useful, usable and

desirable, and where people are seen more or less as passive actors and participation is at the level of communication, needs assessment and product evaluation (the lower rungs in the participation ladder). Today the "user" is seen as having a more active role in the design process. The user can be involved as an adapter, which means design artefacts that are also reusable and customizable. The user can also become an actual actor of the design process as a participant, and in this case design should also support immersive and collective experiences (Sanders 2006). More recently the users/actors are also invited to work collaboratively throughout the design development process, as co-designers (Sanders 2006). Co-design has been identified under a number of different definitions like "underdesign" (e.g. Brand 1995), "meta-design" (e.g. Ficher *et al.* 2004) or "loose fit design" (e.g. Shabha 1993). Any of these approaches to design implies a much deeper and active involvement of people and designers in the design process (Sanders 2006). As with participation and participatory approaches, this evolution also implies a progression on activeness and participation of several actors (other than designers) in the process and development of design, and simultaneously an opposition between designing for the users, and designing with users or actors. Furthermore, and still in a close parallel with the participatory approaches, there is a sense that each of these perspectives on PD are not better or worse, but coexist as option for "design spaces" (Sanders 2006) with specific benefits for different situations.

Within this logic, the focus on practice had generated several new approaches to design and design thinking, such as: *"*design-as-practice*"* (Kimbel 2009); *"*Practice Oriented Product Design*"* (Shove *et al.* 2007); experience-based design (Bate & Robert 2007; Buxton 2007; Wright *et al.* 2006); *"*user centred design*"* (Abras *et al.* 2004); or *"*user-led innovation/design*"* (von Hippel 2001; Seybold 2006). These approaches, in different degree, highlight the social nature of design and the need to integrate different interests and knowledge. and also new tool beyond the user-centred design, like collages, mapping, 3D mock-ups, storytelling, cards to rate, organise, Participatory envisioning and enactment or role playing (Sanders *et al.* 2010). These tools could be organised into toolkits, like Make-tools (Sanders & William 2001), which people can use to unleash their creativity and give them the means with which to ex-press their tacit needs, expectations and ideas express their ideas. Beyond new tools and methods and a new language for designing Co-creation also requires the acceptance of new *design partners* and a *new attitude* about the inherent creativity of everyday people. Again this is a move also mirrored in participatory approaches with PRA for instance. Another similarity with the participatory approaches described above is the diversity and wide range of influences that shaped the PD design spaces. From critical design, generative design research, the "Scandinavian" design school, applied ethnography, ergonomics and design and emotion, among others, several design fields contributed to the present co-designing landscape and format (see Sanders & Stappers 2008 for an historical perspective).

However, some differences persist between participatory approaches and PD. The first is the obvious lack of PD in DCs. The ideas, concepts and application developed within the framework of PD, particularly co-design, have all been conceived *for* and *in* Developed countries and focused on creating commercial objects, not ESy or DCs contexts. Another difference is the range of co-design in the design process and development compared with the participatory approaches in the planning of initiatives (essentially projects) in DCs. Participatory approaches, even the more incisive and participated, tend to leave beneficiaries, stakeholders or actors (the terms vary according to the initiative) outside the most conceptual stage, the ideation or conceptual design of those initiatives. On the other hand, co-design, by definition includes the users, actors or lay people, in all stages of the design process and development, with particular emphasis on the conceptual design stage (or ideation stage, §9.4.4). As designers move closer to the future users of what they design, the conceptual design stage also grows with inputs and participation of those future users and other affected or affecting the design usage.

In resume, participation, through participatory approaches or PD, provides a political and practical framework to improve empowerment, learning and effectiveness of action, as well as, a space for the designing artefacts. In the context of the preset research, these two properties were combined to implement in DCs design principles usually applied to develop artefacts in Developed Countries while expanding participation to the conceptual design stage, turning actors and future users as co-designers *de facto*.

9.4.2 Visualization And Visual Tools Supporting Design

One of the design criteria identified in §9.3 for a non-deterministic design tool to support WES was the need for a visual format, that is, the tool is expected to be presented is a visual and interactive platform, where different actors could share and communicate ideas. Here the theoretical and practical arguments for a visual tool presented above (§9.3.5) will be extended and complemented with and analyse in the links between visualization and participatory approaches and design.

While the design thinking and systems thinking have been using visual tools as learning devices (§9.3.5), the high level of illiteracy and lack of conditions in Mozambique (and most DCs), the socio-ecological context for the tool, also present a strong argument for considering visual design tools.

Visual design tools are inherently exploratory, interpretative and analytical, providing, thus, the proper techniques to elicit represent and analyse the perspectives and concepts that participants have on WF and WES. Moreover, by the nature of participatory visual methods, those perspectives and concepts will be represented and mapped using the participants own terms, materials and mind frames. With the support of verbal methods, visualisations provide a reliable common ground where knowledge on WES and related issues can be openly shared, enabling the emerging of the conceptual designs, descriptions of the problems/situation, as well as, the strategies of each participant.

Therefore, there is an array of interweaved advantages of visual design tools and/or methods relevant for this research, namely:

- Facilitate social learning and knowledge sharing- Visual methods provide a physical support where knowledge can be interactively worked-out, manipulated, analysed, shared, created and inquired, allowing thus, learning, knowledge share, cross-checking and insight by participants in their own terms (Bass *et al.* 1995; Brock & Chambers 1994b, 2007; Grenier 1998; Pettit 2007).
- Facilitates communication- Favouring the "concept of talking through the pictures" visual aids and visualization improves communication (e.g. Helming & Göbel 1997), by recording and reflect on needs, promoting dialogue and enhancing the understanding between different people on a more common level (Brock & Pettit 2007; Leach & Scoones 2006).
- Democratise participation- Visual techniques allow illiterate people or participants with difficulties to express orally to participate (Brock & Pettit 2007; Defoer 2002; Helming & Göbel 1997) and adds transparency to the process since drawings and images can be publically exposed for everyone to see and change (Bass *et al.* 1995; Brock & Pettit 2007; Chambers 1994a).
- Bridges cognitive divides supporting all the previous points- Drawings help participants to express their knowledge within their own mental maps, providing, thus, a medium to share ideas and explanations in indigenous conceptual terms (Cornwall 1992). Visualisation also improves the retention of thoughts, and raises attention to opinions and viewpoints of other participants (Helming & Göbel 1997). Additionally, visualizing the reasoning path and rationale behind the decisions in this way could be an effective means for facilitating communication among a group of actors (Marashi & Davis 2007).

While the visual methods tend to favour the group over the individual, the visual over the verbal, and comparison over measuring, (Bass *et al.* 1995; Chambers 1994a, 1994b), what is relevant for Chambers (1994b) is the horizontality in terms of roles, knowledge exchange and control over the design process that visualisation methods create between the outsider (typically a researcher) and the insider. With visualization, there is a kind of equal ground for expression (Chambers 1994b). Therefore, visualization and visual methods also play an important role in design, particularly in participatory design.

Design as an interface between action, artefact and context, requires some sort of intermediate representation which is technically feasible and affords practical interpretation by non experts (e.g. Asaro 2000; Bots & van Daalen 2008). Notably, this "dialogue" can occur in any stage of the modelling process, since visual methods tend to be "performative", linking action and planning, data and analysis, blurring, consequently, the distinction between data collection and data analysis (Scoones & Thompson 1994). Drawing as a process of "constructing a visual representation" is, in itself, an "analytic act" since participants are simultaneously exploring, describing and analysing, using their own

concepts, terms and materials (Cornwall & Jewkes 1995: 1671). This property of visualization clearly resembles the arguments around wicked problems. In fact, when addressing design in complex societal problems, visualization is rather useful, both in showing the connectedness of elements in wicked systems, and in surfacing assumptions that people hold about wicked problems, increasing that way effective communication during the decision-making process (Massey & Wallace 1996).

The advantages of visual methods have been used in several relevant fields including: environmental planning (e.g. Bass *et al.* 1995; Tippett *et al.* 2007); energy planning (e.g. Geeta 2009; Hinshelwood & McCallum 2001); natural resources management (e.g. Reed *et al.* 2009; Sanginga *et al.* 2006); technology transfer and design (e.g. Leach & Scoones 2006); and decision support (e.g. Eden & Ackermann 1998; Leeuw 2003; Trochim 1989; Vaessen 2006). While a multitude of visual methods and toolkits, the preference goes for "visual devises" like: sketches (Buxton 2007); cognitive maps (Eden & Ackermann 1998); the CAUSE framework (Belton & Stewart 2002); dialog mapping (Conklin 2006).

All this being said, it is important to recall that while visual literacy is considered to be universal (Bradley 1992; Chambers 1994a), visualization does not offer a neutral culture-free language since visual data may have cultural nuances and drawings can have cryptic meanings (Cornwall & Jewkes 1995; Delavande *et al.* 2011; Grenier 1998).

9.4.3 Sense-Making & Dialogue: Beyond Traditional Decision-Making

Broadly sense-making defines the structuring of the unknown, the construction of meaning, or the realisation on individuals construct what they construct, why, and with what affect (e.g. Weick 1995). Conceptually close to social constructivism (Thomas *et al.* 2001), proponents of sense-making emphasise that problem solving and decision making have an irrational and ambiguous nature (Walsham 2001; Weick 1993) and that knowledge is linked to ongoing interaction by individuals within social systems (Cecez-Kecmanovic & Jerram 2002).

Consequently, as a social process, sense-making co-evolve continuously with the sense-maker, its actions and surrounding contexts. Therefore, sense-making depends on time, context, previous experiences and the perception of how others will learn or interact with such knowledge (Weick 1993). Sense-making is also an ongoing activity. Very much like design operates with, and on, artefacts as "quasi-objects" (Jonas 2010) each representing a transient stage of knowledge interaction able to generate new designs, individuals are always making-sense of reality (Winograd & Flores 1986; Orlikowski 2002) dialogically influencing and being influenced by the dynamic unfolding of events. As part of this social interaction, sense-making, is driven by plausible information in a sufficient quantity rather than accuracy (Weick 1993), which justifies the absence of rationality in decision-making.

In collaborative practice, sense-making allows the engagement with knowledge beyond one's own domain, facilities the understanding of the underlying concepts of each

participant's work. Nonaka (1994) lists three instruments that help collaborators in these objectives (after Holzer 2009): Metaphors; Analogies; and Co-Experience. Metaphors reveal hidden tacit knowledge in order to make a standpoint explicit between participants and assist practitioners in intuitively creating a network of concepts to draw future knowledge from existing knowledge. Analogies, on the other hand, harmonise contradictions incorporated in metaphors using rational thinking. Finally co-Experience represents the actual enactment of the conceptual common-ground, based on metaphors and analogies that that can be understood and interpreted by all participants.

Addressing collaborative work in multi-disciplinary design teams, Holzer (2009) emphasises the metaphorical value of visual representations as a powerful medium to convey ideas, interpretations and understandings in a format that could easily be understood by colleagues regardless of professional affiliations. In these collaborative design contexts, to understand the meaning behind the reasoning that has led to a specific design option is crucial (Holzer 2009) and should happen as soon as possible (Achten 2002), which highlights the value of conceptual design as an opportunity for design knowledge integration and share.

Remarkably, the importance of visual metaphors and analogies in the construction of common understanding in participatory design, suggests the importance of meta-levels of abstraction in building sense-making in design. This is one of the main arguments of this research. Instead of base participatory design in closed models implemented in sophisticated software, it seems more productive to rely on simple visual formats to explore and build sense-making with meta-models (§11). The idea is not to facilitate the definitive design, but the meta-design, that is, the conceptual arguments that justify that definitive design. Providing a visualization of an argument, converts that visualization into an interactive platform to build upon, facilitating the making-sense process. In other words, knowledge representation tools support both the dialogical argumentation of the participants and the representation of the argumentation by the individuals as well (van Bruggen & Kirschner 1999).

Design "is choice" (Tufte 2001: 191), comprises a sequence of choices (Buxton 2007), a "conscious decision-making process" (Von Stamm 2008) or a reflective series of judgements (Schön 1983), which end-up incorporated in the designed artefact (Cucuzzella 2011). However, due to the degree of uncertainty, ambiguity and pure ignorance present in the wicked/unstructured design problems (§9.3.5), decision-making cannot rely solely on technocratic approaches (Fiorino 1990) based on analytical or instrumental rationality, i.e., solution based on expert-knowledge and rational selection of means to achieve clear ends (Kruijf 2007; Keen & Morton 1978). Instead, decision-making in wicked problems involve different actors, each embracing different knowledge and seeing the problem differently (Mitroff & Linstone 1993). However, all actors engaged in a constant interactive dialogue between the creative generation of meaningfully distinct options, and the reasoning on those ideas (Buxton 2007; Gray *et al.* 1994; Kruijf 2007; Laseau

1980; Rowe 1987). In this interactive process, dialogue and visual aids are fundamental to support people with different perspectives to understand the meaning behind the reasoning that has led to a specific design option and/or decide among options (§9.4.2).

In fact, collaborative conceptual design is conveyed through dialogue, i.e., is a dialogue process of back and forward refinement between problems setting and decision-making (Buxton 2007). Participation is notably an inherently process of dialogue involving an iterative and two-way learning between participants (Chase *et al.* 2004; Johnson *et al.* 2004; Lynam *et al.* 2007). Visualization is dialogue through images (Chambers 2007). Moreover, all these dialogues are not just between people, or between mental models in peoples' heads, there is a dynamic and continuous dialogue and interactive process between people, contexts, actions and artefacts. As so many time in this §9 it was emphasised, Design is reflexive dialogue between tool, context and practice (Schön 1983). Participation is notably an inherently process of dialogue involving an iterative and two-way learning between participants (Chase *et al.* 2004; Johnson *et al.* 2004; Lynam et al. 2007). Visualization is dialogue through images (Chambers 2007). Moreover, all these dialogues are not just between people, or between mental models in peoples' heads, there is a dynamic and continuous dialogue and interactive process between people, contexts, actions and artefacts.

9.4.4 Conceptualisation & Conceptual Design

The reframing of WES using design thinking (§9.3) defined the conceptual design as the design stage to support. The main reason behind this choice is the fact that both problem structuring methods and design visual tools support conceptual design. However, even without such indication, there are good reasons for consider conceptual design as the most suitable design stage to address.

Starting from more or less loose design criteria, ideas and concept are elaborated, resulting in one or a series of prototypes that will eventually result in the final deliverable of the design process (e.g. a product, service, system), fig. 9.5.

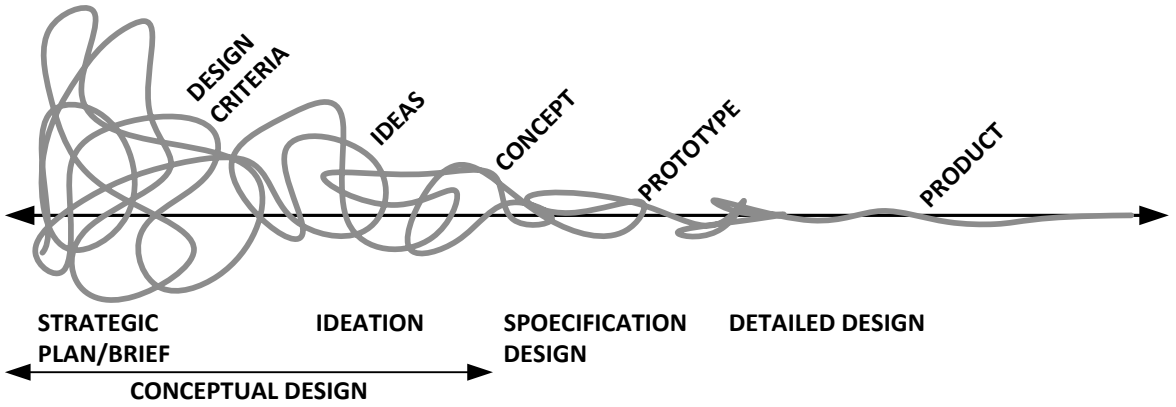


Figure 9.5| A representation of the design process including the main activities and design life cycle till the product (other stages include: Install & Implement, Operation and Decommission & Remediation) [Source: the Author based on Sanders & Stappers (2008) and fig. 9.4]

The design lifecycle progresses through a series of more or less overlapped stages, involving a number of gradually more detailed and technically complex stages until the actual construction of the design and end of life (fig. 9.5). Like with most ESy, in WES design decisions tend to become rather technical after the conceptual design, that is, become the realm of experts.

Since the objective is to include knowledge from the all possible actors in the WES, which in DC include several non-expert, conceptual design emerges as the obvious choice. Conceptual design is an up-front design activity that comprises ideation, generation of concepts, problem formulation/structuring and initial design outcome representations (e.g. Kroll *et al.* 2001; Spellman 2010; Takala 1989). This stage is also called ideation or "fuzzy front end" (Sanders & Stappers 2008) and has a fuzzy nature, due to its ambiguity and chaotic nature. At this stage the final deliverable of the design process (e.g. a product, service, system) is often not known in detail and data and information are very scarce, subjective and/or incomplete. Considerations of many natures come together in this increasingly critical phase, e.g. understanding of users and contexts of use, exploration and selection of technological opportunities. Therefore, the importance of including participation and visual representations/abstractions as design aids at this stage. This fuzzy front end is, therefore, mostly an exploratory which will afterwards serve as a basis to define ideas for the deliverable of the design process, which develop to concepts and then into prototypes that are refined on the basis of the feedback of future users. In this design context, the great advantage of conceptual design is the possibility to accommodate different knowledge through interactive visual ideation, learning, decision-making and problem formulation an early stage, when learning, mistakes, and fixes are the least expensive (Buxton 2007), fig. 9.6A.

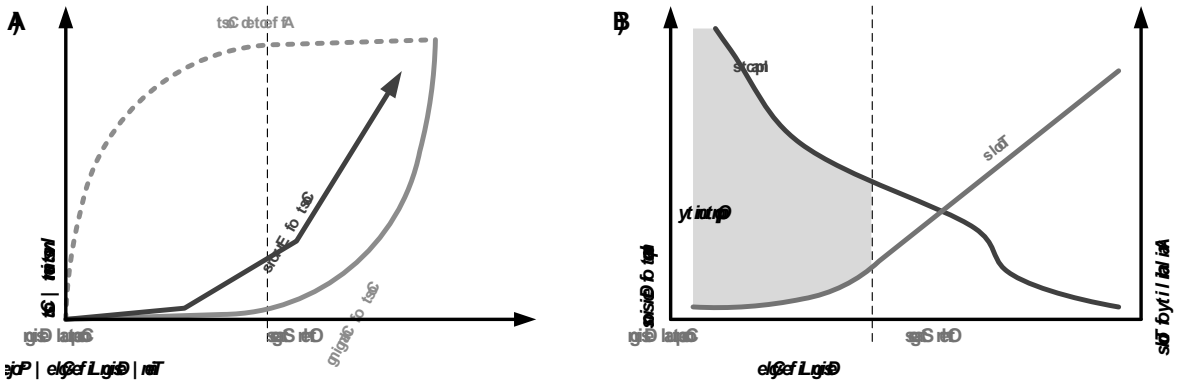


Figure 9.6| A) Variation of cost by design life-cycle stage (Andreasen & Hein 1987) and B) opportunity in conceptual design [the Author Wang *et al.* 2002].

Indeed, results from engineering, quality management and product design show that although representing only a small fraction of the project cost (~5%), the decisions taken in conceptual design have a huge impact in all design costs (85~100%), fig. 9.6A, as well as on the improvement in the process/product performance, producibility, reliability,

maintainability, schedule, costs, environmental performance, time-to-market (e.g. Moody & Shanks 2003; Siirola 1997; Yang & Shi 2000).

Specifications are not so intense and central. Indeed, the conceptual design aim is not the detailed technical specification, but rather the outline form of the final system, a structured representation of the major characteristics, elements and functions of the WES. The idea in the conceptual design is to create an overall view of the WES allowing *exploration* of that WES-to-be prior to actual implementation (see e.g. *Tiensuu 2005*). Afterwards, these elements and views could be taken for more technical and expert driven design and eventually implementation. Thus, conceptual design, offers a unique window of opportunity for people interacting with the WES to include knowledge, ideas, perspectives, cultural experiences, insights and requirements in the design of WES with a minimum cost for, and the highest impact in, final design (e.g. *Andreasen & Hein 1987; Wang et al. 2002*). This *window of opportunity* was thus also used as a space for participatory design.

In resume developing conceptual design tools has the potential to improve design at a minimum cost, while promoting participatory decision making and problem formulation. However, very few design tools exist to explore that window of opportunity and in the field of energy systems design even less (e.g. Holzer 2009; Wang *et al.* 2002).

10 COMPARING APPROACHES AND MODELS

The §9 refocused WES modelling beyond the usual positivist and determinist energy planning and decision making. Such new refocus implied the consideration of new fields of inquire with respective modelling approaches and models. This chapter is set to identify such relevant models or modelling approaches which will be added with the WF models already described in §6.3 (§10.1) to be assessed with design criteria derived from the explorative and critic analysis done in §9.2-4 (§10.1).

10.1 AFTER-REFRAME MODELS & MODELLING APPROACHES

Focusing on the main design specifications derived from §9, the literature was scoped for participatory models and modelling approaches in relevant research fields. Comparatively with the energy models in §6.3 the number and diversity of options is much wider once participatory approaches are considered. However, like with the analysis done for the energy models, (§6.3) instead of focussing in individual models, a classification for *type of approach* or *kind of format* was used to compare a larger set of possibilities. Bellow the results are presented alongside a brief description and some key authors.

Co-design Tools- In these tools are include Sketching and tools to (Sanders *et al.* 2010): make tangible things (including techniques like 2-D collages; 2-D mappings; 3-D mock-ups); Talking, Telling and Explaining (including techniques like storytelling, cards); and Acting, Enacting and Playing (including techniques like role playing, Participatory envisioning and enactment). Sketching is a prototypical physical design technique where simple schematic drawings on paper provide graphic means to store ideas and concepts in a format accessible by others, allowing thus, further comparison, manipulation, and integration of different concepts form different people, allows thus different users to freely and dialogically structure the problem at hands while experiment with different ideas, options and possible solutions (e.g. Buxton 2007).

Soft Systems Methodology- A formal tool from applied systems thinking methodology where participants use drawings, text or combination of both to express concepts and the interaction of parts of a system in complex systems to derive a participatory rich-picture from which fundamental concepts are devised and principles for action are devised and discussed (Annex 2).

Participatory modelling- an umbrella term to define a wide range of techniques, methods and approaches (e.g. Voinov & Bousquet 2010) that use several different tools (see Lynam et aI 2007) to elicit perspectives from participants in different graphic formats (network graphics, drawings, text) which are then used to define parameters and relations between parameters (i.e. conceptual models) implemented in computational formats (mostly on systems dynamics but also agent-based technology) to explore alternatives and simulate different scenarios possibly defined by the participants too. Among the most well know

are: *Group Model Building* (e.g. Andersen *et al.* 1997); *Mediate modelling* (e.g. van den Belt 2004); *Companion Modelling* (e.g. Souchere *et al.* 2010).

Collaborative conceptual design- A participatory simulation process physically enabled by the Internet and Web technologies, and functionally supported by the technologies in the domain of artificial intelligence (agent based technology, knowledge management, knowledge-based systems) which enable different actors to simulate and explore alternative in group (Wang *et al.* 2002).

Networked Graphics- the designation given in this work to the set of tools that explicit in the graphical form of networks of boxes and arches elements and relations that express participant perspectives on a given problem/situations. The boxes could include, e.g., concepts, people, ideas, subjects, items while the arches could imply, e.g., power relations, connections influences and together form a networked map that helps to develop collective decision making, clarify perspectives and/or to explicit the proble structure. These tools include the already mentioned cognitive maps (e.g. Eden & Ackermann 1998); the CAUSE framework (Belton & Stewart 2002); dialog mapping (e.g. Conklin 2006), mind mapping (e.g. Buzan & Buzan 1996).

Participatory & Rapid Appraisal- A family of approaches and methods emerged as an alternative to top–down approaches to development and which enable people to share, enhance and analyze their knowledge to plan and action. These methodologies make use of participatory diagramming, a method of including people in analysing various aspects of community life using large diagrams with locally available materials is based on participatory diagramming with locally available materials (e.g. Chambers 1984a, 1984b).

Integral Assessment- An assessment framework that bridge environmental science and policy combining knowledge, models and themes from a variety of disciplines to support the practical implementation of public participation in sustainable development contexts (e.g. Rotmans & van Asselt 1996).

Multi-Criteria Approaches- Structured frameworks composed by a set of formal methods, mathematical models and explicit criteria designed to structure decision problems, explore trade-offs and ranking alternatives/preferences. Coming in a variety of forms including *Multi-Criteria Decision Analysis/Aid* (§6.3), *Multi-Criteria Decision Making* (Dyson 1980), *Multi-Objective Analysis* (e.g. Keeney & Raiffa 1976), takes into account multiple, possibly conflicting, objectives criteria or attributes using different forms of data and information to assist participatory decision-making through rational, justifiable and explainable decisions (e.g. Belton & Stewart 2002; Bouyssou *et al.* 2006;

Besides the listed tools, it is also possible to combine different tools within the same type or across types. For instance, e.g., Multi-Criteria Decision Analysis could be used in coordination with Group Model Building. There are also a number of clones of these generic families of modelling approaches (Lynam et aI 2007; Tippett et aI 2007; Voinov & Bousquet 2010)

10.2 CRITERIA AND COMPARATIVE ANALYSIS

The comparison of the relevant tools identified in §10.1 will be done using design criteria extracted from the problem analysis (§9) in conjunction with relevant criteria obtained from other relevant reviews on participatory methods in natural resources management (Lynam *et al.* 2007; Tippett *et al.* 2007). The comparative analysis is not intended to be a normative of "goodness" or "efficiency", rather the objective is to visually explore the possibilities of available tools in the arrangement of criteria directly derived from the theoretical and practical critical analysis conducted on the WF reality in DC, notably Mozambique before (§B) and after the resetting using a combination of systems and design thinking (§9). The criteria has been organised around the model/modelling definition provided in §9.1, covering thus: purpose, format and modelling approach.

1| Purpose:

1.1| Support to design and conceptual design:

- Can the tool support WES problem structuring/setting?
- Can the tool inform WES conceptual design decisions?
- Can the tool produce a WES conceptual model?
- Can the too support WES creative design?

1.2| Support to participation, interaction, dialogue and learning:

- Can the tool promote communication or dialogue among participants?
- Can the tool facilitate learning?
- Can the tool allow dynamic, iterative or recursive use?
- Can the tool facilitate any knowledge process (*reuse*, *transfer, representation, creation*)?
- Can any participant (including illiterate people) use it themselves?

1.3| Applicable in DCs

- Has the tool been used in WES design?
- Has the tool been used in DCs?

2| Format

2.1| Have a simple, non computer based visual format

- Is the tool based on simple interactive and visual platforms?
- Is the tool is computer based

3| Modelling Approach

3.1| Tool build in complete participatory approach

- Does the tool involve stakeholders in all modelling stages (*data collection, model definition, model construction, model validation, model use*)?

The result of the application of these criteria to several research papers found during the literature review, including the models described in §6.3 (OEM, OSM, SM) is summarized in tab.3.2

Table 10.1| Visual assessment of relevant tools according with criteria listed above (SSM- Soft Systems Methodology; NG- Networked Graphics; PRA- participatory Rural Appraisal; IA- Integral Assessment; PM- Participatory Modelling; CCD- Collaborative Conceptual Design; MCM- Multi-Criteria Methods; §6.3 Models in §6.3, OEM, OSM & SM). Colour code: ■ Yes; ■ Could be; ☐ No/Not Applicable. [Source: the Author]

MODEL	RELEVANT TOOLS / PROPOSED CRITERIA		Co-Design Tools	SSM	NG	PRA	IA	PM	CCD	MCM	§6.3 MODELS
PURPOSE	1|	Supports problem structuring/setting?	■	■	■	■	■	■	■	■	■
		Informs conceptual design decisions?	■	■	■	☐	☐	■	■	☐	■
		Produces a conceptual model?	■	■	☐	■	☐	☐	■	☐	☐
		Is creative?	■	■	■	■	■	■	■	■	■
	2|	Promote communication or dialogue?	■	■	■	■	■	■	■	■	☐
		Encourages co-learning of skills?	■	■	■	■	☐	☐	■	☐	■
		Allows dynamic, iterative or recursive use?	■	■	■	■	☐	■	■	☐	■
		Allows Knowledge Reuse by users	■	■	■	■	■	■	■	■	☐
		Allows Knowledge Transfer to users	■	■	■	■	☐	■	■	☐	■
		Allows Knowledge Representation by users	■	■	■	■	☐	■	■	☐	☐
		Allows Knowledge Creation by users	■	■	■	■	■	■	■	☐	☐
		Can any participant use it themselves?	■	■	■	■	☐	■	☐	☐	☐
		Used in rural energy systems design?	☐	■	☐	☐	■	☐	☐	☐	■
		Used at rural areas in DCs?	☐	■	☐	■	■	☐	■	■	■
FMT	3|	Use simple interactive visual platforms?	■	■	■	■	☐	☐	■	☐	■
		Is low tech (<u>not</u> computer based)?	■	■	■	■	☐	☐	☐	☐	☐
MODELING	4|	Participant involved in Data Collection	☐	■	☐	■	■	■	■	■	■
		Participant involved in Model Definition	■	■	■	■	■	■	■	■	■
		Participant involved in Model Design	■	■	■	■	☐	■	■	☐	☐
		Participant involved in Model Validation	■	■	■	■	■	■	■	■	■
		Participant involved in Model Use	■	■	■	■	■	■	■	☐	☐

Considering the relative amount of each colour in each set of criteria in tab. 10.1, it is possible to obtain a graphical representation of potential tool gaps for each group of criteria, fig. 10.1. Each slice of the hexagon in fig. 10.1 results from the combination of the three colours used (black, gray, white) to assess the compliance of each tool with the

chosen criteria. Therefore, the highest the percentage of positive replies for a given set of criteria, i.e.; black cells in tab. 10.1, the blacker the equivalent slice in fig. 10.1, indicating thus that most tools comply or observe that set of criteria. Conversely, a high percentage of negative answers (i.e. white cells) indicate the opposite: lack of tools that respect that criteria.

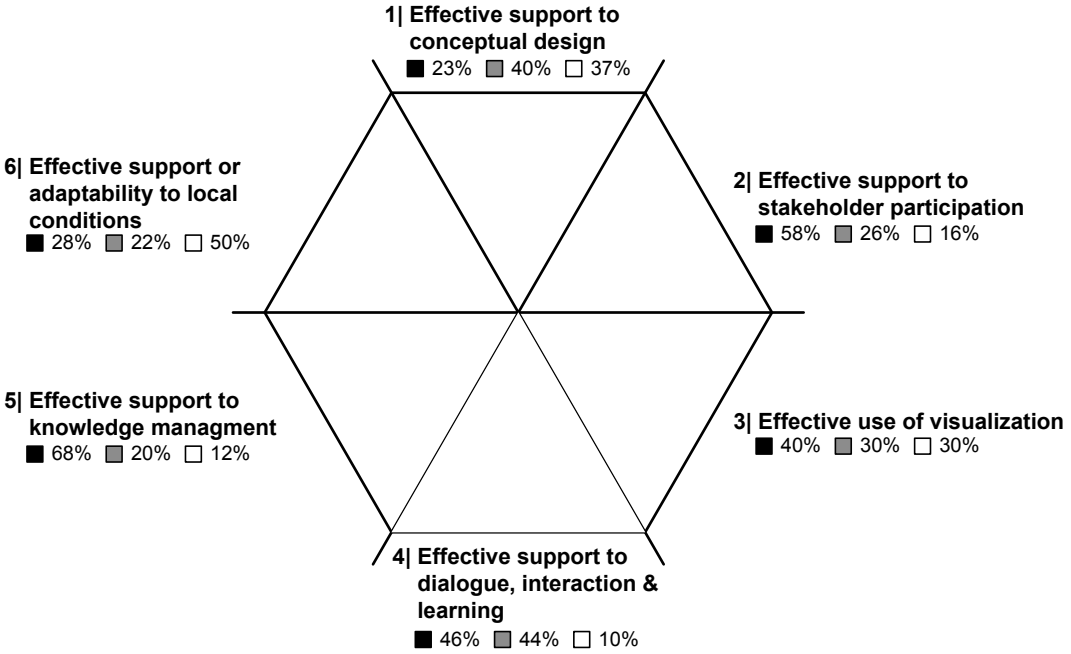


Figure 10.1| Cumulative results of the comparative analysis performed in tab. 10.1. The colours of each slice reflect the combination of colours (black, gray and white) used in tab. 10.1.

A combined analysis of tab. 10.1 and fig. 10.1 reveals that most tools considered as useful to support participatory design of WES are In fact, decision support tools (DST) goal seeking and computer based, or do not cover the entire conceptual design requirements or have never been used in DC and/or energy or WES. Not surprisingly, the §6.3 models also perform rather poorly, which is a clear indication of their deterministic, expert driven nature. Another aspect that emerges from tab. 10.1 is related with nominal participation of stakeholders as data providers or end-of-the-process evaluators. On the other hand, the tools that scored best in tab. 10.1 (higher percentage of black cells) can deal with design without computer support and involve actively stakeholders in interactive and dynamic knowledge management processes, but are not, or at least very rarely, used to design WES (or ESy) in DCs. This mismatch of tools is reinforced by the apparent lack of simple visual tools to support conceptual design of WES in DCs, as can be seen by the lighter slices of the hexagon in fig. 10.1. In resume, there is a lack of design tools based on simple visual interfaces that could support participatory design of ESs in rural areas of DCs.

11 INTRODUCING THE ENERGY SYSTEMS DESIGN METAMODEL

The previous sections presented the argument and characterization of an effective tool to support WES participatory conceptual design in DCs. The present chapter will introduce metamodels as viable formats to support the arguments presented and fulfil the defined useful characteristics. Accordingly this chapter defines metamodel (§11.1) and identify its role, place and potential uses in participatory design (§11.2).

11.1 DEFINING WOOD FUEL ENERGY SYSTEMS DESIGN METAMODEL

Since WES and WES design have been defined (§9), it is important to determine what is meant by metamodel in the context of the present research. A metamodel is an explicit model of the constructs and rules needed to build specific models within a domain of interest (InfoGrid 2011). As a model, a metamodel can be used to graphically illustrate concepts, conditions and constructs and their relations to each other (e.g. Henderson & Venkatraman 1999; Rothenberg 1989). Therefore, a metamodel is a representation of formal knowledge, that is, it is based on a conceptualisation of concepts or constructs that are assumed to exist in some relevant domain and the relationships that hold among them (Genesereth & Nilsson 1987). A conceptualisation is an abstract, simplified, explicit or implicit representation of reality (Gruber 1983).

Another possible term could be ontology, meaning a systematic account of reality and its nature (what can we know?) ontology can also be understood as “an explicit formal specification” of a shared conceptualisation (Gruber 1983; Gruninger & Lee 2002). In a knowledge-based perspective, ontology is a description of the set of concept/terms and relations that can exist in a specific domain (Gruber 1983). Another definition possible for a metamodel with these properties is conceptual framework. A conceptual framework explains the key conditions, main constructs/variables and the presumed relationships among them to be studied within a domain of interest through descriptive and graphical illustrations (Miles & Huberman 1994). Here description refers to “making complicated things understandable by reducing them to their component parts” while explanation means “making complicated things understandable by showing how their component parts fit together according to some rules” (Miles & Huberman, 1994: 90). Therefore, metamodels, ontologies, reference-models and conceptual frameworks share a number of characteristics, namely:

1| They are approaches to help structure, classify, model, and or represent the concepts and relationships pertaining to some subject matter of interest to some community;

2| They are high-level conceptualisations of a domain and can be used to derive models using consistent standards or specifications accepted in that context;

3| They do not providing any testable propositions, only elements that are useful for explaining and/or describe the phenomenon studied;

In resume, all these abstract representations are useful to capture and preserve knowledge that helps users to understand the "essence" of the domain. However, unlike ontologies, reference-models do not allow automated reasoning since they lack the formal semantics and rules basic to ontologies (Infogrid 2011). On the other hand, while a formal ontology can be used to formally describe a particular reference-model and a valid metamodel is an ontology, not all ontologies are modelled explicitly as metamodels. In fact, "a metamodel is an ontology used by modelers" (Infogrid 2011).

The term metamodel was selected based on the research purposes and simplicity. Ontology can be confused with philosophical meaning and requires a high degree of formalism, which may be detrimental to use in practical conditions. Reference-models have lower degree of formalizations, but act much as blueprints, constraining creativity to add and change the model structure. Finally, conceptual-frameworks are also prone to confusion with research theoretical-frameworks. Moreover, metamodel, explicitly includes the modelling activity as "creating models" which is an essential part of participatory design. Thus, here, the ESy design metamodel should be viewed as:

1| A design ontology (an abstract representation of the design logic of biomass ESy in rural areas of DCs) being design logic of the abstract comprehension of the way stakeholders consider energy systems design: "what they consider and how they consider it".

2| A graphical representation of the design logic composed by a set of distinct concepts/constructs and relations used to structure and specify WES for DCs.

3| An intermediate design layer (acting as a sort of glue or translation) between strategic design and operational design (after Osterwalder 2004).

In design terms, a metamodel is a form to deal with complexity (e.g. Becker 2007; Love 2000) since it corresponds to a "step backwards" to focus on the problem rather than the solution, applying a higher level of abstraction in order to perceive the conceptual commonalities between different design perspectives, that is, metamodels (e.g. Voinov & Busquet 2009). This "unravelling" of stakeholders metamodels essentially flattens the hierarchy of the other models, thus freeing the implementer to create his/her own specific, relevant, and informed model (after Becker 2007).

Under these perspectives, the WES design metamodel is not a guarantee for "success" or does not seek to achieve "more efficient design", but rather a tool to support creativity by integrating the design logic that several stakeholder hold on ESy design. Moreover this is not a metamodel of the WES, that is, a meta-representation of the entire system as it is, but the ontological representation of the *conceptual design* of the WES. What the model abstracts is not the set of elements and relations that compose a WES, but the set of design elements and interactions that describe the logic of conceptual design of WES. However, using the metamodel as a design device, conceptual designs of WES (models) could be produced.

11.2 ENERGY SYSTEMS DESIGN METAMODEL ROLE AND PLACE

Derived from the definition established in the previous section it is possible to see WES metamodel as a conceptual link between three elements: design strategy; people; and technology, fig. 11.1. Remarkably, each of these elements expresses a different way to conceptualise WES design and normally are represented by different stakeholders/actors at different stages in the design process. Strategic design is normally undertaken by policy-makers or project-managers that define the direction principles and formulate objectives and goals for WES design. People represent the users or final beneficiaries and all actors involved in WES design life cycle, including communities and intermediaries in the process. Technology is the main perspective of engineers, and probably, social scientists who try to understand and implement strategic design visions in accordance with concrete realities. All these perspectives are meaningful and are carried within a specific socio-ecological system, which imposes a number of external factors influencing design, designing and perspectives, as exemplified in fig. 11.1.

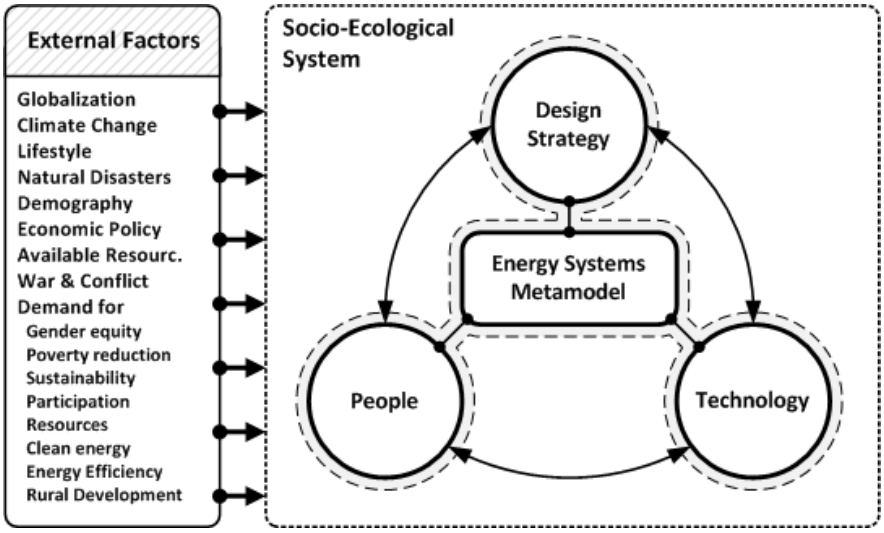


Figure 11.1| Interaction between energy systems metamodel, people, technology, design strategy and socio-ecological systems [Source: the Author].

To have a successful collaboration each participant should "understand, to a certain extent, the social construction of their counterpart collaborator" (Hamid *et al.* 2006: 92) to find common ground by drawing upon a "network of knowledge" (Holzer 2010; Kvan & Kvan 1997). By definition, metamodels provide these capabilities. Focusing on the internal elements, the integrative nature of an WES metamodel is even more evident.

Starting from design strategy as a the definition of a set of design goals, objectives, principles and steps to achieve them (Kaplan & Norton 1996), it is possible to see an ESy metamodel as a strategic design canvas. Providing a set of conceptual constructs that describe the design logic of WES, the WES metamodel can be a translator (a mapping in the geographical sense) of design strategies into specified WES conceptual designs. Likewise, people and social structures are reflected in the metamodel use and definition.

Therefore, the use of the metamodel can motivate debate on the social structure where design is to be implemented and motivate change (design for empowerment) and, conversely, social structures and communities can be reflected in the outcomes of metamodels, i.e.; WES specifications. Finally, while the relation between design and technology is obvious, the relation between a WES conceptual design metamodel and technology could be less obvious. Hence, besides the clear support that the metamodel provides by helping people specify WES or WSF, other roles of the metamodel include the participatory questioning of technological options and perspectives for specific realities.

In line with previous arguments, it is the need to adapt design for socio-ecological conditions and internal logic while learning from previous experiences that calls for knowledge-management support tools in WES design.

12 SUMMARY: THE CASE FOR ENERGY SYSTEMS METAMODELS

ESy are complex mutually embedded social-ecological systems and their conceptual definition/specification is wicked problem, a complex design problem. Involving a network of issues, actors, stakeholder and decision-makers with different, and often contradictory, formulations of the problem, solution and resolution path and methods. This kind problem cannot be solved, or rather; there is no objective rational measure of success accepted by all involved. An important consequence is the dispersion of perspectives and increased commendation and coordination difficulties across disciplinary boundaries along design life-cycle. Isolated in “operational islands” different actors use different “languages” and no consensual translation exist.

To address these problems, a combination of systems thinking and design thinking has been proposed. Systems thinking revisited the concept of WES to identify the need to focus more in the interaction and dynamics, than on the precise definition of elements for modelling purposes. Design thinking highlights the importance of the social nature of design, dialogue and interaction (with objects, practice, context), problem understanding as generators of creative and innovative solutions, in easy to use and operate visual devices. Rather than prescriptive methods, models or rationalist fixes, design thinking endorses creative knowledge construction, wide participation, proper interfaces and careful problem setting. Adding to this, an analysis on the design life-cycle and the specific conditions of DCs, leads to the conclusion that ESy design tools should address: conceptual design where the impact of decision is higher; participatory design where the participant is integrally involved and not a nominal data provider; a non-prescriptive, non-normative space for problem exploration since focusing on the problem allows for wider scope of exploration of the design space; and visual formats considering the absence of sophisticated hardware and software in rural areas.

Departing from the research purpose and perspective, a range of relevant research fields were identified as a possible source of tools (an umbrella for methods, models, approaches and methodologies), tab. 10.1. The range of tools identified were then compared against a sets of criteria defined according with the systemic analysis performed on the research problem (§9). The results show a lack of tools to support non deterministic participatory design of WES. Some tools exist to support non-deterministic design, promoting dialogue and creative interaction, however, these tools are not suitable for WES conceptual design and/or DCs conditions. On the other hand, some tools are very efficient for conceptual design, but are very complex, computer based and seldom offer the opportunity to change their components, and therefore, are very deterministic and limited in terms of learning possibilities and dialogue stimulation. A problem common to most tools is the absence of participant input in the definition of the model itself, that is, a full participation on the modelling process. In particular, participatory modelling is done in specialised software by experts.

The results of the comparative analysis of modelling approaches (§10) combined with the analysis made possible with the combination of systems thinking and design thinking (§9) seems to indicate that a tool to fully address the non-deterministic WES conceptual design should combine the properties of tools that support creative leaning and design with those that offer a more formalised vision of the entire WES. Moreover, more than provide a solution, such design tool should try to provide an environment for informed discussion, problem setting, creative thinking, learning and knowledge exchange. In this context, a metamodel would be more suitable than a predefined model.

The confluence of design thinking with inter-subjective perspectives on KM, suggest that metamodels (§11) presented in simple visual platforms are suitable candidates to support the conceptual design of WES. Metamodels present the ontological constructs and their relationships as a conceptual description of design. Therefore, metamodels are not prescriptive and provide users with an opportunity to interact with the design knowledge of the group in the process of designing. Moreover, conceptual-design, problem setting, sense-making and reflection-in-action are carried typically on the meta-level, and common-ground is easier to produce on a metaphorical level, that is, a meta-level.

Responding to the characteristics of the problematic WES design in DC and the limitation of the available relevant tools to address the nature of that problematic (§4) the present research proposes WES design meta-modelling to encapsulate a set of modular design concepts/constructs that are the logic behind WES design. The metamodel proposed presents a number of potential advantages. As an ontology, i.e.; as an abstract representation of the design logic of WES in DC, a WES design metamodel provides a common language between participants to translate tacit knowledge within participants mental models into explicit knowledge to be used by others. Providing a set of well defined necessary and sufficient set of design elements that describe the logic of WES conceptual design, the metamodel proposed operates as a visual, modular and interactive learning device, in many ways similar to the already mentioned metaphor of the LEGO™ block (§2). This learning device has, moreover, the advantage of being visual, allowing the easy explicitation of knowledge in a formalised manner, that is, the metamodel indicates *what piece of information* to include and *where* to include it. Once made visible, the discourse shifts from abstract to concrete, greatly improving the dialogue, understanding and possibilities of leaning and refinement of ideas. Furthermore, the visual display of the WES design logic in a simple format, allows the grasp of the big picture rapidly without oversimplify the complexity of the WES, providing thus a common ground for discussion and design. Conversely, participants can express their creativity in a structured formalised mode. In conclusion, the proposed metamodel provides a common ground for participatory exploration, learning and knowledge share, facilitating thus more comprehensive problem structuring, more informed decisions and a learning device to foster innovation and creativity. Finally, this WES conceptual design metamodel will be, from now on, defined by the acronym 2MW, for simplicity.

SECTION **D**

CREATING AND TESTING THE 2MW

All these things I think about, I think about
They always come unglued.

Stone Temple Pilots, Song Unglued, Album Purple (1994)

I must create a system,
Or be enslaved by another Man's;
I will not Reason and Compare,
My business is to Create.

William Blake, In: *Jerusalem The Emanation of The Giant Albion* (1804-1820), plate 10, 1. 20

… Where the wood fuel energy system conceptual design metamodel is built and evaluated in the context of Mozambique current Wood Fuel Energy Systems…

13 METHODOLOGY

Having discussed the theoretical challenges of WES design in Mozambique and arguing for metamodels as valuable tools to support leaning, dialogue and sense-making in the WES conceptual design, this chapter describes and discusses the methodology used to build and test the WF energy system conceptual design metamodel (the 2MW) (§11-12). In practical terms, defining the methodology to build and test the 2MW requires the articulation of methods, approaches and processes/practices, coherent with the research paradigm (§2), the 2MW format and purpose (§11), and the socio-ecological context where the 2MW is to be implemented (which includes the researchers and the people participating in the methodological process), fig. 13.1.

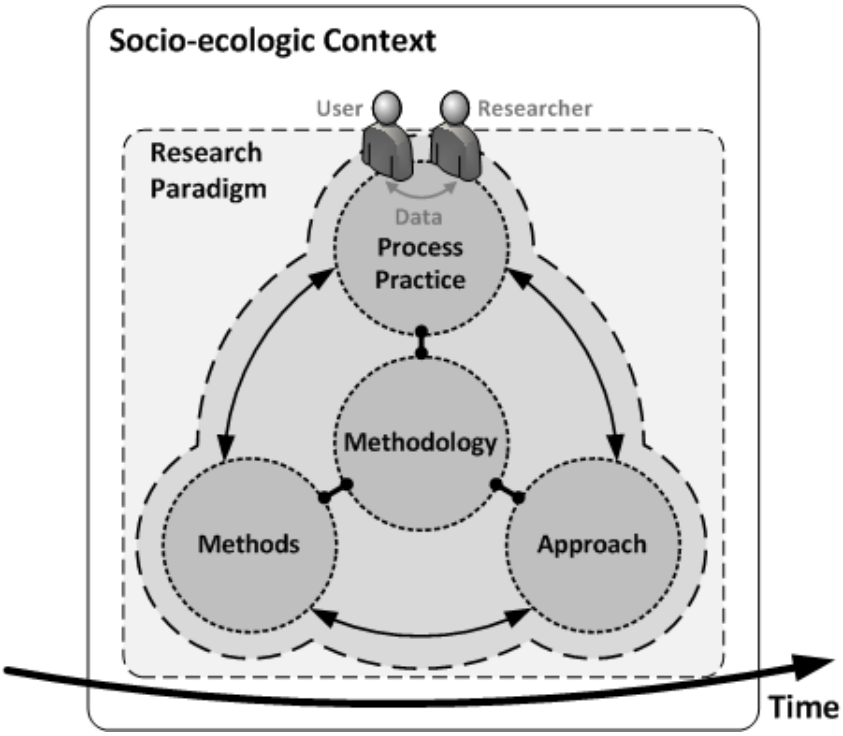


Figure 13.1| The methodology to build and test the WES contextually embedded and involved in of a continuous interaction between methods, approach and process/practice (see also §9.1) [Source: the Author].

As the fig. 13.1 shows, the interaction between the methods, approach and process interacts dynamically with the research paradigm and socio-ecological context. As the result of the enactment (practice of) the methodology, those involved in the methodology and the researcher would generate contextualised data, to be considered by the methods according to the approaches and paradigms selected. Therefore, considering the purpose of the 2MW and format (§11) in the following the research paradigm, implications on the methodology are explained (§13.1), the methodological approach (§13.2) and the socio-ecological context (§13.3) exposed and finally the methodological process with associated methods are described (§13.4).

13.1 RESEARCH PARADIGM INFORMING THE METHODOLOGY

In previous chapters (§2, §9.2), the research paradigm was already exposed as aligned with the emerging alternative ontologies that view humans as part of dynamic dwelt-in world (e.g. Ingold 1996: 42). In this view organisms are not discrete, bounded entities, but the ongoing product of the continuous and dynamic interactions with objects and processes the environment he/she are embedded. This perspective was fundamental to represent the WES as a set of transient and co-evolving systems, defining and being defined by each-other in a continuous mutual embedment (§9.2). This perspective on WES will be instrumental to define the design dimensions (DD) that ultimately will lead to the design elements and thus the 2MW (§14-15). This alternative ontology also posit perception as the active acquisition of information that was inherently available in the environment (Gibson 1950). The information can be seen to exist as affordances, i.e., the opportunities for action which emerge from the unique meeting point between the characteristics of the organism and the characteristics of its environment (de Klerk 2007).

The relationship between the characteristics of the environment and the functional or behavioural capacities of the organism determines what the organism perceives as affordances, and thus an affordance is different for different observers in different environments, since they are products of both the environment and of behaviour. In all perceptions, the organism is actively involved in detecting information ambient in its environment, while simultaneously detecting information regarding itself within the environment. Thus, if meaning is an outcome of the active perception of an organism of its environment and of itself in relation to its environment, then, Gibson (1950) argues, meaning and knowledge should be re-conceptualised as inherently part of an organism's actions, situated in an environment. This alternative ontology from Gibson (1950) is, thus, in line with Schön (1983), which instead of following the analytic-positivistic framework of science where design is seen as a rational problem solving process (Simon 1969), proposes the reflective practice paradigm in design. The reflective practice paradigm refers to Schön's concept of the designer as a reflective practitioner (Schön 1983). The basic assumption of this paradigm is that the ambiguous quality of design problems cannot be addressed by scientific methodology, but with a rather explorative and subject-driven approach (§9.3) that Schön calls "a reflective conversation with the situation" (Schön 1983). Therefore, the situation of a design problem is mainly constituted by user/designer perspectives and the rather tacit human-centred information is a key component of design processes. In other words, the designer is continuously making sense of the design, while doing and reflecting on it through a creative dialogue. It follows that design support tools (like the 2MW) should target the interaction designer/design/context, facilitating the sense-making, dialogue and learning in design. In view of the above, knowledge is a situated practice, and is context specific because it must match with both bio-physical and socio-cultural conditions where people are embedded (Kaufmann 2011). Situated practices are dynamic and change if processes

become inadequate, either due to changes in the environment or to the development of new knowledge (Kaufmann 2011). Therefore, if the objective is to build and test a tool that is "explicit in the form of fundamental design elements what one has to think about when one thinks about WES conceptual design" (the 2MW), it is important to develop a methodology that: explores and understands what fundamental elements people (actors in the WES) think while doing WES design and capture that knowledge in the process of design, i.e., by putting the people in the role of designer in context. This requires:

- A notion that knowledge does not exist as an objective representative of the world and is waiting to be discovered by the human agent (the functionalist/objectivist perspective), neither is knowledge completely dependent on human experience and social practices of knowing (the interpretive/subjective perspective), but conceptualised inherently as part of an organism's actions, situated in (Gibson 1950), and co-evolving (Norgaard 1994) with an environment;
- The notion that the people are actively involved in detecting ambient information in its environment, while simultaneously detecting information regarding itself within the environment (Gibson 1955);
- The assumption that people have adaptive mental models (frames) of information which can be partly elicited through specific techniques and translated/transcribed into conceptual models (Becu *et al.* 2003), i.e., through a synthesis/coding process;
- The argument that individuals belonging to the same group might share the same representation, but their behaviour is driven by personal motivations and tacit knowledge (Dray *et al.* 2006).

These requirements will be put in practice in §13.4.

13.2 METHODOLOGICAL APPROACH

The methodology followed two major approaches: the ontological approach; and the participatory approach. Both these approaches are described.

13.2.1 Ontological Analysis

The main objective of this research (§3), is to build a metamodel of the conceptual design of WF energy systems (WES) in Mozambique, or simply 2MW (§11). The metamodel, 2MW, as theoretically defined here in §11 is a model (§9.1) with the sufficient and necessary set of essential building blocks and relations explicitly represented and defined, which describe the WES conceptual design and thus can be used by designers (users of the 2MW), alone or in group, to describe and define their own WES conceptual design. Because these essential, necessary and sufficient building blocks constitute an explicitly specification of a conceptualisation (the WES conceptual model), they can be said to be the ontological building blocks of WES conceptual design, and the 2MW can be said to be an ontology, (§10.1). Using once more the LEGO™ metaphor, if a WES conceptual designs

were made of LEGO™, each LEGO™ piecestone would be a ontological building block, and with the set of the constituent LEGO™ pieces, stone designer(s) could build (design) their own WES conceptual designs. Thus, those design elements operate as ontological elements, key concepts or building blocks of the domain of interest (the WES conceptual design). Therefore, the purpose of the research can be reframed as the search for these ontological building blocks, i.e., to perform an ontological analysis on the domain of interest for WES conceptual design. This work uses an ontological analysis, i.e., the "process of eliciting and discovering relevant distinctions and relationships bound to the very nature of the entities involved in a certain domain" (Welty & Guarino 2001: 56).

Note that being "ontological" is fundamental, since the research is not looking for just any concept, e.g., to explain an event or describe a theory, but rather is searching "what exists" in a domain (e.g. the domain of WES conceptual design) and what "provides meaning" to that domain. Separating what is essential from what is not implies a process of categorisation which, depends on biological, cultural and perspective factors (e.g. Bertalanffy 1955). Then, the alternative is to inquire directly from the actors implied in the WES design, or those knowledgeable to operate or design all of part of the WES, e.g., charcoal makers, firewood collectors, local governments, rural entrepreneurs of WESs, experts, and NGOs working on WES. Therefore, if knowledge and meaning exist inherently as part of an organism's actions situated in its environment; if people have adaptive mental models (frames) (§13.1) of that reality and their role in it, and if people make sense of design by reflecting on it while doing it, then building an ontology of WES conceptual design corresponds to eliciting the WES conceptual design thinking held by those actors (their mental models) in a hands-on interactive design process. In other words, since it is not possible to have people design thinking projected on a screen in a format understandable by all, a viable way to make available for discussion and analysis that design knowledge is to conduct an interpretive, critical and exploratory ontological analysis with other co-designers and literature, fig. 13.2.

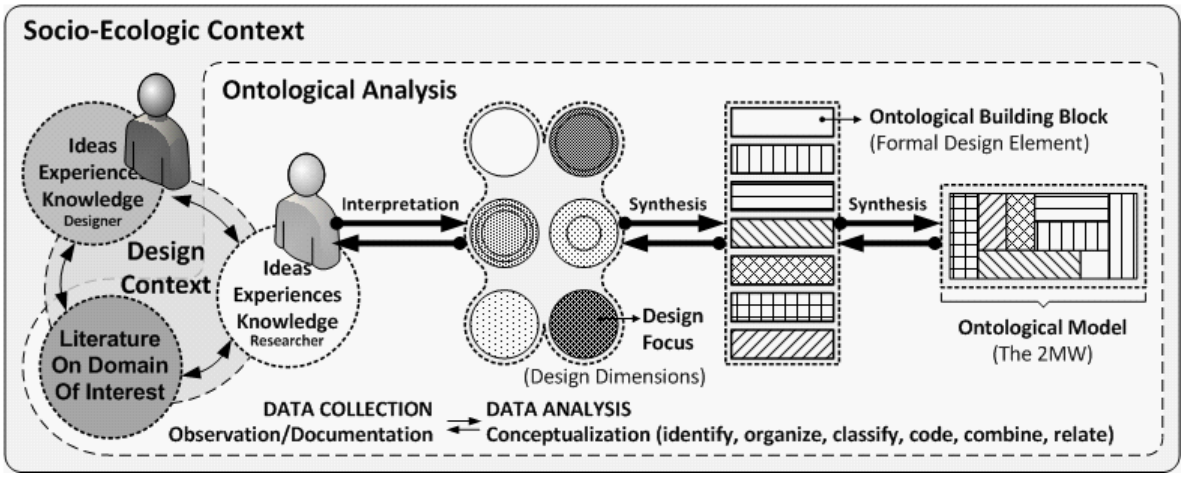


Figure 13.2| Representation of the Ontological Analysis as used in this work, linking design and socio-ecological contexts, possible users of the 2MW as designers, the researcher, synthesis and conceptualisation data is converted into an ontological model (the 2MW) [Source: the Author].

This ontological analysis conducted bears similarities with other data analysis used in a number of different disciplines, including Grounded Theory (Strauss & Corbin 1998), conceptual modelling (e.g. Wang & Rong 2009), Content Analysis (e.g. Cole1988), Analytical Induction (Hicks 1994), Meta Analysis (e.g. Glass 1976), Meta Synthesis (e.g. Walsh & Downe 2005), Information Synthesis (Gumienny *et al.* 2011), Cognitive Maps (e.g. Portugali 1990), Discourse Analysis (e.g. Gee *et al.* 1992), Narrative Analysis (e.g. Coffey & Atkinson 1996; Riessman 1993), and Ethnographic Microanalysis (e.g. Erickson 1992). Ib particular, as already referred in §9.2, this approach also coincides with the first stages of SSM where root definitions are defined (Annex 2). Ontological analysis was selected because it focuses explicitly on ontologies and can be conducted without mathematical formalisms, statistical tools (unlike e.g. meta analysis) or computer support (e.g. grounded theory), which are fundamental advantages to working in groups, or sharing information with other designers who have low, or no, literacy skills living in areas without any form of electricity. Moreover, the ontological analysis configures a design activity, in its reflexive and practical aspects, more than the other possible analysis structured and dependent on informatics, interfaces or statistical analysis.

However, like these data analysis methods, the ontological analyses conducted here tried to make sense of facts and knowledge from the body of evidence, which here is constituted by data from literature, and ideas, experiences and knowledge from actors in the WES in Mozambique (fig. 11.2) collected through interviews, observation in the field and participatory design workshops (§11.4). The purpose was to systematically organise, classify, combine and relate that data and information into the essential building blocks that constituted the 2MW, (the ontological building blocks in fig. 11.2) keeping, simultaneously, the knowledge and the analytical process itself accurate and suitable to address the research questions and goals (§3) while fulfilling the purposes of the evaluation (§11.4). This search for “patterns in evidence” was done in a continuous comparison with each data source (e.g. interviews), and between that data and other sources (e.g. comparing the interviews with data from literature). Far from being a static process, this interpretive exploratory research maintained a continuous cycle of collect/process-analyse-decide/conclude on data and results. Therefore, the ontological analysis truly is neither induction nor deduction, but rather an abductive sense-making design process (Kolko 2010; Patokorpi & Ahvenainen 2009). Through efforts of data manipulation, organisation, pruning, and filtering, the researcher produced coherent design elements (i.e. knowledge) that are used to assign meaning and/or encapsulate complex ideas. In the present research, such encapsulation was done in two stages, first in the main basic DDs, each expressing a “way of looking” at WES design (the DDs in fig. 11.2) and then exploring further those perspectives to identify the ontological building blocks, the design elements in fig. 11.2, from which the 2MW is made.

Finally, the contextual involvement of people while being the central concern and objective of this participatory research (§2), unavoidably involves interpretation of

meanings and contexts (e.g. Nandhakumar & Jones 1997: 111) since people, integrated in a given context, "develop and use their own subjective understandings of themselves, their setting, and their history" (Lee & Baskerville 2003). On the researcher's side, the process of "fracturing" the data to rearrange it into meaningful categories to support the definition of the design elements was not supported by pre-established set of categories to be applied using explicit rules, instead, categories are "derived" from data following interpretive stances from the researcher. However, the involvement of as many actors as possible also granted a shared ownership of the analysis process, increased the researcher's confidence in the accuracy of some of his interpretations and provided many sources of confirmation from a wide range of perspectives in the conclusions reached. However, if this "interpretation of interpretations" conducts to the insights that enrich the conclusions, they also pose important issues and limitations (§16). Hence, in the absence of a "single interpretive truth" to guide the qualitative interpretive research (Denzin & Lincoln 1994: 481), the confidence, rigour, and thus, the validity of data analysis was seriously considered (§11.5).

In resume the ontological approach emerges as the result of the nature of design, knowledge and metamodel perspectives considered there. Conversely, conceptual analysis links row data and design elements in a coherent and clear way, since the design elements were designed straight from data with the support of the interviewees as co-designers.

13.2.2 Involving Other Participants In Design

To guarantee internal coherency, between the purpose and the actual design of the 2MW, an effort was done to include other participants in the conception of the 2MW. Therefore, considering the purpose of this research of developing a model to support participatory conceptual design, best practices for participatory modelling were used (Hare 2011: Reed 2008; Voinov & Busquet 2009). As a result, while the compiling and final analysis of interviews and relevant literature was done by the author, the tool layout emerged from the insights, inputs and knowledge provided and shared by the several co-designers involved in the interviews and participatory workshops. In the following each of the best practices followed is related with the modelling or model.

Participatory Modelling Purpose. The participatory purpose in the modelling is the promotion of learning and dialogue. The idea is to provide participants with a platform to jointly share perspectives, develop collective problem-solving skills (Barreteau *et al.* 2010) and, probably, generate more creative solutions through reflective and informed deliberation (Fritsch & Newig 2009). These learning effects of through modelling have been identified as "clarify arguments" and "design and recommend" (Bots & van Daalen 2008) and/or "co-learning" and "co-management" (Lynam *et al.* 2007). Indeed, successful learning might not directly influence decision-making (Squires & Renn 2011), but could be a major outcome of the participatory design activity (Buxton 2007).

Model Type. The outcome of this research is not computational simulation model of a system which allows the user to simulate system behaviour. Rather the outcome is a metamodel, that is, a model that qualitatively describes the design logic behind energy systems design based on how local people and experts conceive those systems (§11). Regarding the role of the model, again in accordance with previous analysis, the mode will support designers/users deliberations, discussions and communication making explicit designers/users perspectives to others. Regarding such explicit representation, the 2MW was designed to fit the context of those who designed it and the reality of Mozambique. Therefore, the tool was conceived to have a simple, modular, visual and non-computer format. In specific, this would be a paper-based ontological representation of the WES, i.e., a layout showing the essential design elements arranged like boxes, each with a name and few suggestive questions on a piece of paper. The questions do not tell what to do, or what is expected to do, but define a field of meaning and concerns to be explored jointly by the users. Users them fill those boxes, and while composing, describe and specify their WES design.

Modelling Process Stages and Participatory Methods. Since the tool is derived from the conceptual design that actors hold in their heads, each stage of the 2MW design was done with the several participants in the research. Exception to this general rule was the research on literature, done entirely by the Author In practical terms, the participation of the actors/users was done through design interviews and participatory design workshops, where a design challenge was always posed (§13.4).

Participation Mode. Participants were involved as individuals and as part of a group, which were defined to have the highest possible degree of heterogeneous interests (§13.4).

13.3 SOCIO-ECOLOGICAL CONTEXT

The socio-ecological context was considered in two dimensions in the context of the research methodology: the participants; and the settings.

13.3.1 The Settings

The metamodel 2MW intends to support the participatory conceptual design of WES which, as seen in §5, unfolds from the country side to urban and peri-urban areas in Mozambique and most DCs in Africa. Moreover, the metamodel 2MW intends to support the participatory conceptual design of WES across different background, skills, and perspectives in relation with the WES design. In particular, there was the assumption (later confirmed, Annex 5E-I) that rural areas in Mozambique hide an untapped human potential in WES design. The combination of these factors resulted in the selection of three rural areas in Maputo Province and the city of Maputo as the researched settings.

Maputo City was selected because it is the major charcoal and firewood hub and consumption centre in the centre and south of Mozambique and, nationally, is only second to the City of Nampula. Moreover, Maputo is the place of residence and work of most experts (e.g. NGOs, academics, researchers, consultants, government officials) in the WES in Mozambique. The rural areas offered a wider range of choices, which forced a selection, and thus the definition of criteria. Therefore, three criteria were defined for the selection of the rural sites for research in Mozambique:

1| Be, or have been a major area of charcoal and/or firewood production. This criterion is clearly necessary to increase the possibilities of finding experienced charcoal makers or firewood collectors with relevant experience and knowledge in WES;

2| The degree of legitimate and effective local/traditional power. Several researchers working in Mozambique on natural resources (Bergstrand 2003; Cau 2004; Haaland 2008) relate the political power and social legitimacy of traditional leaders with the enforcement (or not) of the traditional practices on natural resources with impact on the WES. Moreover, areas with respected and endorsed leaders would be easier to research due to the power of assembly that such leaders facilitate;

3| The degree of electrification. The degree or electrification was set to accommodate the eventuality that WES actors could have their design affected due to the use or access to electricity. In this end, this proved to have no sensible effect on the design

Based on these three criteria three sites have been identified in the Maputo Province for research, tab. 13.1:

Table 13.1| Rural areas defined for the research according to the several criteria identified for selection [Source: the Author].

AREA	ZONE	WF		ELECTRICITY[1]	STRONG LOCAL AUTHORITY?
		CHARCOAL	FIREWOOD		
GOBA	**Goba Estação**	Not Much[2]	Yes	55~70%	No
SANTACA	**Tinonganine**	Yes	Yes	~50%	Very Much
	Djabula	Yes	Yes	~0%	Very Much
INHACA	**Ribjene**	No	No	100%	Yes
	Nhankene	Yes	Yes	80%	Yes
	Ingwane	No	Yes	80%	Yes

NOTES- 1- Information from the local Electricity branches of the EdM (Electricidade de Moçambique) the national utility provider; **2-** It used to be a major producer, but the trees are gone and banana farming is the employer of most inhabitants.

The tab. 13.1 shows that the case studies provide a good range of variability of criteria across possible options. From former great producers of charcoal with low local authority power to exclusive producer of firewood with strong local authority to good producer of charcoal with very strong local authority; several cases are presented.

13.3.2 THE PARTICIPANTS

The definition of the participants is a crucial aspect of participatory design and modelling (e.g. Hare 2011; Reed *et al.* 2009). Therefore, a particular care was taken in the selection and involvement of participants in the design and testing of the 2MW in order to grant:

- A wide, inclusive and pluralist set of perspectives, roles, knowledge, frames of meaning, interests on the WES (after Achterkamp & Vos 2008) to build a rich picture of the WES in Mozambique (after Berkes 1999; Olsson et aI 2004; Reed *et al.* 2009; Woodhill & Röling 1998), and to do data triangulation (Saunders *et al.* 2003: 260);
- Enhance the participation, design richness and possibilities for learning and creative design (after Loevinsohn *et al.* 2002; Reed *et al.* 2009).

To achieve these objectives, a three stage participant engagement strategy was conceived for this research, which included (after Miles & Huberman 1994: 28-29; Patton 2002):

1| The definition of criteria to identify the participants;
2| Definition of a sampling process;
3| Definition of a sufficiency and quality principle to stop the sampling.

Criteria to identify the participants. A Participant was considered a knowledge actor in the WES, and thus a potential participant in the research. Any individual that fulfilled at least one of the two criteria:

- Be knowledgeable in charcoal, firewood, WES, and/or bioenergy in Mozambique, East Africa, Africa or DCs;
- Be affected by and/or influence any stage of the WES in Mozambique.

Sampling process. The sampling process was different in the urban and rural areas due to marked differences in social structures and organisation. Therefore, in urban settings, a snowball sampling was implemented (Miles & Huberman 1994: 28). Starting from news, scientific papers and conference participation lists, authors or organisations involved with any of the two criteria defined above were identified. Through communication with people on that small list (the number of published papers is low), other knowledgeable people were identified. The snowball sampling effectively reduced the number of interviews or contacts (virtually all those contacted through a previous contact were available, sometimes more than once, and when not, that was due to schedule or geographical impediments) and was particularly suitable for the case of Mozambique, where the number of experts is relatively small and practically all live and work in Maputo (see Mayoux 2007). To avoid the possibility that snowball sampling could limit the researcher to acquaintances and social networks of the initial interviewee (Palys 2003; Reed *et al.* 2009), thus discriminating and/or influencing viewpoints of the interviewees, a number of measures were taken. Alongside the request for a new contacts, requests were also made for possible individuals that hold completely different opinions, disagreements or were well known for their controversial opinion on WF issues (after

Cuppen *et al.* 2010; Miles & Huberman 1994: 29). Moreover the search for experts and other actors aimed for pluralism without overlapping roles and balancing the relative amount of actors from different perspectives and roles. The sampling process terminated once there were no more experts or professional working in the area of WES to be identified. Beside in the city of Maputo, the snowball process was used to identify and interview experts living outside Mozambique. In this case, the contact was done by email after expert's referral or as the result of literature review.

In rural areas, the snowball was not practicable due to language barriers, lack of contact points and the existence of an institutional protocol to conduct research in rural areas of Mozambique. The protocol consisted in informing the local authorities, the Régulo and/or the Official Authority, regarding the purpose of the research and the kind of participants that could be interested in the research. The local leader or the local government official would then invite, inform or request possible interested to be present in a designated place. In Santaca, over 25 persons went to Tinonganine to be interviewed in a 5 hours period, in Djabula around 45 persons assembled at the traditional leader house, but only 16 were interviewed due to time constraints and clear power issues (all the respondents followed the most relevant person in the group). In Goba, due to rather limited local traditional influence, the interviews were carried almost door by door. In Inhaca, due to the dimensions of the island lack of local institutional coordination (involving the traditional, the official and the national reserve administration) there was a mix of group interviews facilitated by the intervention of the local Leader, individual interviews facilitated by the acquaintances of the guide/translator and also indication of local people interviewed (a micro snowball). In total 131 persons have been, tab. 13.2.

Table 13.2| The Interviewed co-designers, divided by occupation and origin (Auth.- Authority; Urb.- Urban) [Source: the Author].

SETTING	AREA	ZONE	ACADEMICS	GOVERNMENT OFFICIALS	CONSULTERS	INTERNATIONAL AGENCIES	CIVIL SOCIETY NGO	BAKERS	LOCAL GOVERNMENT	LOCAL AUTH.	CHARCOAL MAKER	FIREWOOD COLLECTOR.
URB.	**Maputo**	**City**	11	6	7	3	2					
		Other	3		3		1					
RURAL	**Inhaca**	**Ribjene**					1	2	2			3
		Nhankene					1	2		1		11
		Ingwane					1	2		1	1	9
	Santaca	**Tinonganine**								1	23	
		Djabula								1	15	
	Goba	**Estação**					6		2	2	8	
		TOTALS	**14**	**6**	**10**	**3**	**12**	**6**	**4**	**6**	**47**	**23**

As tab. 11.2 shows, a total of 131 persons have been interviewed (95 in rural settings and 36 in urban settings), with three great groups dominating, the experts (36), charcoal makers (47) and firewood collectors (23). Nevertheless, government officials, both technical (6) and administrative at the local level (4) are also well represented. All the local chiefs were interviewed (6) as well as several NGOs members and civil society organisations dealing with charcoal at the local level (a total of 12 people). These 12 people were involved in rural area with commissions, associations and activity groups in relation with WES or with natural resources management. As for the experts, the majority were from the forestry sector (11 in 36) and the remainder were scattered along other disciplines like biology, physics, economics, anthropology, environmental management, sociology and journalism/activism.

13.4 METHODOLOGICAL PROCESS

The methodological process sums up and integrates in practice the previous aspects (§13.1-3) of the methodology. However, before describing the process it is relevant to explain the path followed, from data to DDs and from DD to design elements and finally the 2MW. In practical terms, the direct and obvious way to produce an ontology, such as the metamodel 2MW, would be to scope the domain of the interest, i.e., WES conceptual design, in order to identify the set of design elements that describe, make explicit the conceptualisation of that domain. This method is prescribed in ontological analysis (Ushold & King 1995) and used in practice in related research (Osterwalder 2004). However, such specific domain is nonexistent. Research on WES design is quite scattered (§B-C). The option followed, thus, was to identify the possible DDs on WES, to build a rich picture of the domain by enumerating specific representations of the WES. The DD, while composing an interesting analytical framework of the WES conceptual design did not provide the level of detail necessary to be useful for the conceptual design of WES. However, the DDs provided a valuable platform to further analyse the WES in Mozambique. The result of that further ontological analysis was the thirteen design elements that constitute the 2MW tested in real settings in Mozambique.

The methodological process used in this research rests upon three interlinked research activities, data collection, data analysis, and testing, to assist two research stages, the design of the 2MW and the testing of the 2MW. Like the methodological approach already exposed (§13.2), being that this research is interpretative and supported in reflexive co-design, the dialogue between data, the research, the participant and the knowledge produced is dynamic and constant in both research moments. As such, data analysis, data collection and testing are not closed and sequential methodological spaces, but rather flexible components of the overall research strategy. Likewise, the design stage also tests assumptions in successive refinements, and the testing is also an opportunity to design. However, to keep some simplicity, the methodological process was organised around the two research stages, design and testing. The design stage encapsulates the

data collection and data analysis to produce the 2MW prototype tested in the design stage. Each stage uses different research methods suitable for the purpose of the research stage and activity in accordance with the research approach, local socio-ecological context and paradigm, as it is explained in the following.

13.4.1 The Design Stage

Data Collection- Semi-Structured Interviews

The design stage interweaves data collection with data analysis to produce the version of the 2MW tested in the subsequent testing stage. Therefore, both in urban and rural settings, semi-structure interviews were carried out in design contexts to elicit design knowledge on the WES from several participants in the design interviews. Semi-structured interviews are particularly suitable to elicit knowledge (Mulugetta *et al.* 2005) since their open-ended questions provide the due flexibility for respondents to express their views on WES design in their own words, allowing thus the exploration of the answers to build, with the interviewee, a more explicit image of his/hers WES design. In particular, following the search approach it was important to create a design context for the interviewee to explore, i.e., the idea was to simulate a design experience, and retrieve from the process the clues of "what" the interviewee considered (conceptualised, thought) while doing conceptual design of an hypothetical WES. Considering the differences between rural and urban settings, the strategy used was different.

With experts in Maputo, the semi-structured interviews were all personal and conducted in Portuguese (a language native or almost native for all interviewees and for the researcher), except for the eight international experts, with which the interview was conducted in English over Skype™ or email sometimes (see Annex 4). The design context was developed in three moments of the interview

In the first moment, the interviewee was asked to indicate which generic dimensions they could associate with WES, in one of the following ways:

"What dimensions do you think could be conceived regarding the WF situation in Mozambique (or other country where the expert has experience)?"
"What viewpoints are possible to address the WF research?"
"When you think about the WF situation, what dimensions can you identify?"

In the second moment, the expert was challenged to engage in an imaginary design exercise where the interviewee would have to lead a task force to address the design of a perfect WES. The interviewee should then elaborate on the following questions:

"What would be the main focus of the task force?"
"Who would you invite for that task force?", and finally
"What for? Why would you invite such a person to your task force?"

In the third moment, the expert was asked to return to reality again, to answer two more questions:

"From your experience, what real life barriers, problems, difficulties, and opposition would exist if you were to implement the ideal WES?"

"What would you do, considering the present reality, to overcome those difficulties?"

This set of question, carefully designed and adjusted to each expert field of expertise or experience, and deployed in the right time of the interview were very effective in identifying the main concerns, perspectives and thinking process (design logic and process) that each expert used in its WES design. In other words, seeing the expert interacting with imagination and reality provided a window for his ontology of the WES. Moreover, the questions allowed a crisscross of information to reinforce or clarify questions of ontology and epistemology, very much like a design cross check or a triangulation of data. Simultaneously, the interviewee was introduced to the co-design of DDs (§14.1.2) and the actual 2MW.

In rural areas, while individual interviews were preferable, and April-July was selected for the lower incidence of farming (it is Winter), around 50% of the interviews in rural areas where done in groups of two to five persons because of the presence of some winter farming and practical difficulties associated with administrative and assembly procedures . Moreover, the design context was markedly different from the interviews with the experts. Instead of creating an imaginary design challenge, a stage where experts might feel comfortable, the option was to use something more familiar and close to the rural interviewee. Therefore, the interview was still semi-structured, but the technique used was storytelling about WF production. Storytelling is also a useful knowledge elicitation technique used in a number of fields (e.g. Alvarez 2002). Therefore, in rural areas the interviewees were invited to describe their interaction with the WES in different ways, depending on the literacy level, and their interaction with the WES using the story of their "thinking and undertaking of WF related activities." For instance, while charcoal makers were asked to describe the charcoal making process as a story of a typical charcoal making day, local authorities, particularly the official ones, were asked about WES in informal terms, very similar to those used with experts. Story telling is a common tradition in Mozambique, so people could feel comfortable to expose their daily life. Through this description, it was possible to perceive which DDs or aspects each interviewee or group of interviewees consider while interacting with the WES. To further confirm and/or identify extra DDs, an assessment of energy use, consumption and expectations was done. The interviewees were asked to describe the benefits and problems with the energy technology/sources they used and they desired to use. Once the desire to change, as well as the benefits/problems posed by new energy technologies/sources were identified, a transition barrier question was asked:

"What prevent you to change to electricity (gas)?"

"If electricity (gas) is so good, why don't you change?"

Despite the differences, both in group interviews in rural areas, and in individualised interviews in the city, the purpose of the interviews was always the same: elicit the thinking logic that people employ in WES conceptual design, in order to "extract" what people use as essential design building blocks. This elicitation of knowledge was done in a design context and with mechanisms to cross information to further specify, clarify, or reinforce the WES design as done by the interviewees.

Data Analysis- Operationalise the Ontological Analysis

The data analysis was carried mostly through an ontological analysis (§13.2) but also using comparative analysis with similar results or approaches, using as many as possible quantifications. In more practical terms, the data analysis was included three phases:

Phase one explored the data available. This included the data from the literature review and the data produced in the fieldwork. The data from literature review was embodied in the representation of the WES generated in this research (fig. 9.2-3), which was used as the systems view on WF design existing in the literature reviewed. To this data was also added literature on barriers to the success/failure (e.g. in diffusion, implementation of technology) of biomass systems, bioenergy initiatives or WES in Africa and DCs, as a proxy for the main perspectives held by evaluators on the WES and similar systems in similar contexts. The data is available in the field notes, and when possible recordings were also taken to extract the design perspectives from the interviewees. Both sets of data were analysed and compared over and over again for the content that strives to answer some questions regarding the following themes: what are the main perspectives and conceptual DDs that reflect basic issues in the WES. From this phase, DDs were derived, each expressing an "individualised" view point on the WES conceptual design (§9.4.4). Still in this phase, and in order to assert the comprehensiveness of the framework composed by the DDs, an extensive comparative analysis was done with other similar approaches (e.g. the capitals frameworks).

Phase two, searched deeper and further into those DDs by trying to reduce the conceptual granularity by increasing the level of ontological detail. This was done by searching and identifying patterns within the results of the first phase, and assembling them according to categories of meaning.

Phase three, synthesised those categories with similar meanings and themes and created independent basic concepts with distinctive meanings and representations of close ideas, perspectives and views. These are the design elements, the essential ontological building blocks that describe the WES conceptual design. Again, it is important to mention that the mechanism of concept-making is an iterative, interactive and interpretative process, using abductive mechanisms to identify, verify, confirm or qualify the design element. The last part of this phase implied the organisation of the design elements in an easy to use layout, which constitutes the 2MW visual format used in the participatory deign workshops and in the testing stage.

These phases emulate with some degree of liberty, the coding process of much of the data analysis methods mentioned as similar to the ontological analysis in §13.2.1, including the knowledge coding (or what in grounded theory would be pre-coding, open coding, consolidate coding and axial coding), and knowledge synthesis/integration (Strauss & Corbin 1998; UNDP 2009: 179). Therefore, all these phases relied to a great extent on the interpretation capabilities of the researcher since a general description of a process available in the WES representation, relevant literature and peoples' speech had to be translated into a set of categories (DDs first and design elements in the end) as defined by the researcher as coherence and consistent with the available data. Each part had to make sense within the whole, and the whole had to make sense on its own. The result was sixteen design elements grouped in an easy-to-navigate visual platform, the 2MW. These sixteen the turned into thirteen after the testing stage, which reminds one that testing can also mean design.

13.4.2 The Testing/Evaluation Stage

The nature of the design tool developed puts some difficulties in the definition of testing processes. The 2MW is a metamodel and, as such, it is not mathematical defined, does not prescribe a solution, neither does it define an optimisation of a process, therefore, it is difficult to set up a "static standard" of comparison, which by the views of the post-normal do not really exist as objective, neutral entities (Funtowicz & Ravetz 1993). In the simplest terms, the 2MW is a success, that is, fulfils its purpose, as long as it makes sense for the people using it, produces surprise, meaning the sensation of realising that something so simple actually makes sense. Therefore, the testing is done under a view of suitability for the users and learning and always in a design perspective, i.e., considering the 2MW a design support tool that is, in itself, as design artefact suitable to be improved on or changed by those using it. Still, the quality of 2MW in use, the ultimate test of practice, should be defined in some way. Therefore, in the present study, testing is the process of determining how well the 2MW performs according to a suitable set of criteria in a logic of reflexion, participation and learning aiming the improvement of research results. To fulfil this task, a set of evaluation criteria and methods were defined.

Evaluation Criteria & Strategies

The ambition with the 2MW is that it should be of relevance from both a practical and conceptual point of view. Practical relevance is here referring to the usefulness of the 2MW to be "worked on" and used in several different context, particularly, contexts marked by low literacy levels, different paradigms and world views and, lack of supporting structures (e.g. electricity). Conceptual relevance is related with the capacity of the 2MW actually to support the participatory description and specification of WES in a simple and comprehensive way, generating in the process, dialogue and learning dynamics. To address these dimensions and objectives of evolution three criteria have been identified from the literature as relevant to evaluate the 2MW:

1| *Workability*- concerns the useful support the 2MW provided in a specific situation for the conceptual design of a particular WES (after Nilsson 1995). These capabilities of the 2MW were tested in real setting both in terms of outputs, the actual precipitated descriptions of WES conceptual design, and by the participants themselves

2| *Realisation*- refers to how much and how well can the 2MW be operationalised. In this thesis, the 2MW realisation was assessed according to its ability to be used and operationalised in seven practical participatory design workshops.

3| *Logical Structure*- includes the consistency, comprehensiveness, parsimony and flexibility of the 2MW. Consistency refers to the logic among different parts of the 2MW and the absence of contradictions. Comprehensiveness defines how well the 2MW covers the design aspects necessary to perform WES conceptual design, i.e., no necessary design element was forgotten. The parsimony (or stringency) is achieved when the 2MW only describes what is should describe, i.e., the design elements in the 2MW are sufficient and without redundant parts. Flexibility includes the possibility to add or adjust parts of 2MW, which is actually implied in the modular nature of the 2MW.

Knowing the evaluation dimensions, it is possible to define the strategies and methods that will operationalise the evaluation. Adapting common evaluation strategies from the literature to this specific research conditions, three evaluation strategies were selected:

1| Rating With Criteria. As part of the workshop evaluation, the participants evaluated the 2MW in the above criteria individually and anonymously using a five-point scale to allow a sufficient granularity around a midpoint (Hunter & Beck 2000). The use of qualifications was further applied to quantify the difference in terms of design elements covered and described without the 2MW during the design stage and with the 2MW during the testing stage at the workshops;

2| Evaluation by Use. The hands-on evaluation of the design tool, where participants actually used the tool to address a design problem, explored the process the functionalities, qualities, usability and workability of the 2MW.

3| Evaluation by Observation. The quality of participatory process was evaluated by the researcher in terms of number and enthusiasm of interventions during the workshops.

Participatory Design Workshops

The testing of the 2MW was performed through seven participatory design workshops (PDW) in rural and urban settings. In the rural setting, five design workshop were conducted in two different localities each with its own WES: in Santaca two PDWs were conducted with charcoal makers; and in Inhaca three PDWs where conducted with groups composed essentially of firewood collectors, but including also some bakers and local authorities. In the urban setting, two design workshops were conducted both involving a mix of experts on WES, consultants, project managers and academia staff. Being that the

2MW has been the interpretative work of the researcher in coordination and close collaboration with all the participants, co-designers, the realisation of a design space where those co-designers could use and rate the 2MW was a logical step both in methodological terms and participatory framework. Moreover, it is in the real-world experiment that results come to fruition ("Mise en Valeur"). It is the "experimental implementation" (Daele & Krohn 1998) that enables learning and testing processes. On one side, observations can perceive the use and reaction to the tools. On the other hand, surprises might appear, serving as an indication that the tool actually provoked unexpected impacts, i.e., challenged the assumptions, models and explanations developed by the users, "forcing" the review or use of prior knowledge to explore the design elements he/she did not know they did not know, or never related with the WES conceptual design. In either case, knowledge is created, used and transferred, i.e., learning happens. In resume the participatory design workshop tested the ability of the 2MW to:

- Promote collective creativity, learning and knowledge sharing across different conceptualisations on WES in Mozambique;
- Facilitate the integration of different knowledge bases in the form of a congruent WES conceptual specification meaningful to all participants.
- Provide benefits for participants, as enhanced creativity, new perspectives, useful information and new contacts.

Notably, the testing of the 2MW in rural setting with rural actors of the WES in Mozambique poses challenges different from those felt in the participatory design workshops with experts in Maputo City. In rural Mozambique, the literacy level is low, Portuguese (the native language of the author and most experts in Maputo) is not the common language so, communications are more complicated to establish (less network, less access to devices). The protocol and the setting of meetings were strongly dependent on the institutional contexts. However, and despite all these differences, the overall assessment and modelling objectives continue to be the same, and have been achieved rather successfully.

13.5 VALIDATION

Validity is defined as "correctness or credibility" of accounts (Maxwell 2005: 105) which are relative concepts contextually determined (Spaapen *et al.* 2007). Validation is, thus, a goal achieved by the identification and ruling out of validity threats, i.e., the contextual construction of evidence (Maxwell 2005: 4, 105; Campbell 1988; Putnam 1990; Törner 2003: 11). As a result, methods, procedures or principles, by themselves, do not guarantee validity, but are instrumental in the process of ruling out validity threats and increasing the credibility of results and outcomes (Maxwell 2005: 109; Brinberg & McGrath 1985: 13).

As mentioned in so many points in this chapter, the 2MW was built through an interpretative process involving many actors and perspectives. This characteristic of the 2MW might raise concerns over the validity of the results and, ultimately, over the quality of the research. Therefore, a particular care was taken to increase the validity of the results. Below the strategies and actions suggested in the literature and adapted to this research to increase the results' validity are presented.

Quantification And Quasi-Statistics- every time that it was possible, numbers and quantification have been used to generate meaning, and build evidence, facilitate data visualisation and verification (after Milles & Huberman 1994: 253-254). In particular, every time a new conceptual construct was identified, the DD or the design elements, there was a concern to compare those constructs with other similar tools using quantifications and graphics depicting the degree of conceptual overlapping. The same strategy was used to compare the design performance, in terms of design elements considered and described, before and after the implementation of the 2MW.

Checking For Representativeness- Sampling was taken very seriously, trying to avoid non-representative informants; generalising from non-representative events or activities; and drawing inferences from non-representative processes (after Miles & Huberman 1994: 263-264). In this research, the interviews that were not so productive and some promising leads that proved to be rather disappointing, were not included in the results. In this research, the option to reduce bias and increase validity was to apply the snowball sampling. Sampling was conceived to be a purposeful, but simultaneously random process where there was a constant and systematic analysis of actors and knowledge gathered, as well as, a purposeful search for contrasting opinions and perceptions (negative, extreme, countervailing). A visible result was the fact that the experts in Maputo have virtually all been contacted and interviewed.

Use Of Rich Data- Through semi-structured interviews, critical literature review, observations, rigorous and exhaustive ontological analysis and enthusiastic debate in the PDW, this research intensively collected and registered rich data with a high level of detail and variety revealing a global picture of reality simultaneously with a high richness of details that were very useful to generate and test the design elements considered in the 2MW.

Respondent Validation- To reduce misinterpretation, better illustrate, ground and support evidence (Miles & Huberman 1994: 275), promote "phenomenological validity" (Bronfenbrenner 1976) and behave ethically towards the informants (Stake 1976) and help the researcher to self-assess biases (Maxwell 2005: 111), feedback, or "member checks" (Bryman 2004: 78-80; Guba & Lincoln 1989), were solicited to people involved in the research at the end of both stages. Therefore, after each interview a small report of the conclusion was made; after the Workshops with the experts, a report with the main results was sent for validation and after the rural Workshops an overview of the results

was declared to assess if everyone understood and agreed with the contents. The possibility to suggest alternatives in the 2MW was repeatedly provided for all the participants and several suggestions were actively implemented in the final version of the 2MW.

Triangulation- This strategy used to enhance validity by involving different data sources, methods, theories or combinations of these (after Denzin 1989; Patton 2002). To specify, data referring to the same issues was collected in different times and places from a pluralistic and wide range of knowledge and perspectives, including people in rural and urban settings of Mozambique, experts from other countries and relevant literature. Different methods were combined to identify, elicit and integrate the design knowledge on WES in Mozambique, including mathematical quantification, participatory design workshops and, semi-structured interviews. Finally, design and systems thinking broadened the theoretical base informing this research.

During the research process, different sources of data that are affected by different biases and have different strengths so they can complement each other (Yin 1994) were used. However, the research process have been described, analyses made, and the sample selection has been as detailed as possible without exposing the participants. In retrospect, it can be said that triangulation of data sources, methods and data types were used. Notably, despite this efforts, the research was still affected by limitations, addressed in §17.

14 DESIGINING THE 2MW

This chapter will present the process used to build the WF energy system conceptual design metamodel, the 2MW. As explained in §13 in practical terms, building the 2MW, entails the explication of a minimal set of essential building blocks, the design elements, which allow users to jointly conceive the conceptual designs of WES in Mozambique. In order to achieve this objective, seven DDs have been identified as the minimum and sufficient set necessary to describe the WES (§14.1). Subsequently, those DDs were converted into thirteen interrelated design elements, which together, compose the layout of the 2MW (§14.2) that was finally tested with charcoal makers and experts (§15).

14.1 DEFINING THE WOOD FUEL ENERGY SYSTEM DESIGN DIMENSIONS

As already explained above, the main goal of this research is to provide an ontology that allows to accurately specify and describe, in a non-normative and non-prescriptive way, the conceptual design of WF energy systems in Mozambique. Following the strategy defined in the methodology (§13), the first step towards that objective consists of identifying DDs that could be seen as: main design issues, areas of concern in the conceptual design of WES (in a design approach); WES (sub)systems (systems perspective); or systemic design perspectives on the WES conceptual design (systems design perspective). This was done through a conceptual analysis of the domain of interest (i.e. the design contest): WES in Mozambique. The final result was a framework of seven interdependent DD for/of WES defined below and in fig. 14.1:

- **Technological (TI)**- Focus on the design of WES as a technological problem, considering technological options, interaction, chains, impacts and approaches affecting the process of transforming resources from nature to energy service required. Included here are issues like technical properties of the technology, cost-effectiveness, implementation, management, maintenance and suitability to local social and biophysical conditions, ownership and management.
- **Institutional, Political (IP)**- The view of the WES in an institutional and political arena where energy related policies, legislation, regulation, strategies, ideologies and other institutional/political networks are affecting and interacting with the WES design. Hence, includes all entities and organisations with legitimacy and/or power to decide and implement laws and policies as well as the formal and informal social rules that structure social relations.
- **Economical, Financial, Business (EC)**- The economical, financial and business logic of the WES, focusing on the value creation, the costumer, business structures and financial aspects to be considered in the design of WES.
- **Livelihood, Socio-cultural, Behavioural (BC)**- The WES as a network of actors, beliefs, norms, conflicts, psychological and cognitive dynamics within a socio-cultural context is expressed in livelihood, energy behaviours, strategies, consumption patterns and

preferences, affecting and being affected by consumption, production and design of WES. Risk management in households and other entities are also placed here.

- **Knowledge, Skills, Communication (KI)**- Focus on WES as a set of knowledge systems, skills and capabilities in play. This dimension considers the knowledge, skills and organisation required to design, operate, manage and influence the WES, as well as, the platforms, networks and channels available, accessible and used to assist the communication, knowledge sharing, learning.
- **Nature (NT)**- The natural environment where humans are imbedded and focuses on how nature is involved in the WES design through flows of matter, energy and information. Nature includes geomorphology, climatic conditions, natural resources, natural processes and associated properties and possible effects and impacts on WES.
- **Integrated Infrastructure & Networking (IN)**- The view of WES design as an integral part of wider socio-ecological context or network within which the WES is embedded or integrated, e.g., the design of WES as a component of socio-economic strategies for rural areas. This dimension includes, hence, not only physical infrastructure (e.g. roads), but also financial (e.g. networks of banks) and social services (e.g. schools, health centres) and relative geography (distances from relevant energy infrastructure). In a sense this DD links the other DDs with the wider socio-ecologic context which might impact the WES design.

The DDs are all interdependent. Each DD represents an aspect or area of concern in the conceptual design of WES requiring specific design decisions and thinking perspectives, which influence and are influenced by the dynamics of the other DDs specific design decisions and thinking perspectives. For instance, the decision to engage in ecological or "nature friendly" design might favour different conceptual design specifications for: technology; communication channels and knowledge; and financial mechanisms. In turn, different impacts of the chosen technology might be considered about the energy habits of consumers and/or nature. In addition, none of the DDs imply normative or prescriptive design. None of the DDs explains why and how to do the conceptual design of WES. In fact, this is a fundamental criterion for the definition of each DD.

Another important aspect is the process from which DDs are derived and used. The DDs resulted from a conceptual analysis of the context of design and WES, but will also be used in context, that is, it will assist designers to describe and specify the conceptual design of WES that exist in a given context. Moreover, as a result of the endogenous interdependency, the set of DDs is non-hierarchical: none of the DDs is deemed to be more fundamental than the others or a privileged starting point. This brings two consequences. First, the DDs' definition emerges from interpretations (translations) the author makes from the dynamic and contextualised interaction people establish with the WES design, which might be expressed through words, e.g., in scientific papers on WESs or daily practice in charcoal making in

Mozambique. Second, the DDs are not yet a conceptual design tool since, as it will be explained bellow, the low level of conceptual and description granularity is not yet the desired for the objective of this research (§3). At best, the DDs could provide a generic list of topics organised and formalised according to each DD. However, DDs can be used together to analyse or describe a given WES. Note that it is expected that every user/designer: makes different design decision or have different perspectives on the same DDs; starts the analysis/description using different DDs at different entry points; follows different DDs sequences (paths) in the definition of the conceptual design description of the WES; and (possibly) changes their perspectives by interacting with other users/designers and with the WES conceptual design being defined.

Perceiving the WES design from a systems perspective, the DDs mirror WES composing sub-systems, e.g., the technological DD could be the technological systems or the Nature DD could be the ecosystem. Moreover, the DDs mirror those subsystems (and WES as a whole) as open and co-evolving systems (e.g Norgaard 1994; Rammel *et al.* 2007), i.e., each subsystem evolves under its own dynamics which is affected and affects other dynamics, through complex interactions (not always perceivable or predictable) and, the WES evolves the same way interacting with the wider socio-ecologic systems where it is embedded. In fact, the inclusion of the DD integrated infrastructure and network reflects exactly this design concern. Moreover, since evolution might leads to a general increase in complexity (Beinhocker 2006) it does not necessarily imply progress toward any given end-point, and thus WES and each of its sub-systems are not deterministic.

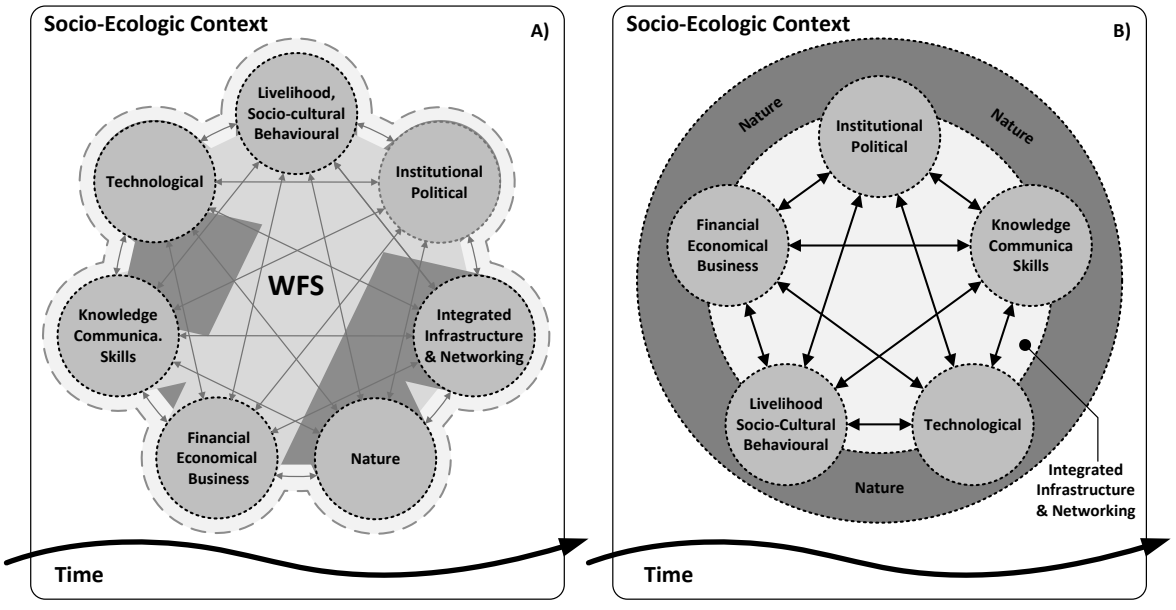


Figure 14.1| Two possible representations of the main DDs on WES embedded in a socio-ecologic context co-evolving in a dynamic, interactive and complex process [Source: the Author].

Graphically, these possibilities are represented in fig. 14.1 with dotted border lines to indicate openness and embedment, i.e., there are no real borders, or at least physical static lines separating the elements in the model. A wavy line crossing the socio-

ecological context represents time, which indicates that the DDs are dynamic, interdependent and in continuous interaction with each other in the context of WES, as well as, with the wider socio ecological context where WES is embedded. This idea of interaction is conveyed by double arrowed lines and dotted borders, which show interdependency, but also conflict, impact and struggle. In simple terms, DDs are dynamic spaces of making sense and enact design ideas, perspectives, experiences and knowledge, i.e., practices.

The set of DD (like the 2MW) only organises the design conceptualisation within a given context by translating that same context into a set of DDs. Therefore, the question is to know how to derive those DDs form the relevant context and how to be sure that those DDs cover all the design thinking required in that context (i.e., how comprehensive is it). Accordingly, in the following, it will be explained how these DDs emerged as the result of the interaction between the author, the WES and other actors in the context of the 2MW co-design process in Mozambique, and how is it possible to assess the comprehensiveness of the set of DD.

Before entering the actual definition and comparison of DDs it is relevant to mention that while the conceptual analysis process is presented here as a straight line from definition of DDs to comparison, the actual definition of each DD and the comparison was a rather interactive and reflexive process. The meaning, definitions and elements in the DDs were built as the interviews, comparisons and literature reviewed was being carried on.

14.2 FROM SYSTEMS ANALYSIS TO MAIN DESIGN DIMENSIONS

Here, a DD simply defines a facet, a way to abstract, of making sense of a multidimensional set of complex design issues affecting the conceptual design of the WES. Each of these dimensions defines, and is expressed by, a specific set of concerns, representations and dimensions of the WES design (as seen in the list in §14.1). Since concerns, dimensions often remain tacit (e.g. Argyris 1995; Rein 1986), some sort of conceptual analysis had to be carried out to make them explicit (Cuppen 2009), i.e., visible and open to discussion. However, the purpose of this conceptual analysis is not to explain, understand or find knowledge gaps between why and how to accomplish WES design, but rather to identify what is the minimal set of ontological dimensions able to describe and specify the conceptual design of WES (see §13.2.1). Moreover, unlike in §A, the purpose now is not to make a critical exploratory analysis of the WF problem in Mozambique, but rather to engage in a conceptual, critical analysis of WES conceptual design in the context set by the critical exploration done in §A. Simply put, in §A the purpose was to uncover what is going on in the "domain" of WES in Mozambique to build an argument, now the purpose is to identify what are the DDs one thinks about (conceptualises) when thinking about conceptual design of WES. Therefore, the conceptual critical analysis did not imply a re-analysis of the "domain", but rather a

conceptual (ontological) interpretation of the argumentative analysis of §A, or of any other available analysis on WES design (i.e., an ontological interpretation).

Inspired by SSM use of rich pictures to derive root concepts (Annex 2), and assuming the participatory design as the design method (for internal coherence, see §13) the sources of WES design analysis considered were: the WES graphical representation in fig. 9.1-2; the interpretations and representations, representations, mostly implicit and tacit, that WES actors hold; and other similar approaches available in the literature (while used for comparative purposes too). The fig. 9.1-2 are system representations of the critical and exploratory analysis conducted on the complex subject of WF in Mozambique (§A-B). The purpose of fig. 9.1-2 was exactly to make a sort of enriched systems picture of the WES integrating the elements, boundaries, flows, co-evolutionary and embedded vision of WES as derived for the critical analysis. Rich pictures, from which fig. 9.1-2 might be a highly formalised example, can act as analysis tool to understand what an individual (or group) thinks about a very complex problem (Bell & Morse 2012). But rich picture are also open to interpretation. Thus, fig. 9.1-2 were an obvious visual starting point to for the critical exploratory analysis, from an ontological perspective expressed in the question:

"What are the main design dimensions guiding the conceptualisation of WES?".

In the process of answering this question, seven main DDs in different degrees of explicitness were identified, tab. 14.1.

Table 14.1| Main DDs identified through inquire fig. 9.1-2 (SYMBOL- elements representation in fig. 9.1) [Source: the Author].

Dimension[1]	Symbol	Degrees of Explicitness
Technological **Nature** **Cultural/Behavioural** **Economical/Business** **Institutional/Political**		**Explicit and direct:** Dimensions are represented as systems building blocks (and also as flows, implying mutual interaction).
Knowledge/Skills		**Explicit and indirect:** Dimensions are defined only as flows (lines) linking the explicit and direct DDs.
Infrastructure/Network		**Implicit and direct:** DDs are not explicit in any form (block or arrows), but the indication of interaction (dual arrows) in a dotted border indicates interaction and possible networking.

NOTA: 1- definitions as in the list presented at §14.1.

14.3 FROM INTERVIEWS TO MAIN DESIGN DIMENSIONS AS BARRIERS

The interviews conducted to actors active in the use and research on WES in Mozambique and elsewhere were also used in a co-research effort to derive the main DDs for WES. The interviews were broadly divided into interviews conducted with experts on WES in Maputo or over Skype™, and with WES actors in rural areas of Mozambique.

14.3.1 Interviews With Experts

Using the strategy described in §13.4.1 for data collection using semistructured interviews with experts, both in face-to-face interviews and over Skype ™ it was possible to derive main DDs. In resumed terms, by challenging the experts to identify barriers preventing the actual implementation of a hypothetical ideal WES, the main dimensions emerged as specific concerns associated with those barriers. The results from this knowledge elicitation strategy are compiled in tab. 14.2:

Table 14.2| DDs identified in interviews conducted with experts working on WES at Mozambique and elsewhere. (☐-generic dimensions on WES identified in the beginning of the interview; ●- barriers specific ideas on WPS identified in the end of the interview; Design Dimensions are defined in §14.1; AE- Academic outsider Mozambique; CE- External Consultant; CN- National Consultant; AN- Mozambican Academic; AS- Graduate Researcher; PS- Private sector; GN- Government official; IA- International Agency; O- ONG; NI- National Institute; PMg- Project Manager) [Source: the Author]. *[Continues in next page].*

#	CODE	DISCIPLINARY BACKGROUND	ROLE IN WES	DIMENSIONS AS BARRIERS						
				EC	IP	TT	IN	NT	BC	KI
01	**#4W**	Geography	AE	☐	●	☐	☐	☐		●
02	**#5W**	Environment Sciences	AE	☐	☐	☐	☐	☐		●
03	**#02W**	Forest	AN/CE		●	●	☐	●	☐	●
04	**#01W**	Geography	CE	☐	☐●	☐●	●			
05	**#6W**	Environment Sciences	CE	☐●	☐●	☐	☐●		☐●	●
06	**#8W**	Environment Sciences	CE	☐●	☐	☐	☐		☐●	
07	**#7W**	Journalism	O	☐	☐	☐	☐	☐	☐	●
08	**#14M**	Biology	AN	☐	●		☐●	☐●	☐●	●
09	**#20M[1]**	Engineering	AN	☐	☐	☐		☐		
10	**#21M**	Engineering	AN	☐	☐	☐	☐●	☐	☐	●
11	**#03M[1]**	Physics	AN			☐	☐		☐	
12	**#04M**	Forest	AN	☐	☐●	☐	☐	☐●	●	●
13	**#09M**	Physics	AN	☐●	☐●	☐	☐	☐	●	
14	**#12M**	Physics	AN	☐●	●	☐●	☐●	☐	☐●	
15	**#15M**	Physics	AN	☐●		●	☐	☐	☐●	
16	**#22M**	Physics	AN	●	●	☐	☐	☐	☐	●
17	**#23M**	Physics	AN	☐	●	☐	☐	☐	☐	●
18	**#05M**	Forest	AN/CN	☐●	●	☐	☐	☐●	●	
19	**#10M**	Physics	AN/CN	☐	☐●	☐	☐	☐	●	
20	**#01M**	Forest	CN	☐●	☐●	●		☐●	●	
21	**#08M**	Environment Sciences	CN	☐●	☐●	●	☐	☐	☐●	●
22	**#28M[1]**	Anthropology	CN	☐	☐	☐	☐			
23	**#02M**	Physics	GN	☐		☐●	☐●	☐	☐	●
24	**#07M**	Sociology	AS	☐	☐●	●	☐	☐	●	
25	**#17M**	Forestry	AS	☐●	☐●		☐	☐	●	●
26	**#06M**	Agronomy	GN	☐	●	☐	●			●
27	**#16M[1]**	Anthropology	GN	☐	☐		☐	☐	☐	
28	**#25M**	Forestry	GN	☐	☐●	☐●	☐●	☐●	●	●
29	**#27M**	Economy	GN	☐	●	●	☐	☐	●	●
30	**#18M**	Economy	GN/A	☐●	☐	☐	☐●	☐	☐●	
31	**#11M**	Forestry	PS/PMg	☐●	☐	☐●	☐●	●		
32	**#19M[1]**	Engineering	PM	☐		☐	☐	☐		
33	**#13M**	Forestry	IA		●	☐				

Table 14.2| *[from previous page]* DDs identified in interviews conducted with experts working on WES at Mozambique and elsewhere. The (☐) indicate generic dimensions on WES identified in the beginning of the interview and the (●) indicate the barriers specific ideas on WPS identified in the end of the interview (Dimensions are defined in §14.1; AE- Academic outsider Mozambique; CE- External Consultant; CN- National Consultant; AN- Mozambican Academic; AS- Graduate Researcher; PS- Private sector; GN- Government official; IA- International Agency; O- ONG; NI- National Institute) [Source: the Author].

#	CODE	DISCIPLINARY BACKGROUND	ROLE IN WES	DIMENSIONS AS BARRIERS						
				EC	IP	TT	IN	NT	BC	KI
34	**#03W**	Economy	IA	☐	☐	☐	☐	☐		
35	**#26M**[1]	Forestry	IA/NC	☐	☐●	☐		☐	●	●
36	**#24M**	Sociology	NI		☐				●	

NOTE: 1- Expert only provided generic dimensions on WES.

An interesting result of the interviews to experts is related with the absence of the DD Knowledge/Skills/Communication (KI) in the beginning of the interview (☐, in tab. 12.2), when experts were directly inquired on the possible dimensions, perspectives or viewpoints on WES. However, KI is a DD recurrent later in the interview, when experts are questioned on the real barriers they would expect to face if they decided (and had the power) to implement their ideal WES (●, in tab. 14.2). Therefore, the ideation exercise with the use of "barriers" as an abstraction for design problems, prove to be a useful strategy to bridge gaps in the interview and by making explicit tacit knowledge on WES.

14.3.2 Interviews In Rural Areas Of Mozambique

Following the principle consideration that all actors in WES are co-designers of the entire design process (§13.2.2), the actors active in the WES in rural areas of Mozambique were also challenged to make explicit their DDs on WES.

Six research sites in three locations have been selected for the fieldwork: Inhaca (Ribjene, Ingwane, Nhankene); Goba (Goba Estação); and Santaca (Tinonganine; Djabula). The research areas have been selected based on a number of criteria, including: being a source of charcoal to Maputo within the province of Maputo; being the target area in previous charcoal related projects; having different levels of traditional authority presence and; little to no access to electric power (§13.3.1). The reference case, Inhaca, was selected due to the proximity to Maputo City, total absence of charcoal production, close to 100% electrical grid coverage and existence of a forest reserve (§13.3.1).

The choice of the kind of actors desired, that is, the choice of the relevant roles (stakes) was done in a previous stakeholder analysis based on the WES definition (§12) and included, among others, charcoal makers, firewood collectors, related business entrepreneurs, local and traditional authorities. However, the actual choice of people was done by indication of the local authorities (customary or not). This was the procedure possible and recommended by the protocol generally followed in Mozambique (§13.4.1). As explained in §13.4.1, the interviews with the rural participants had its obstacles, but was carried out with the assistance of the local authorities. The actors' main mode of

expression was storytelling, which is a traditional method of sharing ideas and information in Mozambique. The DDs identified through such storytelling method have been compiled in tab. 14.3:

Table 14.3| DDs identified in interviews conducted in rural areas of Mozambique. The (☐) indicate DDs on WES identified by interpretation of storytelling on firewood collection and/or charcoal making and the (●) indicate the DDs as barriers to energy transition, Number in brackets, "()", indicate number of interviewee in group interviews (Dimensions are defined in §14.1; BM- Baker; CM- charcoal maker; CS- Charcoal Seller; FC- Firewood Collector; FS- Firewood Seller; LG- Local Government; TA- Traditional Authority) [Source: the Author]. *[Continues in next page]*

#	REFERENCE[1]	AREA[2]	STAKE	DIMENSIONS AS BARRIERS						
				EC	IP	TI	KI	IN	BC	NT
01	#I-01	Inhaca	BM	☐●	☐	☐		☐		
02	#I-03	Inhaca	BM	☐●	☐	☐				
03	#I-06	Inhaca	BM	☐	☐		☐	☐	☐●	
04	#I-12	Inhaca	BM	☐	☐	☐●	☐●	☐●	☐	☐●
05	#I-14	Inhaca	BM	☐●		☐	☐●	☐		☐
06	#I-15	Inhaca	BM	☐●	☐	☐		☐	☐	☐
07	#I-20(2)	Inhaca	BM/LG	☐	☐	☐●	☐●	☐●	☐	☐
08	#I-04(4)	Inhaca	FC	☐	☐	☐	☐	☐		☐
09	#I-10	Inhaca	FC	☐	☐	☐●		☐	☐	☐●
10	#I-17	Inhaca	FC	☐	☐	☐	☐	☐	☐	☐●
11	#I-19(2)	Inhaca	FC	☐	☐	☐●	☐●	☐●	☐	☐
12	#I-21(2)	Inhaca	FC	☐	☐	☐●	☐●	☐●	☐	☐
13	#I-22(2)	Inhaca	FC/BM	☐	☐	☐●	☐	☐	☐	
14	#I-07(2)	Inhaca	FC/FS	☐●	☐	☐	☐	☐●	☐	☐
15	#I-09	Inhaca	FC/FS	☐●	☐	☐●	☐	☐●	☐	☐
16	#I-11	Inhaca	FC/FS	☐●	☐	☐●	☐	☐	☐	☐
17	#I-24	Inhaca	FC/FS	☐●	☐	☐●	☐	☐	☐●	☐●
18	#I-23(2)	Inhaca	FC/LB	☐●	☐	☐●	☐●		☐	
19	#I-16(2)	Inhaca	FC/TA	☐	☐	☐●	☐●	☐	☐	☐
20	#I-08(2)	Inhaca	FS	☐●	☐	☐	☐			☐
21	#I-25	Inhaca	FS/CM	☐●	☐	☐●	☐●	☐●	☐●	☐
22	#I-18(2)	Inhaca	LB/FC	☐	☐	☐●	☐	☐	☐●	
23	#I-02	Inhaca	LO	☐●	☐	☐	☐	☐●	☐●	☐●
24	#I-05	Inhaca	LO	☐	☐	☐	☐	☐●	☐	
25	#I-13	Inhaca	TA	☐	☐	☐	☐●	☐●		☐
26	#G-1	Goba Estação	CM	☐	☐	☐	☐	☐	☐	
27	#G-4(3)	Goba Estação	CM	☐●	☐	☐	☐	☐	☐	
28	#G-5	Goba Estação	CM	☐	☐	☐	☐		☐	
29	#G-6(2)	Goba Estação	CM	☐●	☐	☐●	☐	☐	☐	☐
30	#G-9	Goba Estação	CM	☐	☐	☐	☐	☐	☐	☐

Table 14.2| *[From previous page]* DDs identified in interviews conducted in rural areas of Mozambique. The (☐) indicate DDs on WES identified by interpretation of storytelling on firewood collection and/or charcoal making and the (●) indicate the DDs as barriers to energy transition (Dimensions are defined in §14.1; BM- Baker; CM- charcoal maker; CS- Charcoal Seller; FC- Firewood Collector; FS- Firewood Seller; LG- Local Government; TA- Traditional Authority) [Source: the Author]..

#	REFERENCE[1]	AREA[2]	STAKE	DIMENSIONS AS BARRIERS						
				EC	IP	TI	KI	IN	BC	NT
31	#G-8	Goba Estação	CS	☐●	☐	☐●	☐	☐	☐	
32	#G-7	Goba Estação	LB	☐			☐	☐	☐●	
33	#G-10	Goba Estação	LB	☐●	☐	☐	☐	☐	☐	☐
34	#G-11	Goba Estação	LB/LO	☐●	☐	☐	☐	☐	☐	
35	#G-2	Goba Estação	LG	☐	☐		☐	☐	☐	☐
36	#G-3(5)	Goba Estação	LO	☐	☐	☐	☐	☐		☐
37	#T-1(2)	Tinonganinie	CM	☐●	☐	☐		☐	☐	
38	#T-2(3)	Tinonganinie	CM	☐●	☐	☐●	☐	☐	☐	
39	#T-3(3)	Tinonganinie	CM	☐●	☐	☐	☐	☐		☐
40	#T-4(3)	Tinonganinie	CM	☐●	☐	☐●	☐	☐	☐	
41	#T-5(3)	Tinonganinie	CM	☐	☐	☐●	☐	☐	☐●	☐
42	#T-6(3)	Tinonganinie	CM	☐●	☐	☐	☐●	☐	☐	☐●
43	#T-7(3)	Tinonganinie	CM	☐●	☐	☐	☐	☐	☐●	
44	#T-8(3)	Tinonganinie	CM	☐●	☐	☐●	☐	☐	☐	
45	#T-9	Tinonganinie	LG	☐	☐		☐		☐	

The results of the interviews conducted, both in rural areas and with experts, are in close agreement with the literature analysis regarding the existence of a minimum and sufficient set of seven DDs on WES which are able to fully describe and specify the design of WES, at least for Mozambique.

14.4 Comparison With Other Frameworks/Metamodels

Considering conceptual frameworks as descriptive and graphical illustrations, i.e. models, that facilitate thinking by making explicit the main constituent elements to be considered in a given subject (Miles & Huberman 1994: 90; §D) it is clear that the seven DDs already represent a conceptual framework: the DDs framework (DDF). Indeed, the DDs are both a graphical and descriptive illustration of the main design aspects, facets, key building blocks to be considered in the design of WES. Therefore, it is important to compare the DDF and other relevant conceptual frameworks to evaluate the comprehensiveness, originality and relevance of, and possible refinements on, the proposed DDs.

14.4.1 Frameworks Of Barriers To Energy Transition

As explored in §6-8, the conceptualisations, and consequently the design and intervention on ESy in DC is market by a pervasive, normative and prescriptive endorsement of energy

transition, the ETP. However, the outcome of energy transitions initiatives had a modest impact in DCs and almost none in Mozambique. These results are normally justified with a number of barriers on ESy transitions, dissemination or deployment[1], fig. 14.2A. While "barrier" is still a controversial concept, there is a large agreement that barriers are interrelated, contextual and, hence, it is complex to isolate the impact of any one barrier in particular, fig. 14.2B (Amigun *et al.* 2008; Verbruggen *et al.* 2010; Wilkins 2002: 120).

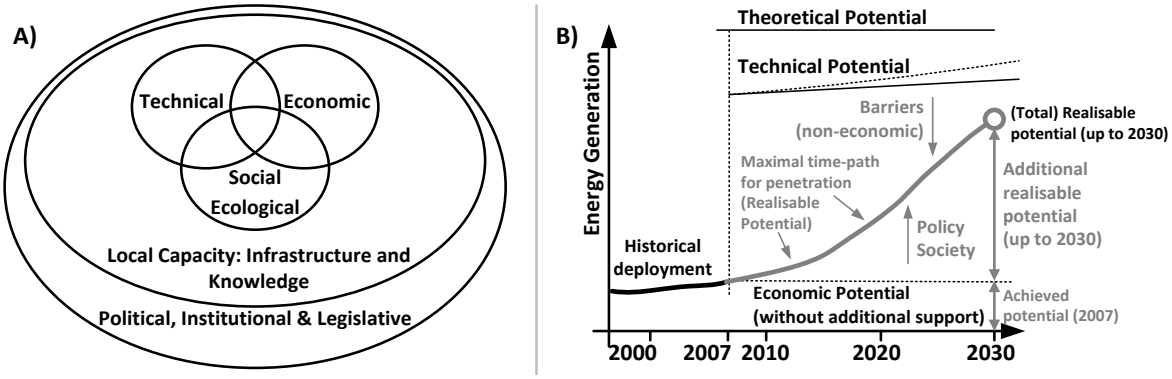


Figure 14.2| A) Interrelationship of barriers to renewable energy technology in DCs [the Author after Wilkins 2002: 121); **B)** Metrics relating to renewable energy technology potentials in South-East Asia [Source: the Author after Ölz and Beerepoot 2010).

Despite the conceptual ambiguity and analytical difficulties that barriers pose in the context of energy transitions, barriers do offer a window of interpretation regarding the dimensions experts (e.g. analysts, designers) hold on WES. By explaining "why things go, or might go, wrong" and/or "how to proceed for things to go better" with WES in real life, barriers also express "what has to be considered" in the first place, that is, the "unfulfilled expected purpose" in the WES design. Another view is to understand barriers as metaphors for design challenges, in the context of a highly interactive and hands-on approach to design (§C). For the purpose of this research, the interest on the barriers of energy transition analysis is not so much the theory, the why designs fail or tend to fail, or the normative design, the how to do design to overcome those failures, but rather the conceptual/ontological analysis on those "why" and "how" to identify (conceptualise) what dimensions (e.g. aspects, dimensions, elements) to consider in the WES design. For instance, if author "A" identifies "high initial cost" as a barrier to the adaptation of improved biomass technology in the WES in Africa (why), and propose subsidy policies to overcome that barrier (how), it is reasonable to admit that this particular author "A" considers/has economic and political dimensions for the design of a WES.

Following this line of thought, a literature search on energy transition barriers was conducted to identify main DDs on WES. The literature search was conceived to keep the coherence with the research purposes while recognising that WES shares common

1 A question never considered is the possibility that all these ESy could be In fact, ultimately very fit for the targeted socio-ecological context. Instead, what is implicit in the notion of "barrier", that something is faulty (not doing what is should), and that could be the technology, humans and nature, and thus (as it will be seen in the end of this part) the usual reply is to change technology, people and/or nature.

properties and resemblances with other ESy in a wider socio ecological context. Therefore, since the focus was analysis that covered as much as possible the entire WES over a wide range of approaches within contexts of development, the search was focused on WES in Mozambique, but included:

1| Other DCs considered to share geographical, biophysical and/or socio-economic characteristics, e.g., African DCs;
2| Other biomass based energies involving similar processes to fulfil the same energy services (i.e. heating for, e.g., cooking);
3| Technologies that respect 1| and2|, but have some commercial experience, essentially biogas and possibly biofuels;
4| Generic research on rural energy and bio energy in DCs.

This review did not considered barriers to standalone technology (e.g. improved stoves), other non-biomass renewable energies (e.g. solar panels) or Developed Countries contexts (e.g. USA and EU members), for being too specific and biased. Therefore, on this order of preference, only WF, generic research on biomass, bioenergy with some linkage with woody biomass, and generic renewable energies that are considered biomass in the bundle, were considered for ESy. Likewise the geographical location of the review was limited, by order of preference, to Mozambique, Africa, DCs and developed countries if dealing with WF only. The results are summarised in tab. 14.4. Considering that all the barriers and comments of the several authors have been included in the conceptual analysis, the seven DDs, §14.1, constitute a remarkably comprehensive conceptual framework covering all the dimensions and perspectives represented by the barriers.

Table 14.4| DDs as barriers for WES identified as barriers in selected relevant research in energy systems in DCs (Dimensions as Barriers are defined in §14.1; In the cells, SSA-Sub-Saharan Africa; RE- renewable with reference to biomass; Biom.- biomass; RE Ck- RE for cooking; RE Elct- RE for Electricity; Biog- Biogas; BioF.- Biofuels; BioE- Bioenergy) [Source: the Author]. *[Continues in next page]*.

#	REFERENCE	ESy	LOCATION	DIMENSIONS AS BARRIERS						
				EC	IP	TI	KI	IN	BC	NT
01	**Aabeyir *et al.* (2011)**	WF	Ghana	●	●	●		●		●
02	**Afgan *et al.* 1998**	RE	N/A			●				●
03	**Ahlborg & Hammar (2014)[1]**	RE Elct.	Mozambique[2]	●	●	●	●	●	●	
04	**Akinbami *et al.* (2001)**	Biog	Nigeria	●		●			●	
05	**Amigun *et al.* (2008)[+]**	Biof	Africa	●	●	●	●	●	●	●
06	**Asadullah (2014)**	Biog	N/A	●		●		●		
07	**Aschaber (2010))**	Biog	Burkina Faso	●	●	●	●	●	●	●
08	**Barnes & Foley (2004)[3]**	RE Elct.	Several[4]	●	●	●	●	●	●	
09	**Bi (2011)[+]**	RE	N/A	●	●	●	●	●	●	
10	**Biggs (2009)[+]**	BioE	Africa	●	●	●	●	●	●	●

NOTES: **1-** Based on an expert survey; **2-** conducted also in Tanzania, but only Mozambique data was considered; **3-** Based on several World Bank Projects; **4-** Costa Rica, Philippines, Bangladesh, Thailand, Mexico, Tunisia, China, Chile, Kenya; **+** Review Paper.

Table 14.4| *[From Previous page]*.DDs as barriers for WES identified as barriers in selected relevant research in energy systems in DCs (Dimensions as Barriers are defined in §14.1; SSA-Sub-Saharan Africa; RE-renewable with reference to biomass; Biom.- biomass; RE Ck- RE for cooking; RE Elct- RE for Electricity; Biog- Biogas; BioF.- Biofuels; BioE- Bioenergy) **[Source: the Author].** *[Continues in next page]*.

#	REFERENCE	ESy	LOCATION	DIMENSIONS AS BARRIERS						
				EC	IP	TI	KI	IN	BC	NT
11	**Brass *et al.* (2012)[+]**	RE Elct.	DCs	●	●	●				
12	**Bravo *et al.* (2012)**	Biofuels	N/A	●				●	●	●
13	**Clancy (2011)**	RE	DCs	●	●	●	●	●	●	
14	**Dasgupta *et al.* (2007)**	RE	India	●	●	●	●			●
15	**ECA (2006)**	RE	SSA	●	●		●			
16	**Eswarlal *et al.* (2011)**	RE	India	●	●	●	●			●
17	**EU-Commission**	Biom.	DCs		●		●			
18	**Himri *et al.* (2009)**	RE	Algeria		●		●			
19	**Holland *et al.* (2001)**	RE Elct.	Several[5]	●	●	●	●	●		
20	**Howells *et al.* (2010)**	Biom.	N/A	●	●		●	●	●	●
21	**Khennas (2012)**	RE ect.	Africa	●	●	●		●		
22	**Kruger**	RE	SSA	●	●	●	●	●	●	
23	**Lall (1995)**	RE	DCs		●	●	●			
24	**Laumanns & Reiche (2004)**	RE	DCs	●	●	●	●	●	●	●
25	**Mirza *et al.* (2009)**	RE	Pakistan	●	●	●	●	●		●
26	**Mondal *et al.* (2010)[6]**	RE	Bangladesh	●	●		●	●		
27	**Murphy (2001)**	RE	East Africa	●	●	●	●	●	●	
28	**Mwakaje (2012)**	Biog	Tanzania	●	●		●	●	●	●
29	**Ni & Nyns(1996)**	Biog	DCs	●	●	●	●	●	●	●
30	**Practical Action (2009)[7]**	WF	Congo basin	●	●	●	●	●		●
31	**Painuly (2001)[+]**	RE	DCs	●	●	●	●	●	●	
32	**Painuly & Fenhann (2002)**	RE	Several[8]	●	●	●	●	●	●	
33	**Pandjaitan (1990)**	Biog	Indonesia	●	●	●		●		
34	**Parawira (2009)[+]**	Biog	SSA	●	●	●	●	●	●	●
35	**Parthan *et al.* (2010)[9]**	RE	DCs	●	●	●	●			
36	**Petersen & Andersen (2009)**	RE	N/A	●	●	●		●	●	
37	**Puustjärvi *et al.* (2003)**	RE	N/A	●	●	●	●	●		
38	**Quadir *et al.* (1995)**	RE Ck	DCs	●	●	●	●	●	●	
39	**Reddy, Painuly (2004)**	RE	India	●	●	●	●		●	
40	**Sathaye *et al.* (2011)**	RE	N/A	●	●	●	●	●	●	●
41	**Schlag & Zuzarte (2008)**	Biof.	SSA	●		●	●	●	●	
42	**Shujing (2012)**	RE	N/A	●	●	●	●		●	
43	**Sims (2002)**	Biom.	N/A	●	●	●		●	●	

5- Thailand, Sri Lanka; **6**- Based on pilot project data; **7-** Based on huge project in Congo Basin; **8-** Egypt, Ghana, Zimbabwe; **9-** based on 129 projects in 56 Countries;

Table 14.4| *[From previous page]* DDs as barriers for WES identified as barriers in selected relevant research in energy systems in DCs (Dimensions as Barriers are defined in §14.1; In the cells, SSA-Sub-Saharan Africa; RE- renewable with reference to biomass; Biom.- biomass; RE Ck- RE for cooking; RE Elct- RE for Electricity; Biog- Biogas; BioF.- Biofuels; BioE- Bioenergy) [Source: the Author].

#	REFERENCE	ESy	LOCATION	DIMENSIONS AS BARRIERS						
				EC	IP	TI	KI	IN	BC	NT
44	**Sims *et al.* (2012)**	BioE.	N/A	●	●	●		●		
45	**Stapleton (2009)**[10]	RE	DCs	●	●	●	●	●		●
46	**Turkenburg (2000)**	Biom.	N/A	●		●		●	●	●
47	**UNIDO (2006)**	RE	Africa	●	●	●	●			
48	**Valencia & Caspary (2008)**	RE	DCs	●	●	●	●	●	●	
49	**Wilkins (2002)**[11]	Biom.	Several[12]	●	●	●	●	●	●	●

NOTES: 10- Based on an expert survey; **11-** Based on literature and case studies on biomass cogeneration; **12-** Thailand, Indonesia, India.

This tab. 14.4 also represent a reverse argument. If the energy transition itself is analysed using the DDF. The literature on energy transition is intrinsically normative, prescriptive and ideological since the very own idea of "energy transition" implies a vision to where that transition should be headed, normally informed by a given idea of development or other design target (§8). While the DDF has been conceived to be non-normative, the DDs can well be considered analytical dimensions to possibly normative approaches. Using the DDF as an analytical framework, allows linking to each DDs the question:

"What energy transitions to design when conducting conceptual design of a WES".

In other words, DDs become "transitions dimensions", creative and thinking spaces where energy transitions could be planned, designed, decided upon and implemented. Under this conception the DDs could be reformulated into seven energy transition dimensions (for the first five DDs see, e.g., Foxon 2011):

- **Technological-** Change the device (e.g., from diesel motor to solar panels), change the process (e.g. from "boat" charcoal production to "casamansa"), change the product (e.g. from charcoal to wood pellets).
- **Institutional/Political**- Change the policy, institution and/or WES strategy e.g., implement pro-biomass policies and create a department of biomass energy in the governmental structure.
- **Economical/Financial/Business**- Change the economic and business model to influence the market, e.g., create a market for biomass through economic and financial mechanisms (typically subsidies, banks) allowing business to be developed around biomass from forests and/or agriculture.
- **Livelihood/Socio-cultural/Behavioural**- Change consumption/production habits, e.g. voluntarily reduce the consumption of WES.
- **Nature**- Change the natural resource and landscape, e.g., move from oil to charcoal or biofuels, use wasteland instead of farm land.

- **Knowledge/Skills/Communication**- Change the knowledge base and communication channels and relations, e.g., include different knowledge in the design of all other changes, focus on two-way communication channels and perceive energy as a capability to acquire skills.
- **Infrastructure/Integrated Network**- Change the socio-economic context, or include WES as part of wider development strategies, e.g., to reduce poverty, improve conditions in rural areas creating synergies with rural energy projects.

Note that the "transition dimensions" are essentially DDs conceptualised under a logic of energy transition, and thus, they retain the ontological value of their DDs counterparts, i.e., these design arenas indicate "what" transitions a decision maker, designer, planner or implementer should consider, but is completely mute regarding "how" to make the transition and "why". Likewise, the transitions dimensions are interdependent and contextualised. Moreover, these seven transition dimensions, together, describe all research done on transition. A proof of this statement is given by Howells *et al.* (2010), when reviewing fuel transition classifications to include:

- No change in the type of fuel used for a particular service, but a change in the way it is used, e.g. replacing a traditional WF stove with a more efficient wood-stove.
- The consumption of a new energy service, e.g., the purchase and use of a battery powered radio for the first time.
- The substitution of one fuel and appliance for another, e.g. heating water in an electric kettle, rather than in a pot on the stove.

In other words, these are basically technology, Nature and probably behavioural changes, that might be accelerated (or not) by institutional & political and/or economic, financial & business changes and/or changes in knowledge, skills & communication as part (or not) of a profound strategy for rural development.

14.4.2 Frameworks To Represent Energy & Energy Systems

The DDs, by definition, could also be understood as different ways of representing energy in general and ESy In particular, (e.g. ESy as a business). The existence of these different world-views, perspectives of stands is, as argued in §8, a main expression of complexity and, simultaneously, a major justification for a common-ground translation tool (the 2MW) to facilitate learning and dialogue among those different world-views, perspectives and stands on WES (conceptual) design. In this regard, the framework developed by Stern & Aronson (1984) and adapted by Devine-Wright (2007) on ways of representing energy in the context of policy making is quite relevant in terms of comparison, tab. 14.5:

Table 14.5| Summary of ways of representing energy as adapted by Devine-Wright (2007) from Stern & Aronson (1984) [Source: Devine-Wright added the social necessity].

ENERGY AS:	PROPERTIES	CENTRAL VALUES	INTEREST GROUPS
Commodity	Supply, demand, price	Choice, individualism, private sector provision of energy services	Energy producers, consumers with sufficient resources
Ecological Resource	Resource depletion, environmental impacts	Sustainability, frugality, choice for future generations, favour RETs	Future generations, green movement
Social Necessity	Availability to social groups, meeting essential needs	Equity, justice	The poor and other vulnerable social groups
Strategic Material	Geopolitics, availability of domestic substitutes	National military and economic security	Military, energy suppliers

Comparing tab. 14.5 with the DDs in §14.1, it is possible to see the markedly political nature of the Devine-Wright analytical framework. In tab. 14.5, the four energy representations are also policy stakes around energy in the context of development (Devine-Wright 2007). Each political stand might encapsulate, in different degrees, different DDs (and/or perspectives). Thus, it is expected that each Devine-Wright energy representation finds a stronghold in one of the DDs while also present, less explicitly, in other DDs. In tab. 14.6, these relations are presented in a more structural way.

Table 14.6| Comparison between the ways of representing energy by Devine-Wright (2007) and proposed DDs (Conceptual overlapping (see fig. 15.6): (●) some; (●●) substantial, but not complete; (●●●) fits completely in the DD; Dimensions are defined in §14.1) [Source: the Author]..

WAYS OF REPRESENTING ENERGY	DESIGN DIMENSIONS						
	EC	NT	TT	IP	SC	KI	BC
Commodity	●●●		●[1]				●[2]
Ecological Resource		●●[3]	●[4]				●[5]
Social Necessity	●[6]			●●	●●[7]		●[8]
Strategic Material	●[9]		●[10]	●●[11]			

NOTES: 1- Provision of energy services; **2-** Choice, Consumers behaviours; **3-** Does not consider land and landscapes; **4-** Preference for renewable; **5-** Sustainability, frugality, future generations; **6-** Economic viability to social groups; **7-** Socio-economic context of users; **8-** Livelihoods; **9-** Look for alternative resources; **10-** Provide alternative energy sources; **11-** Does not consider institutional side explicitly.

The tab. 14.6 clearly indicates that the seven DDs completely cover the Devine-Wright ways of representing energy in a more interdependent and integrated way. The ways to represent energy proposed by Devine-Wright give preference to three DDs (Political & Institutional; Economic, Market & Business; and Nature) while the other dimensions are kept in a dependent position or are completely absent (the Knowledge, Skills & Communication DD). This relation of dependency places, for instance, a utilitarian value on technology considered as a tool to accomplish policies, implement market mechanisms and conservation principles. Moreover, the absence of the Knowledge, Skills

& Communication DD seems to indicate that energy is never represented as a network of knowledge requiring continuous learning and communication between actors. Remarkably, these trends reflect the political character of most energy projects conducted in Mozambique. As mentioned before and explicitly stated in several interviews, in Mozambique both energy and forest policies have been made, and market mechanisms implemented under a general (at least on paper) conservationist ideology, resulting in poor technology diffusion, lack of studies on behavioural and cultural dimensions of WF energy consumption and production, and the nonexistence of co-design or design-capacitating incentives sponsored by Authorities, NGOs or international aid agencies.

14.4.3 Frameworks Related To Sustainable Development

In recent decades sustainable development discourse and multiplicity of different interpretations (§7.3) has gained crucial relevance in the international political agenda, which is reflected in the exponential use of sustainable development to justify, or serve as, a management, planning and design principle, objective and strategy (§7.3). Simultaneously, there is an increasing recognition of conceptual frameworks (particularly in visual formats) as useful, relevant and practical management, planning and, in lesser degree, design tools (§11). However, since most modelling practice tends to be expert driven and positivist (§6-8), the models generated, in this case, the conceptual frameworks tend to be normative and prescriptive and useful mainly to experts and decision makers. Therefore, as a result: most conceptual frameworks of/for WES/ESy design and relevant for this research have been defined as normative, prescriptive and expert driven models to describe, analyse, evaluate and classify sustainable development projects, processes and perspectives. While this work criticises this form of modelling and models (§6.3), considering the purpose of this section, to define the DDs to describe conceptual design of WES, sustainable development frameworks provide a relevant ontological comparative ground for the DDF.

There are very few frameworks (related or not to sustainable development) dealing with design of ESy in general and even less with the conceptual design of WES. Therefore, within the immense literature on sustainable development, this comparison considers only conceptual frameworks of/for ESy, and preferably WES, with a similar approach (searching for essential building blocks), purpose (design, plan, model or assess ESy/WES) and visual format. Moreover, since the conceptual design of WES can be expressed in models, policies, energy projects and livelihoods' decisions, some examples of these different design expressions will be presented.

A| Capitals/Resource Models For Sustainable Development

Probably the most well-known capital model of sustainable development is the Five Capitals Model (5CM) (Porritt 2007), fig. 14.3B. The 5CM is based on the ecological model of sustainability (fig. 14.3A), which assumes that (PCE 2002): economy is only possible

within the context of a society; many aspects of society do not involve economic activity; and both human society and the economic activity within are totally constrained by the planet's natural systems. Initially proposed by the Forum for the Future[2] (FF) for business purposes, the 5CM is an conceptual framework to understand and promote sustainability in terms of the economic concept of "capital" or assets defined as[3]: "accumulated wealth" (Porritt 2007) or "stock of productive resources built up by human action [susceptible thus to] depreciate, be consumed or be sold off" (Scoones 1998). According to the 5CM (Porritt 2007) economy, and each and every company, needs only five types of capital (fig. 14.3B & list below) to: function properly (deliver its products and services); and develop "visions" of sustainability for its operations, products and services. Therefore, in the 5CM sustainability is achieved by increasing and optimising the stocks of each capital within the limits imposed by natural systems.

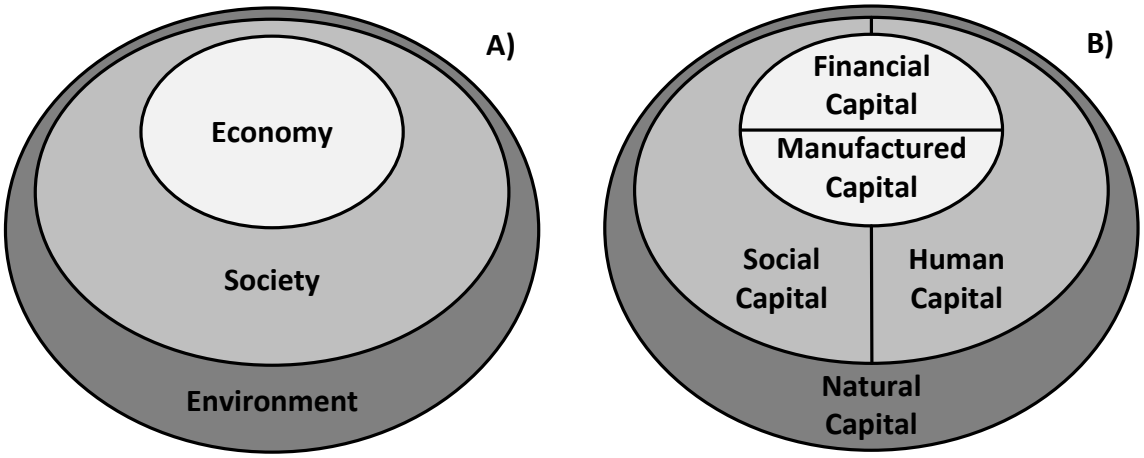


Figure 14.3| The ecological model of sustainability A) (PCE 2002) and the five capital model of sustainable developments as defined by the Forum for the Future [Source: www.forumforthefuture.org].

In the context of energy in DCs, the 5CM is better known as one of the elements in the Sustainable Livelihoods Approach (SLA), an approach created to address rural development in DCs used by several of the main Development Agencies. However, while keeping the definitions of the capitals, within the SLA, the purpose of the capitals and the relation between them is redefined.

In SLA, the term capital or asset gains a more "human face, " and is defined as resources to build livelihoods, survival, adaptation and poverty alleviation (Scoones 1998; Bebbington 1999). Bebbigton (1999) goes further and sees in capitals: capabilities to be and act (Sen 1997); assets able to give people the power to make life meaningful and "challenging the structures (Giddens 1979) under which they make a living (Habermas 1971)". Thus the five capitals proposed by the SLA include (Carney 1988; Morse *et al.* 2009; Porrit 2007; Scoones 1998):

2 http://www.forumforthefuture.org/project/five-capitals/overview

3 Scoones (1998) notes that, since "Capital" means "stock of productive resources built up by human action by investing current income streams [and, as such it could] depreciate, be consumed or be sold off", under this definition, "capital" might not be applicable to natural and social.

- **Human Capital**- The skills, knowledge, ability to labour, intellectual outputs, good health, physical capability and capacity for relationships of the individual (includes empathy and spirituality) important for the successful pursuit of different livelihood strategies.
- **Social Capital**- Includes networks and connectedness, social claims, social relations, social norms, affiliations, associations or relationships of trust, reciprocity and exchanges, communication channels and values upon which people draw when pursuing different livelihood strategies requiring coordination, partnerships and co-operation.
- **Economic or Financial Capital**- The capital base that exist in a form of currency that can be owned or traded (e.g. cash, credit/debt, savings, and other economic assets) essential for the pursuit of any livelihood strategy.
- **Physical Capital (Manufactured capita in the FF version)**- The basic infrastructure (or tools and equipment) that contribute to production or service provision, but do not become part of its output. The main components include buildings, infrastructure (transport networks, communications, waste disposal systems) and technologies (from simple tools and machines to IT and engineering).
- **Natural Capital (Environmental or Ecological Capital)**- the Nature stocks (e.g. energy, matter, genetic resources) and environmental services and processes (e.g. hydrological cycle, pollution sinks that absorb, neutralise or recycle wastes) from which resource flows and services useful for livelihoods are derived.

In terms of graphic representation the FF version, Fig. 14.3B presents an implicit hierarchy of these capitals, assuming that there are only two sources of wealth- the natural capital; and human capital- and everything else (money, machines, institutions, etc) is "derivative of these two primary sources of wealth" (Porrit 2007: 141). However, as part of the SLA, the 5CM is represented as a pentagon (fig. 14.4) to stimulate holistic thinking on the capitals interrelations, rather than proportional quantification (Carney 1998). In fact, not only there is no common measuring unit for the capitals (Bakhiet 2008: 23; Scoones 1998), but also the pentagon rarely would be regular since different livelihoods, accesses and opportunities generate different sizes, shapes and hence a deformed pentagon.

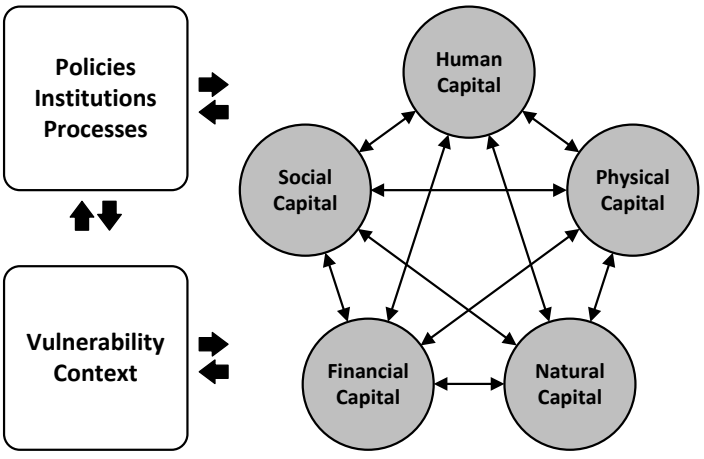


Figure 14.4| The Five Capitals Model as an interlinked pentagon in SLA [Source: partial representation of the SLA in Carney 1998].

In the context of ESy/WES, energy is a fundamental element in the 5CM, particularly as energy resource in the natural capital (e.g. wood and other biomass coming from the forest or agriculture) and in the physical capital (e.g. power lines, energy conversion technology, appliances). The inclusion of energy in these capitals not only confirms the relevance of energy for sustainable development, but also allows an interesting description of energy transition as the transformation of natural capital into physical capital, e.g., from firewood into solar panels. As a conceptual framework the 5CM has been used to describe the linkage between energy and sustainable development in terms of each capital (e.g. Bakhiet 2008; Ramani & Heijndermans 2003), as well as, to assess renewable energy technology (e.g. Cherni *et al.* 2007) and to build an appropriate framework to support the provision of sustainable renewable energy in rural areas of South African (Kruger 2007). As part of the SLA, the 5CM was used to analyse the links between the availability of energy services and the quality of rural livelihoods (e.g. Bakhiet 2008; Dyner *et al.* 2005; Ramani & Heijndermans 2003: 140-145; Salvestry 2006; Zohova 2011). Therefore, in the context of ESy, the 5CM has been used mostly as an analytical/assessment framework to support decision making and/or analyse linkages between energy and sustainable development.

However, the relevant applications of the capital approach do not end in five capitals and assessment purposes. In fact, taking advantage of the modular structure of the 5CM, several authors proposed the addition of capitals to overcome what they considered gaps in the 5CM. Scoones (1998), who ignores the physical capital, added the political and symbolic capitals. A political capital would consider the broader political conditions (including the relationship between the state and civil society) which allows or constrains the pursuit of different livelihood strategies. The symbolic capital would capture the embedded historical and cultural setting within which livelihoods are pursued. Baumann (2000) also proposes the incorporation of the political capital to give policy an equal weight with other capitals in the analysis of livelihoods, but does not provide any definition.

However, neither Scoones (1998) nor Baumann (2000) specifically identify the components of political capital, or explain how to analyse them or how to link them to the other capitals. Highlighting the importance of information in knowledge processes both Odero (2006) and Gigler (2008) suggested “information” as a 6th asset. Gigler (2008) defined this informational capital as a function of four elements: access to information; ability to process such information; the production of information within communities and networks; and the extent to which indigenous knowledge is shared. Finally, based on the 5CM, Fuad-Luke (2009) proposed a framework of ten key capitals (10KC) necessary to “nourish”, to use as a means to strategically and systematically think about existing, retrospective, and future design projects when designing sustainable products and services, fig. 14.5.

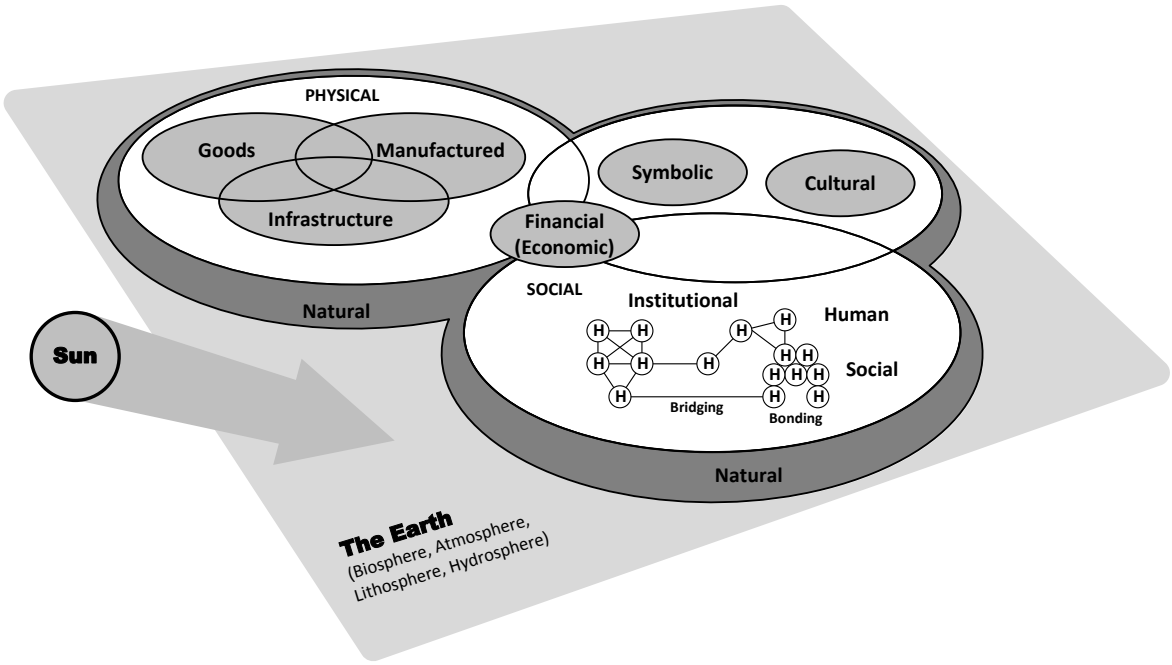


Figure 14.5| The key capitals for sustainable design (H represent people) [Source: Fuad-Luke 2009: 9].

Based on design for sustainability and systems thinking, Fuad-Luke (2009) integrated the institutional capital in the social capital and advanced 4 extra capitals[4] for the 5CM:

- **Cultural Capital**- includes three manifestations (Bourdieu 1986): an embodied state composed of inherited and acquired set of properties that confer meaning to social reality; an objectified state of culture as socially and financial valuable symbol deemed rare or worthy by society; and an institutionalised state recognising the cultural capital conferred by institutions on individuals (e.g. degrees). The currency of cultural capital is subjective and changes in the function of the social units or networks.
- **Symbolic Capital**- Confers meaning and value, and therefore status to all other capitals except the natural. Those meanings and values are both collectively and personally held and negotiated, so will shift within and between different societies and cultures, and over time.
- **Infrastructural Capital**- The Infrastructure elements in the original Manufactured Capital held in public, public/private or private ownership for the purpose of the common good.
- **Man-Made (Material) Goods-** The natural capital converted by manufactured capital using social, financial and human capital and is at the heart of the "consumer economy". This capital represents the primary capital with which design works and it is implicit in the debate around sustainable consumption and production.

The capitals approach has also been used to conceptualise and analyse the process of technological choice in development context, a topic central to energy transition (§7.2).

4 In fact, the same author conceived a framework called Design "Capitalia" with 29 forms which are refinements at different degree of detail of the 10 presented of the 10 presented in fig. 14.5.

Continuing the argument presented by Bebbigton (1999), Kleine (2011) combines Amartya Sen's (1999) Capability Approach as operationalised by Alsop & Heinsohn (2005) and Giddens' (1984) philosophy on agency and structures, to "convert" the SLA (and thus the 5CM) into a Choices Framework (ChF). In order to accomplish that objective, Kleine (2011) starts by identifying the basic blocks of/for individual agency, the "resources" (a term preferred to the equivalent capitals and assets), which, together with the structural conditions, frame empowerment processes. Resources are defined in ChF after Robeyns (2003) as "individual agency-based capability inputs which, together with structure-based capability inputs, can be converted into capabilities", and classified as:

- **Material Resources-** Same as physical/manufactured capital in 5CM.
- **Natural Resources-** Same as natural capital in 5CM.
- **Geographical Resources-** Covers the practical implications of location and relative distances, and also includes the intangible qualities of a location.
- **Human Resources-** Same as Human capital in 5CM, but disaggregated into health and education skills acquired through formal and informal means.
- **Psychological Resources-** Recognised in the capacity to envision and include self-creativity and resilience in complex interrelation with spirituality or religious.
- **Information Resources-** Same as Fuad-Luke (2009).
- **Cultural Resources**- Same as cultural capital in Fuad-Luke (2009).
- **Social Resources**[5]- Set of actual and potential resources legitimised and made meaningful due to membership in a group (defined by e.g., kinship, friendship, shared ethnicity or class, or informal commonality ties) "which provides each of its members with the backing of the collectively-owned capital, a 'credential' which entitles them to credit, in the various senses of the word" (Bourdieu 1986).

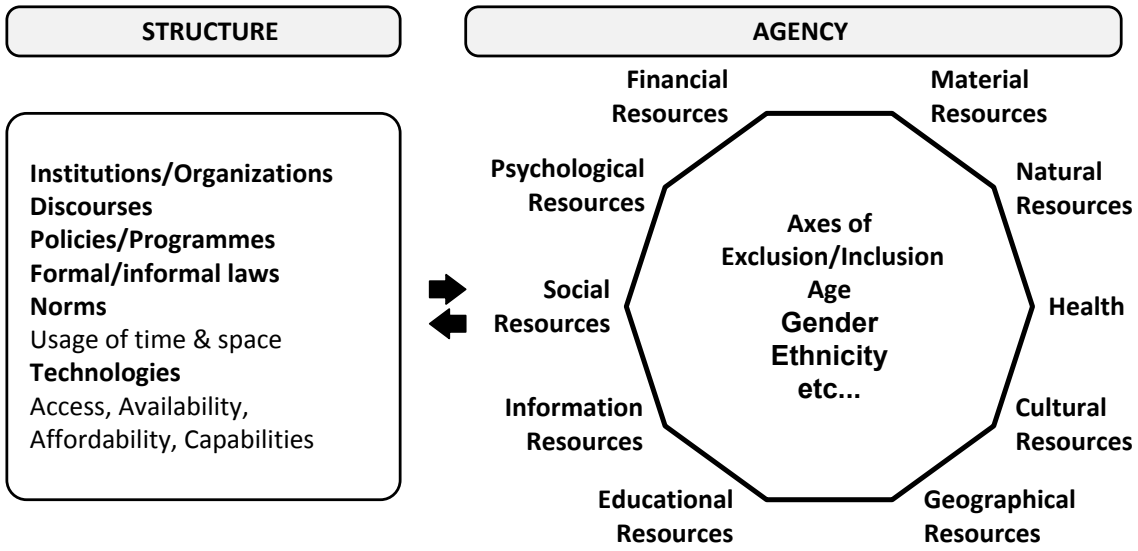


Figure 14.6| The key resources for agency in the Choices Framework (partial view) [Source: Kleine 2011].

5 Instead of Putnam definition considered in the 5CM (Porritt 2007), Kleine (2011) prefers the definition given by Bourdieu (1986). For a comparison between this two definition see Siisiäinen (2000)

Besides these main resources for/of agency, in a given social context individual's personal characteristics, e.g., age, gender, ethnicity, constitute axes of exclusion/inclusion and can affect the number and quality of resources individuals have access to, knowledge of, or possession of. Indeed, like with the capitals in the SLA, resources could be organised in portfolios people use in the choice of technology. Therefore, by identifying the resources and analysing the contextual structure (see fig. 14.6), ChF captures (maps) the way individuals use their agency (conceptualises agency), based on their resource portfolio, to negotiate social structures to obtain choices which may lead them closer to the lives they value, an outcome equated as empowerment.

Note that the ChF was conceived in the context ICT for development and is based in rural Chile, but will be use here as a proxy of a systems and ontological approach to (energy) technological transitions in developing economies. Indeed, by focusing on the building blocks of agency in the process of choosing ICT that empower users, ChF is mostly concerned with the ICT for development 4D as a prime example of a development process which has to be analysed in a systemic way. Indeed, the purpose is to operationalise Sen's Capability Approach and visualise the elements of a systemic conceptualisation of the development process. Therefore, "there is no reason why [ChF] could not be applied to any specific sector of development work or studies" (Kleine 2011: 125).

The capitals (assets, resources) as defined above seem to share a number of features with the DDs. The capitals represent the modular building blocks of complex processes in specific social contexts (e.g. livelihoods, sustainable design, choice and use of technology) i.e., the capitals can be seen as ontological dimensions of those processes, just like the DDs are the modular and essential building blocks for the process of conceptual design of WES. Both in visual terms (compare fig 14.1 and Fig. 14.4-6) and in contents (tab. 14.7, next page) there is great agreement.

The comparison results presented in tab. 14.7, clearly exposes the general good agreement between the DDs and the several capital based approaches combined. However, when considered in isolation, the DDs are always more comprehensive. In the standard 5CM, there is a complete absence of the institutional and political DD (IP), the technological DD (TT) and the Integrated Infrastructure & Networking DD (SC) that seem to have a wider definition than the respective 5CM counterpart: the physical/manufactured capital. In relation with the DDs, there are also issues of classification and perspective resulting in the Knowledge, Skills & Communication (KI) and Livelihood, Behavioural & Socio-cultural (BC) DDs being scattered in social and human capitals. The lack of political capitals in the SLA capitals and ChF resources might be explained by the fact that both SLA and ChF consider political and institutional contexts as separated elements of analysis (fig. 14.4, 6). Except for the sustainable design framework proposed by Fuad-Luke (2009), no framework considered relevant technology outside the production process (e.g. technology held by ESy actors but not directly related with the

production of energy). Likewise, none of the frameworks presented considers intangible human infrastructures (e.g. informal financial networks). Confirming the results with the standard 5CM, the separation considered in the DD between what people think, know, learn and communicate (KI) and how people construct such knowledge as social actors within socio-cultural contexts (BC), is again scattered between human, social, political, informational, symbolic and psychological capitals, which highlights both the parsimony and clarity of the DDs presented.

Table 14.7| Comparison between 5CM within the Sustainable Livelihood approach and the DDF. Besides the standard 5CN framework (Carney 1998) extra capital proposed in the literature are presented. (Conceptual overlapping[36] (●) some; (●●) substantial, but not complete; (●●●) fits completely in the DD; Dimensions are defined in §14.1) [Source: the Author]..

	CAPITALS/RESOURCES	DESIGN DIMENSIONS						
		EC	NT	TT	IP	SC	KI	BC
STANDARD	Human						●●[1]	●[2]
	Social[A]						●[3]	●●●
	Financial	●●●						
	Physical			●●[4]		●●[5]		
	Natural		●●●					
EXTRA	Political[B]				●●●			●[6]
	Informational[C]						●●[7]	
	Symbolic[D]						●[8]	●●[9]
	Cultural[E]						●[10]	●●[10]
	Infrastructural[E]					●●[5]		
	Man-Made Goods[E]			●[11]				
	Geographical[F]					●		
	Psychological[F]							●

NOTES: A- Kleine (2011) offers a different definition, but in terms of comparative analysis the results are the same; **B-** As defined by Scoones (1988); **C-** As defined by Gigler (2008) and Kleine (2011); **D-** As defined by Scoones (1998) and Fuad-Luke (2009); **E-** As defined by Fuad-Luke (2009); **F-** As defined by Kleine (2011); **1-** Lack communication channels; **2-** spirituality; **3-** communication channels; **4-** does not include the technology as goods produced, e.g., improved stove; **5-** Does not include non-physical infrastructure, like informal financial networking; **6-** Includes a cultural; **7-** Does not include channels and or skills and capacities; **8-** Deals with meaning; **9-** Does not include behaviour; **10-** Knowledge, values and skills constructed and enacted in socio-cultural contexts; **11-** Does not include, e.g., the processing technology.

Also, in comparison with the DDs, the capitals/resources seem to have difficulties to define capitals that deal with political and contextual dimensions, i.e., socio-cultural context and networked infrastructures. The addition of the "extra" capitals (political, informational, symbolic, cultural, goods) and resources (geographical, psychological) simultaneously exposes and tries to overcome the gaps identified above. Therefore, not surprisingly, the proposals are mostly defined to present, or clarify the capitals related with the TT, IP, SC, KI and BC. Unfortunately, the additions, aside the Political and Goods

capitals seem to be more heightened clarifications and further refinements, or expressions of the same ontological elements, than actual novel capitals.

Despite these differences of ontological elements, by attempting to define capitals and resources as the main conceptual building blocks to describe (conceptualise) and/or analyse (map) processes (livelihoods, design for sustainability, agency in technological choices), all these frameworks share the same design strategy of DDF, tab. 14.8.

Table 14.8| Comparison between the DDF, the original 5CM-FF, the 5CM-SLA, the 10KC and the ChF **[Source: the Author].**.

ONTOLOGICAL QUESTION: *What key elements are necessary to…*[1]	
DDF	**…think about when thinking about the conceptual design of WES?**
5CM-FF	… manage and design sustainable organisations, projects and business activities?
5CM-SLA	… make sustainable livelihoods?
10KC	… design sustainable design products and/or processes?
ChF	… have agency and make empowering technological choices?
PURPOSE 1, ANALYSIS | Describe complex …	
DDF	**… conceptual design of WES interacting perspectives of multiple actors.**
5CM-FF	... organisations, processes and business in terms of capitals hold by the Organisation.
5CM-SLA	... livelihoods in terms of capitals accessible, claimed or own by individuals.
10KC	... design contexts and processes in terms the design capitals nourished by designers.
ChF	… development around technological choices in terms of access and/or agency of resources.
PURPOSE 2, ANALYSIS | Describe how each design dimension/capital/resource…	
DDF	**… describes the conceptual design of WES.**
5CM-FF	… affects the sustainability of organisations, processes, projects or business operations.
5CM-SLA	… affects the sustainability of livelihoods.
10KC	… affects the sustainability of designed products and processes.
ChF	… affects the capability of agency for technological choices that empower users.
PURPOSE 3, ASSESSEMENT| Use design dimensions/capitals/resources to evaluate…	
DDF	**… the relative comprehensiveness of WES conceptual design.**
5CM-FF	… current and desirable relative sustainability of organisations and its activities.
5CM-SLA	… current and desirable relative sustainability of livelihood from individuals inputs.
10KC	… current and desirable relative sustainability of designed products and processes .
ChF	… current and desirable relative capability of agency for empowering technological choices.

NOTE: 1- This is a clear ontological question aimed at the common building blocks and not at the understanding of why or how to do conceptual design of WES.

The summary provided by tab. 14.8, shows a great degree of similarity between the design strategy defined for DDF and the capitals/resources approach. The ontological

question is basically the same (adapted to each diversified disciplinary context) and so are the related purposes. However, the capitals/resources frameworks are more similar among them in relation with the DDF. This conclusion is basically the result of DDF being non-normative, in particular, not defined to comply with some interpretation of SD unlike the other frameworks. Indeed, while definitely related, the capitals/resources approaches and the DDF are not referring to the same kind of design entities in the same way. While both are dimensions in design, the capitals are, or pretend to be, measurable dimensions, elements that can be combined to produce a predefined objective: the sustainability of processes (e.g. livelihoods). The capitals are the answer to that objective, but taking an "economist's" approach fails to convey the political and contextual side of design. Therefore, the capitals/resources frameworks are inherently normative, they have to be a measure of something, vehicles for instrumental action.

An aspect connecting the capitals/resource frameworks and DDF is the way users are considered designers operating with the modular capitals/resources like someone working with LEGO™ (§2). Implicit in the ontological approach is the definition of ontological elements to be used as "standardised" building blocks. For instance, in SLA, perceiving the five capitals as building blocks allows to create, describe, assess (design) livelihoods by acting on the capital endowments individuals have access to, and control over (Bebbington 1999; Scoones 1998). Moreover, since livelihoods are composed in complex ways, to reduce risk and increase robustness, people might create multiple and dynamic portfolios of different activities (different kinds of manipulations), often improvised as part of an on-going "performance" (Scoones 1989).

Similar conclusions are taken for 10KC (Fuad-Luke 2009) and ChF (Kleine 2011). Hence, in design terms, the 5CM within the SLA assumes that people, even the poorest, do have a design capability, expressed and exerted in a constant interaction with the context where they live. This "perspective" on people as designers is in clear agreement with the definition of design as capabilities, and design as reflexive action, a learning by doing, or experimenting that constitutes the design philosophy behind the DDs (§9.2). The capitals/resources approach does recognise people as reflexive designers, but that acknowledgement is not integrated in the any framework presented. Indeed, as tab. 14.8 highlights, the capitals/resources approach is composed mostly by management or evaluation tools to help planners, and in particular, energy planners, to: quantify and understand what capitals people have access to; what interlinkages between the capitals that different groups may have access to; and what design strategies people came up with.

However, all these analyses will help the planner to design plans and policies more in line with what was assessed. On the other hand, DDs refer to dimensions as aspects, facets to *think about* in participatory, conceptual design process. These DDs will not produce sustainable WES *per se*, and much less sustainable livelihoods, nor evaluate the quality of the conceptual design produced. In resume, the framework composed by the DDF and

the 5CM do not target the same objectives the same way. The 5CM uses the building blocks as assessment devices, while the DDF are used as design spaces. In fact, the attempt of the capitals/resources approach to impose quantifiable or measurable building block (key capitals) is problematic with less tangible and explicit dimensions. Nevertheless, by sharing similar, essential building blocks, the similarities found (tab. 14.7-8) provides a great proof of concept regarding the possibility and usefulness of ontological analysis to build design and planning tools.

B| Frameworks For Sustainable Wood Fuel Production

Reflecting concerns of the impact of WES on DCs' forests, research has been conducted on the possibility to produce certification mechanisms for sustainable WF production. In general, these are adaptations of sustainable forest management (FAO 2010; Rose *et al.* 2009), but there are also some efforts to derive sets of indicators for biomass usage as part of sustainability assessment strategies (e.g. Kurka & Blackwood 2013).

A criterion is a "standard that a thing is judged by", and serves to define and enhance the operability of management goals and principles, but, unlike indicators, criteria do not measure performance (FAO 2011: 12). Sustainability indicators (SDI) are, in general, associated with assessment, but in recent times they have gained relevance as tools for communication, strategic thinking and reporting (Bakkes *et al.* 1994; Cormier *et al.* 1993; Hamilton 1995; IAEA 2005; Warhurst 2002; WB 2004) or have been used to infer and describe the status of a particular sustainability criterion (FAO 2011). As a result, SDI can be viewed as models translating physical and social science knowledge into manageable units of information that can facilitate decision-making and communication (UNCHS 1997; UNCSD 1996). Hence SDI are used as "sustainability representations" from where DDs can be derived.

Indeed, sustainability criteria and SDI are relevant for this comparison not because of their practical or instrumental value, but rather for how SDI can inform about what aspects, element or dimensions have been considered (thought of) in the assessment of generic WES (i.e. as meta-information). Identifying that focus is a way to retrieve the perspectives (DDs) that guided the design of generic WES. For instance, the criterion that "information on the status and use of WF resources is available" (FAO 2011: 62) establishes a generic sustainable WES. The formulation of the criterion implies a concern on "information sharing" and "data collection, " and thus, the conceptual design of a sustainable WES should consider the existence of communication channels and actors' ability and interest in collecting data and sharing it. Sustainability criteria and indicator frameworks can be implemented at local, provincial, national and international level, but only few are dedicated to energy, and even then, the focus is on RETs. The exception is criteria and indicator frameworks developed to assess the sustainable production of WF for energy purposes listed in tab. 14.9:

Table 14.9| Criteria and indicators for the sustainable production of WF in DDF terms [Source: the Author]..

#	REFERENCE	ESy	LOCATION	CRITERIA & INDICATORS						
				EC	IP	TI	KI	IN	BC	NT
1	**Bhattarai (2009)**	Charcoal	Nepal	●	●	●	●	●	●	●
2	**Clarke (2009)**	WF	Dcs		●		●	●	●	●
3	**Clarke (2009)**	Charcoal	Dcs		●		●	●	●	●
4	**Fao (2011)**	WF	General	●	●	●	●	●	●	●
5	**Fao (2011)**	Charcoal	General	●	●	●	●			●
6	**Kurka & blackwood (2013)**	Biofuels	Scotland	●	●	●	●	●		
7	**Lattimore *et al.* 2009()**	WF	General	●	●	●	●	●	●	●
8	**Malimbwi & zahabu (2009)**	WF	Tanzania	●	●	●	●	●	●	●
9	**Malimbwi & zahabu (2009)**	Charcoal	Tanzania	●	●	●	●	●	●	●
10	**Nogueira & uhlig (2009)**	WF	Brazil		●	●	●			
11	**Nogueira *et al.* (2009)**	Charcoal	Brazil		●	●	●			●
12	**Remedios (2009)**	WF	Philippines	●	●	●	●	●	●	●

As with the previous comparisons, the information provided by the criteria and indicator frameworks coded into tab. 14.9 shows a very good agreement is very good, with half of the frameworks compared fulfilling all the DDs with at least one aspect.

C| Frameworks For Planning Energy Projects In Developing Countries

In practical terms, the design on ESy in DC, and particularly in Mozambique, is implemented through projects funded by donors or national governments. Frameworks that make explicit how these projects are conceptualised can constitute a rather interesting reference for comparison. In the following, two frameworks for sustainable energy projects will be presented for their relevance to the present work.

The first framework, the "Framework for Rural Energy Service Provision and Creating an Enabling Environment" (FRES), fig. 14.7, was developed by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP 2007). The FRES was developed from worldwide experience gained on public-private partnerships for integration of energy and rural development policies, to address the sustainable development and poverty reduction in the Asian Region. As a design tool, the FRES was developed as an analytical framework (or guide for replication) to promote, expand and sustain innovative community-driven approaches to energy service provision, in support of environmentally conscience and sustainable economic growth (UNESCAP 2007).

The definition of FRES starts with an analysis of the energy projects involving communities and private sector (whether they are NGOs, public organisations, private entrepreneurs or combination of these), represented as a dynamic event occurring in multi-layered systems, each with several interconnected elements exchanging information with each other and other systems, fig. 14.7.

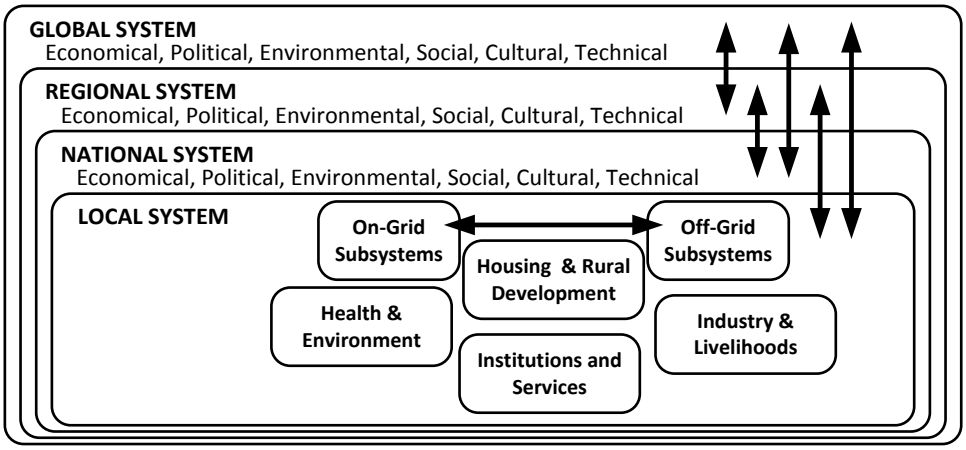


Figure 14.7| Situation analysis for a community-based integrated energy planning [Source: Adapted from UNESCAP 2007].

Each system supplies information to the environment and also gets feedback in a context where economic, political, environmental, social, cultural and technical factors interplay. Assuming that the elements in the challenge that FRES poses is in "how to synchronise governance levels in a way that institutional policy and programme level is brought down effectively to the project level and vice-versa on a programmatic approach" (ESCAP 2007: 6). To address this challenge and situation analysis, the FRES, fig. 14.8, proposes a framework with a core composed by community and private sector, exchanging information and making decisions at the planning stage and, eventually, on a day-to-day operating stage at two levels of application: the macro (national and at the local government level) for the policy, programme, legal and institutional elements; and the micro (community level) for the project delivery/financial mechanism, business plans, sustainability plans, risk management and other relevant issues to ensure economic and sustainable operation of the energy service provision.

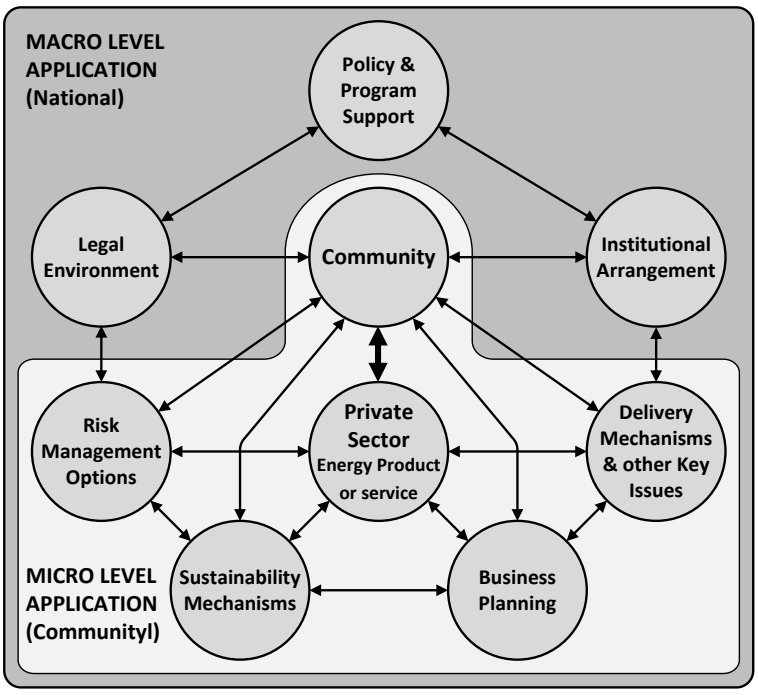


Figure 14.8| The FRES analytical framework for community-based energy service provisions [Source: Adapted from UNESCAP 2007].

The definition of the elements in fig. 14.8 is given in the following list (UNESACP 2007: 10-20).

- **Legal Environment**. Enabling laws supporting energy service provisions in rural areas as well as green (or RE-based) business development includes the support and/or work for the enactment of proactive legislation, which clearly defines social vulnerable consumers and institutionalise policies and programmes supporting green business development.
- **Delivery Mechanisms & Other Key Issues**. Focus on data collection and processing, gender issues, technology options, energy products and services, affordable delivery mechanisms, innovative financing mechanisms and community involvement in all stages of the project or business.
- **Policy And Programme Support**. Includes an array of policies and approaches, e.g., institutional coordination around the energy sector as a whole, and Integration of energy with other development sectors. Emphasis on market or environment conducive to private sector participation, as well as. the formulation of bottom-up approach to rural energy policy, wider access to energy services; smart subsidies; prioritisation of remote rural areas without grid access; supporting sustainable production and efficient utilisation of fuelwood.
- **Institutional Arrangements**. Define institutional structures appropriate and/or dedicated to rural energy service provision, and promote Participatory approach with clear roles for each stakeholder.
- **Business Planning.** Also includes operations for community-driven renewable energy service provision, and intends to satisfy the needs of the community with the suitable investment, community involvement and proper turnover of the project or business to the community.
- **Sustainability Mechanisms**. Includes the Appropriate systems and mechanisms in place to sustain the project or business in the long term, considering aspects such as, technical sustainability/after-sales service, financial sustainability and institutional sustainability.
- **Risk Management**. Define an appropriate risk management system in place to address potential problems in business operations in order to identify, monitor and evaluate risk factors to implement mitigating measures.

Both visually and conceptually, the FRES is remarkably similar with the DDF. However, the evident business nature of the FRES virtually leaves out two important DD, both crucial to describe any WES design, namely: the resource; and the knowledge and communication, only mentioned implicitly. The comparison between the FRES and the DDF is done in tab. 14.10 (next page).

Table 14.10| Comparing the FRES and the DDF. (Conceptual overlapping : (●) some; (●●) substantial, but not complete; (●●●) fits completely in the DD.; Dimensions are defined in §14.1) [Source: the Author].

	FRES ELEMENTS	DESIGN DIMENSIONS						
		EC	NT	TT	IP	SC	KI	BC
MACRO	**Legal environment**.				●●●			
	Policy and programme support	●●[1]		●[2]	●[3]	●[4]		●●[5]
	Institutional arrangements				●●●			
MICRO	**Delivery mechanisms/Other key issues**	●[6]		●●[7]	●[8]	●[9]	●[10]	
	Business planning	●●[11]			●[12]		●[13]	
	Sustainability mechanisms	●[14]		●[15]	●[16]			
	Risk management			●[17]	●[18]		●[19]	

NOTES: 1- Create market; **2-** supporting WF sustainable production; **3-** Appropriate institutional coordination; **4-** Integration of energy with other development sectors; **5-** formulation of bottom-up approach to rural energy policy, wider access to energy services; prioritization of remote rural areas without grid access; **6-** innovative financial mechanisms to deliver affordable electricity; **7-** Technology options and services, deliver mechanisms; **8-** Data collection and processing and involvement of community; **9-** consider gender issues; **10-** knowledge created and shared through participation; **11-** ignores finance aspect; **12**- involvement of community; **13**- knowledge created and shared through participation; **14-** financial sustainability; **15-** technical sustainability; **16-** institutional sustainability; **17-** technological risk; **18-** Implement risk assessment.

Another conceptual framework approach to the design of energy projects in DCs is provided by the UNDP (2008). This report sets to identify the building blocks of energy projects based on success stories in poverty reduction through energy systems in Asia, and identifies nine of these building block, defined bellow (UNDP 2008: 24-44) and compared in tab. 14.11:

- **Consultative Processes And Participation**. Crucial building blocks including the processes of participation used to identify, deliver and evaluate the suitability of energy services for local demand and conditions.
- **Assessments And Analysis**. The collection and processing of accurate and realistic data to ensure effective design, implementation and evaluation of energy projects considering data on**,** e.g., socio-economic context; needs and barriers to sustainable energy; project viability and benefits as perceived by users and beneficiaries.
- **Awareness-Raising**. The effective use, by organisations involved in energy projects (e.g. NGOs, research institutes, government, civil society organisations), of information and communication enacted through proper channels and networks to bring about change, introduce new ideas, approaches and technologies.
- **Capacity Development**. The increase in technical, management, institutional capacities and skills through the transfer of technical information tailored to the socioeconomic and policy context that builds on existing knowledge and practices.
- **Community Ownership And Management**. Highlights the importance to ensure that end-use devices critical to women and men are actually managed and even owned (not only made available) by the users and/or community.

- **Technical Considerations**. All the technical dimension of energy projects, including the suitable technical properties of the technology, cost-effectiveness, implementation, management, maintenance and suitability to local, social and biophysical conditions.
- **Financial Sustainability**. Defines the economic aspects that limit the access to energy service providers, as well as, all the possible financial mechanisms (e.g. grants, subsidies; micro-financing) that should be considered in order to design and implement projects that are financially sustainable and eventually self-financed.

Table 14.11| Comparison between the building blocks of energy projects (UNDP 2008) and the DDF. (Conceptual overlapping[36]: (●) some; (●●) substantial, but not complete; (●●●) fits completely in the DD; Dimensions are defined in §14.1) [Source: the Author].

THE BUILDING BLOCKS OF ENERGY PROJECTS	DESIGN DIMENSIONS						
	EC	NT	TT	IP	SC	KI	BC
Consultative processes & participation				●[1]		●●[2]	●[3]
Assessments and analysis				●[1]			
Awareness-raising						●●[4]	
Capacity development						●●●	●[3]
Community ownership & management			●[5]	●[6]			●[7]
Technical considerations			●●●				
Financial sustainability	●●●						
Institutional support and coordination				●●●			
Market development	●[8]		●[9]		●[10]		

NOTES: 1- participatory processes developed by Institutions; **2-** does not include skills and communication channels; **3-** considers socio-economic aspects for design; **4-** Does not consider learning processes; **5-** ownership of technology; **6-** ownership defined by institutional arrangements; **7-** ownership defined by socio-cultural arrangements; **8-** the business side of the supply chain; **9-** the technological side of the supply chains and energy hubs; **10-** the importance of infrastructures and synergetic effects of infrastructures.

According to the tab. 4.11, the building blocks are not to be articulated to produce an ESy, although that could happen, they are rather a check list to success. The absence of explicit reference to nature or natural resources, the scattering of contextual DDs (BC e SC) and the prevalence of knowledge (KI), institutional (IP), technological (TT) and economic (EC) further denounces the business and normative nature of the building blocks in the FRES. However, the DDF clearly cover all the aspects considered in the FRES.

14.4.4 The Evolutionary Framework

In line with the philosophical perspective defended for this thesis (§2, §9.1), Foxon (2011) proposed a Co-evolutionary Conceptual Framework (here CEF) for analysing transitions to a sustainable, low-carbon economy. CEF Combines ecological and economic insights with ideas from recent thinking on socio-technical transitions, innovations systems, industrial dynamics and evolutionary economics to analyse the dynamic processes that contribute at multiple levels to a transition to a low carbon energy economy. According to Foxon

(2011), current ESy are locked into unsustainable high carbon systems of production and consumption, and thus, the transition to a sustainable low carbon economy requires radical changes in the practices of energy use; innovation and deployment of a range of low carbon technologies; and broader change in the mix of industries within national and global economies. Moreover, focusing on the sustainability of the process, Foxon (2011: 2258) defends that these changes need to "contribute to maintaining and widening economic prosperity in a socially equitable way, whilst ensuring that these socio-economic systems remain within ecological limits". Departing from this disciplinary background and sustainability approach to energy transitions, Foxon (2011) identify ecosystems, technologies, institutions, business strategies and social practices, within a multi-level micro-meso-macro perspective as key co-evolving systems relevant for analysis of a transition to a sustainable low carbon economy, fig. 14.9. These key co-evolving systems constitute the CEF, and the argument follows that any transition analysis should examine the evolution (changes) of each of these systems (and their causal interactions) defined as:

- **Ecosystems**. Systems of natural flows and interactions that maintain and enhance living systems.
- **Technology (Technological Systems)**. Methods and designs for transforming matter, energy and information from one state to another in pursuit of a goal or goals.
- **Institutions (Systems Of Institutions)**. Ways of structuring human interactions, "the rules of the game, " (North 1990) which are taken to include, e.g., regulatory frameworks, property rights and standard modes of business organisation.
- **Business Strategies**. The means and processes by which firms organise their activities to achieve their socio-economic goals. Includes social enterprises which are more explicitly oriented at delivering useful goods and services to citizens and communities, and may or may not have the aim of delivering a profit or financial return.
- **User Practices**- Routinised, culturally embedded patterns of behaviour relating to fulfilling human needs or wants.

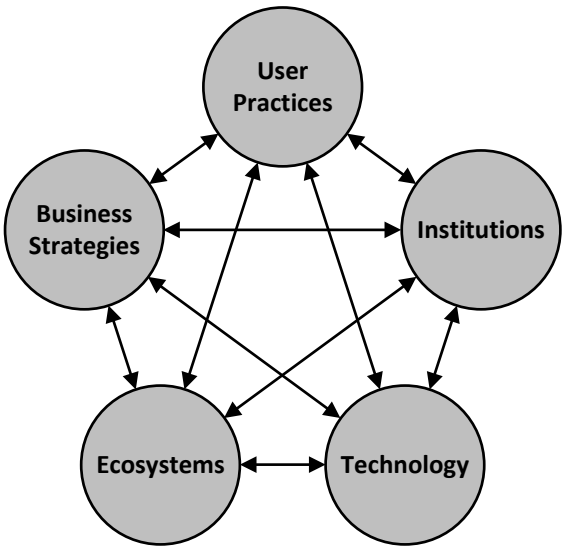


Figure 14.9| A coevolutionary framework for analysing a transition to a sustainable low carbon economy [Source: Foxon 2011].

In conclusion, the changes to low carbon ESy may occur through technological changes, forming of institutions, revisions to business strategies or changes in user practices, and how these changes interact with changes in natural ecosystems. Therefore, the value of the proposed coevolutionary framework lies both in "its identification of key elements and their interactions for analysis, and in providing a particular conceptual framework for this analysis [while avoiding trying to be a 'theory of everything']" (Foxon 2011: 2261-2262). Foxon (2011: 2263-2265) highlights the potentiality of the CEF to: 1) inform detailed empirical analyses of policies to promote low carbon technology innovation; 2) analyse the interaction of social and technological elements within potential transition pathways to a low carbon energy systems; 3) assess economic growth in those processes; and 4) assist the development of more formal, multi-level evolutionary economic models. Note how application 3 and 4 can be seen as the (conceptual) design of assessment and model of sustainable energy transitions.

Table 14.12| Comparison between the coevolutionary framework for analysing a transition to a sustainable low carbon economy (Foxon 2011) and the DDF. (Conceptual overlapping[36]: (●) some; (●●) substantial, but not complete; (●●●) fits completely in the DD Dimensions are defined in §14.1) [Source: the Author].

KEY CO-EVOLUCIONARY SYSTEMS	DESIGN DIMENSIONS						
	EC	NT	TT	IP	SC	KI	BC
Ecosystems		●●●					
Technology (technological systems)			●●●				
Institutions (systems of institutions)				●●●			
Business strategies	●●[1]						
User Practices							●●●

NOTES: 1- Does not explicitly includes economical and business aspects.

Besides the philosophical and structural similarities with the present work, the process and topic are very similar. Foxon (2011) starts from a perspective (coevolutionary) which entails a number of relevant philosophical stands regarding the relationship between humans-nature, technology and society, a context (ESy transitions) and an approach (sustainability) and then scopes the relevant domain (coevolutionary disciplinarians approaches to ESy transitions). Subsequently, a conceptual analysis of that domain integrates key co-evolving systems, their definitions and interactions to constitute a analytical conceptual framework, which can be used to analyse and design interventions and assessment (potential applications 3 & 4). Moreover, CEF is strongly inspired in the five elements coevolutionary framework developed by Norgaard (1994) to analyse how the imposition of external technologies and practices in the name of "development" often undermined more local systems of production and consumption that were well adapted to their local ecological settings, an argument considered in this work (§8). However, as the comparative results in tab. 14.12, show, for the purpose of conceptual design of WES (and probably for any ESy) the CEF fall short in the number and scope of the elements presented. While, Norgaard (2005), Foxon (2011: 2259) states that "the

choice of a particular coevolutionary framework is determined by its usefulness for addressing a specific ecological economic challenge, [and thus a] basic framework could be expanded to include other types of co-evolving factors", CEF does not include any explicit element equivalent to Knowledge/Skills/Communication (KI) or Integrated Infrastructure & Networking (SC) DDs. Moreover, the CEF continues to be analytical and normative, not aiming at the non-prescriptive design. The assessment and modelling would be guided by the inevitability of the transition under the normative stance of sustainability.

14.5 INTEGRATED ANALYSIS OF THE DESIGN DIMENSIONS FRAMEWORK

This part of the chapter will integrated the analysis done so far in this chapter to conclude on the comprehensiveness, consistency and relevance of the DDF. The results obtained in this analysis will allow draw some conclusions and make a bridge to the next chapter.

14.5.1 On The Conceptual Analysis Process

Before presenting the actual analysis of results it is important to clarify some issues with the conceptual analysis. First, the definition of the DDs was not a linear process; neither the comparison was a static assessment of similarities. The results presented and semantic definitions resulted from a permanent dialogue between the classifications done by the several definitions compared and the arguments and critical literature review on WES done in previous sections.

From this critical dialogue, Therefore, most of the results presented are the result of careful, coherent and interactive interpretation of the classifications and explanations given in the documents used. The results are visible both in the definition of the DDs, and in the classification of the other authors. While the main concept of each DDs was defined from the critical and exploratory literature review (§B) it was expanded and clarified by interaction with the insights provided by other authors. On the other hand, some authors had their original classification "re-classified" to fit the definitions and internal coherence of the conceptual analysis. Finally, some of the classifications are the direct result of some of the main philosophical stands on this research. For instance several authors identify the lack of capabilities, skills, training and knowledge as separate barriers.

However, as argued before here (§9.3), communication (dialogue), learning (training), dialogue (communication) are all different aspects of knowledge in action in the context of design, therefore all the barriers associated with communication (information), training, skills and capabilities have been grouped in the *knowledge, skills and communication* design perspective. Operating similar critical conceptual analysis on the others design elements it was possible to establish a direct relation between the barriers to energy transitions identified in the literature and the design perspectives presented earlier in §14.2-4.

14.5.2 Comparing The Design Dimensions Defined By The Interviews

The interviews conducted in the rural areas and with experts in Maputo and abroad to identify the main DDs (tab. 14.2-3) have been assessed for comparative purposes. The data presented here combines for each group (the experts and the rural communities) the results of two interview strategies combined, the question on barriers to energy transitions and the story telling around a typical day of collecting firewood or making charcoal, for rural interviews, and possible perspectives on WES and limitations to an ideal WES, for experts (§14.3). Plotting then number of positive replies on a DD (the interviewee or group of interviewees identified that specific DD as a main fundamental design concern) over the total number of replies, it is possible to obtain a percentage of positive identification for each DD, fig. 14.10.

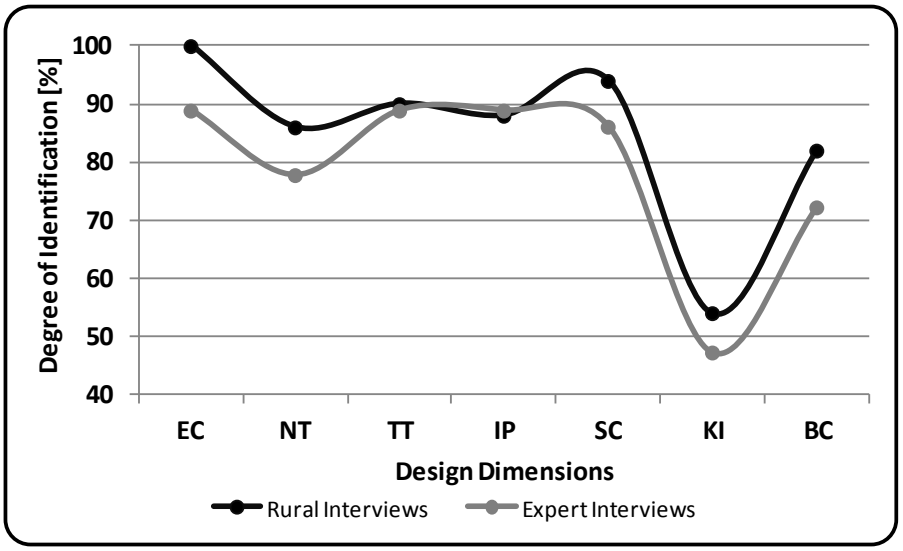


Figure 14.10| Percentage of positive identifications for each DD from the interviews in rural areas of Mozambique and interviews with experts (DDs as defined in §14.1) [Source: the Author].

The results from the interviews conducted in rural areas and with experts show a remarkable ontological coherence expressed is an almost overlapping of data, both in values and general trend. Not only the experts and rural communities consistently see the same problems, but they also value equally, both in absolute and relative value, the importance of the DDs proposed in this work.

14.5.3 Trends On Barriers, Limitations, Criteria And Indicators

Barriers identified by experts, rural communities, and in the literature, as well as, published criteria and indicators (C&I) for sustainable WF production have all been quantified the same way and will be evaluated together here. By “the same way” it is meant, by the same percentage of positive identification for each DD. Since a significant number of papers and interviews is available and most identified as main design concern several aspect included in the definition of each DD, it was possible to define the

percentage of people/authors identifying each DD as it was defined in the DDF. Therefore, the percentages used in fig. 14.11-12, represent the number of interviewee or papers identified a DD (i.e. several elements included in the definition of such DD) as a concern in their barriers and/or C&I frameworks. However, the barriers from different sources, C&I refer to different aspects of the same reality: factors that enhance or prevent a desired change, that is, obstacle challenges or insights in the WES design. The barriers the experts identified referred to possible obstacles for the implementation of what they considered ideal WES. The barriers identified in rural interviews refer to the energy impediments to energy transitions to electricity or gas. The barriers from the literature are mainly related with the problems and difficulties to deploy energy policies, technology and projects. Finally criteria and indicators (C&I) for sustainable production of WF are related with the barriers in the sense that C&I define what should be considered to grant sustainability of production, that is, what should be taken care of in order to avoid possible barriers. These barriers and C&I are all used as ”research probes” into the context of WES design with the purpose of unveiling coherent DDs or, conversely, testing if the DDs’ definitions coherently and comprehensively cover the barriers and C&I . The consequences for the present analytical process are twofold. First, it will not be realised by a side-by-side comparison and (while interesting) it is outside the scope of this work to analyse the reasons why these discrepancies occur. Instead, the barriers and C&I will be assessed as a whole on their capability to identify the DDs and on the cumulative, relative incidence of those same DDs. Secondly, since the barriers and C&I refer to different biomass technologies and resources (see tab.14.4), a calibration based on a multiplication factor, tab. 14.13, was done to privilege the results on ESy based on WF resources for heat in Mozambique or other developing contexts.

Table 14.13| The multiplication factor to be applied to the results obtained with the identification of DDs using data from barriers, criteria and indicators of sustainable WF production (WF- includes firewood and charcoal; Biomass- all biomass resources with some reference to WF or woody biomass; Bio energy- considers at least in part firewood as a resource; Renewable (energy)- includes renewable in general with some reference to biomass) [Source: the Author].

LOCATION OF THE WF SYSTEM	BIOMASS ENERGY SYSTEMS WITH:			
	WF	BIOMASS	BIOENERGY	RENEWABLE
General	2	2	1	1
Developed Countries	3	2	1	1
Developing Countries	4	3	2	1
Africa	4	3	3	1
Mozambique	5	4	3	2

The results of the application of the multiplication factors on the barriers and C&I from the literature are presented in fig. 14.11-12. The results did not change much, presenting only “smoother” curves after calibrations which might be associated with the robustness of the data in relation with the proposed DDs.

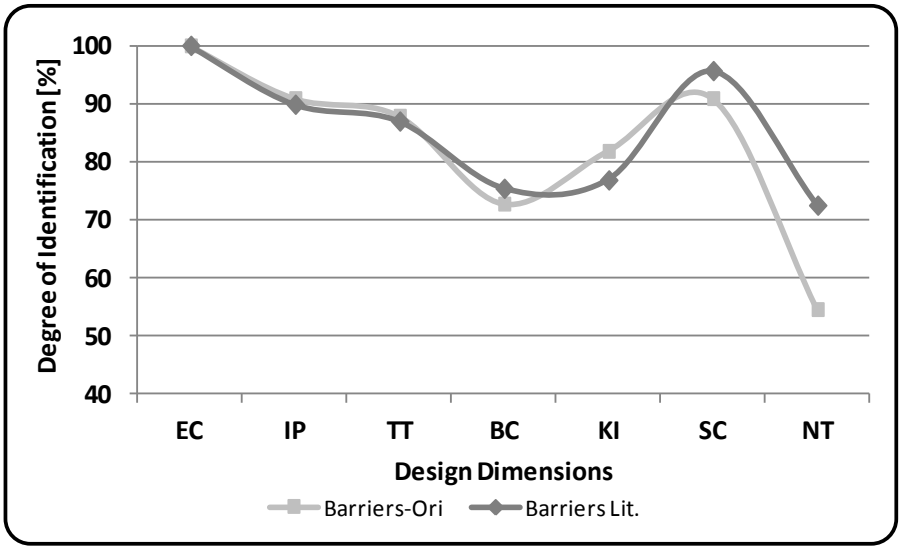


Figure 14.11| The results for barriers identified in the literature (tab.14.4) before (Barriers Ori) and after (Barriers Lit) the application of the multiplication factors for calibration from tab. 14.13 (DDs as defined in §14.1) [Source: the Author].

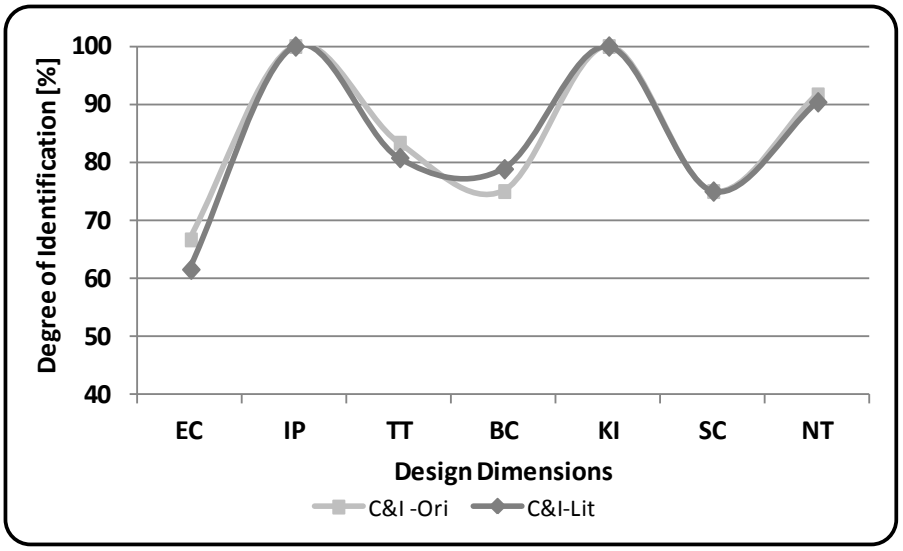


Figure 14.12| The results for criteria & indicators for sustainable WF production identified in the literature (tab. 14.9) before (C&I Ori) and after (C&I Lit) the application of the multiplication factors for calibration from tab. 14.13 (DDs as defined in §14.1) [Source: the Author].

The complete results, including the barriers identified in the interviews and the literature on barriers and C&I after the calibration with the multiplicative factor of tab. 14.13, are presented in fig. 14.13 with the addition of the combined results (i.e., the sum of all results). The combined results (black tick line in fig. 14.3) are closer to the data from interviews (dark gray round markers on fig. 14.3) simply because there are more data points and all them have the highest multiplicative factor (over 98% are WF in Mozambique). However, for the assessment objective defined in this analysis, what is important is the overall trend showing that all DDs have been identified, even if not by everyone all the time in the interviews. That is clear on the quite high values for literature on C&I and barriers. The combined results also present an interesting linear relation for

the DDs (R^2 of 0.93) which might indicate some overall consistency of preferences in the apparent diversity of results. Economical/financial/business (EC), are at the top of these preferences followed by the institutional/political (IP) and technological (TT) DDs, which are in accordance with some similar research on the "fundaments" or "conceptual building blocks" of human society and thus, implies the design of that particular society. For instance, Beinhocker (2006) argues that the western economic development was underpinned by the coevolution of physical technologies, social technologies (institutions) and business strategies by stimulating innovative new ways to meet (and create) end-user demands. Remarkably the three categories indicated by Beinhocker (2006) are the equivalent to TT, IP and EC respectively.

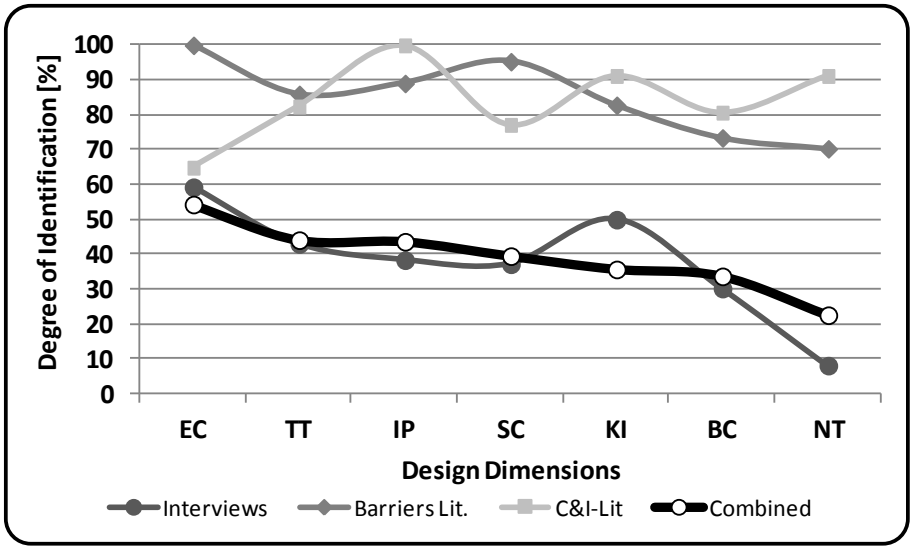


Figure 14.13| Percentage of positive identifications for each DD from barriers, criteria, indicators of sustainable WF production and cumulative results (C&I Ori) and after (C&I Lit) the application of the multiplication factors for calibration from tab. 14.13 (DDs as defined in §14.1) [Source: the Author].

14.5.4 Comprehensive Analysis Of Conceptual Frameworks Comparisons

The previous comparisons with literature and interview data were done on the basis of number of positive identifications. However, with conceptual frameworks, since they shared the "building block" design perspective and presented explicit definitions of each of the "building blocks" considered, the positive identification analysis performed above was not possible. Instead a "critical interview" was engaged with each of these conceptual building blocks, having as reference the definition of the DDs listed in §14.4.

To assess the comprehensiveness of DDF in relation with the other conceptual analysis it is important to identify if the DDs that compose the DDF are fully represented in the other frameworks and vice versa. Evaluating the degree of conceptual overlapping (tab. 14.7, 14.10-12) and assuring that the categories proposed by existing conceptual frameworks were all fully integrated into the DD, it was possible to see how each conceptual framework fitted with DDF (but not obligatorily vice versa) while assuring that

"no conceptual bit was left outside". Thus, to assess comprehensiveness it is necessary to check if all DDs completely overlapped with the "building blocks" of other conceptual frameworks (the "●●●" in tab. 14.7, 14.10-12). The results are in tab. 14.14.

Table 14.14| Identification of the complete conceptual overlapping between the DDs and the several conceptual categories form each conceptual framework, including the Ways of Representing Energy (WRE), the Five Capitals Model (5CM) and related capitals tab. 14.7; the "Framework for Rural Energy Service Provision and Creating an Enabling Environment" (FRES) tab. 14.10; the Energy building blocks framework tab. 14.11; and the coevolutionary framework for analysing a transition to a sustainable low carbon economy (CEF) tab. 14.12 (DDs as defined in §14.1) [Source: the Author].

CONCEPTUAL FRAMEWORK	CONCEPTUAL CATEGORIES	DDs SCORE ●●● IN TAB. 14.7, 10-12						
		IP	TT	EC	NT	BC	KI	SC
WRE	Commodity			●				
5CM & Related	Social					●		
	Financial			●				
	Physical + Man-Made Goods		●					
	Natural				●			
	Political	●						
	Physical + Infrastructural							●[1]
FRES	Legal Environment	●						
	Institutional Arrangements	●						
Energy Projects Building Blocks	Capacity Development						●	
	Technical Considerations		●					
	Financial Sustainability			●				
	Institutional Support & Coordination	●						
CEF	Ecosystems				●			
	Technology		●					
	Institutions	●						
	User Practices					●		
	Total	5	3	3	2	2	1	1

NOTE: 1- In reality this is not a "●●●" score, but it is very closes (see tab. 14.7).

As the tab. 14.14 indicates all (with the relative exception of Infrastructure and integrated network, SC) DDs are represented in all other conceptual frameworks considered and vice-versa. Again, considering that "no conceptual bit was left outside", it is expected that several other key concepts might be scattered in different DDs, making probably more complete overlapping (in graphical terms something like "●"+"●●"="●●●"). However, that analysis was excluded since the purpose is only identify the coherence and comprehensiveness and for that a positive result is already sufficient. Moreover, it is relevant to point that following the same trend displayed in fig. 14.13, IP, TT and EC are the most fully conceptually identified (i.e. more times conceptually overlapped) DDs,

reaffirming then a good coherence and consistency of results across different modes of doing the same comprehensiveness analysis.

14.5.5 Whole Comprehensiveness Analysis

All the previous results can be combined in one single comprehensiveness analysis considering the differences already exposed in the comparison between then between DDF and the conceptual framework and the other "research probes" fig. 14.13.

The fig. 14.14 provides a visual representation of the overlap between all analysis considered in §14.2-4 and the proposed DDF in terms of both DDs and mode of overlapping assessment, i.e., positive identification (+id in fig. 14.14) and conceptual comparison (CC fig. 14.14) as explained above.

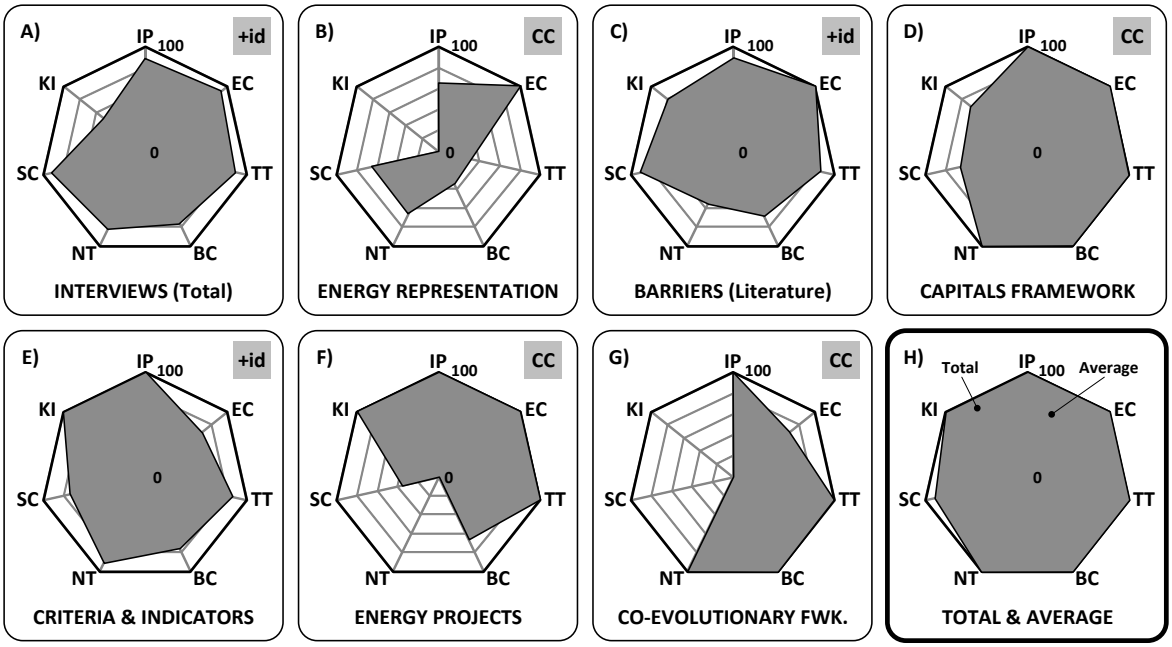


Figure 14.14| Degree of overlapping (%) for all the frameworks analysed in this work, according to DD and mode of overlapping assessment, positive identification (+id) and conceptual comparison (CC). The frameworks included: **A)** Interviews (combined values from rural and expert interviews); **B)** Modes of representing energy; **C)** Barriers for the Literature; **D)** Capitals framework (combined values of the several approaches); **E)** Criteria and indicators of sustainable fuelwood production; **F)** Frameworks to design and plan energy projects (combined values); **G)** Co-evolutionary framework for analysing a transition to a sustainable low carbon economy and H) commutative analyse [Source: the Author].

As it is visible in fig. 14.14, regardless of approach considered or mode of overlapping assessment no approach found in literature or interview done with experts and other WES actors, completely overlaps the DDF conceptual space, as define by the DDs. However, to be truly comprehensive in relation with these approaches, the DDF should also cover the combined conceptual space of all those approaches. Therefore, two commutative comprehensiveness analyses were performed. The first (Total in fig. 14.14) assumed as value of overlapping for a given DD the maximum value of overlapping achieved by any approached for that DD. For instance, if the approach achieved 100% of

overlapping on the DD X, then the overall cumulative overlapping for X would be 100% even if all the other approaches scored 0% for that DD X. The second was a regular average between the values of overlapping obtained both by conceptual comparison and positive identification. Again, the overlapping under these conditions is not total which seems to confirm the assertion done earlier that DDF is truly comprehensive. Moreover, there are no cumulative zero values and, in fact, all DDs scored more than 50% which implies that the DDs chosen find good correspondence on several other relevant approaches.

14.5.6 Limitations On The Design Dimensions Framework

So far, the results shown in this chapter indicate a high level of robustness, consistency, parsimony and above all, comprehensiveness of DDF (and respective DDs) as a useful non normative, non prescriptive conceptual framework to describe and specify the conceptual design of energy systems, without the need of "theory of everything." The process used to derive the DDs proved to be effective and efficient in providing contextualised DDs, to be useful in context. DDs emerge from the design context through semi-structured interviews, critical readings and continuous conceptual analysis and reflection on the results. Therefore, the DDs represent a set of relevant, contextual and comprehensive main design issues that have to be addressed while doing conceptual design of WES.

However, two interlinked aspects are relevant to explain why this work did not rest with the identification of the DDs and characterisation of the DDF, but went further to identify more detailed and formal specification of DDs, which will be named design elements, moving from DDF to the WES conceptual design metamodel (2MW).

The first aspect is related with conceptual interpretation and category building. As already discussed in the methodology chapter (§12), like any conceptual analysis, there is a subjective interpretation associated with the definitions. Indeed, different authors might consider different aspects on the same DD, not only during the conceptual analysis through which conceptual frameworks are built, but also in the process of using those frameworks. Different authors might agree that DD X is fundamental for conceptual design but disagree on the nature, scale or aspect of that dimension. For instance, two authors might identify for the same WES on the same country, the existence of a "technological" DD of/for that WES, but author "A" might be concerned with lack of technology and author "B" might be worried with maintenance. Consequently, author "A" might proceed to create a concept called "access to technology" and author "B" will prefer "maintenance services." However, while building the DDF both concerns were included as technological dimension, which favour the robustness, parsimony and comprehensiveness of DDF, but also hides the descriptive power of the DD, "Technology." On the other hand, author C trying to use the DDF to do conceptual design, when facing the DD "Technology" might have yet another idea of "technology" as "equipment" without considering how easy it is to access and maintain such equipment. Therefore, the

richness of ideas that generated DD is “lost in translation” when used in the DDF (and in most, if not all, frameworks, available).

The second aspect derives from the first and is related with the degree of abstraction. While the DDs constitute the essential conceptual design issues of a WES and represent already a metamodel (or ontology), these dimensions are too abstract and provide little assistance to define a formalised specification of the conceptual design of the WES in Mozambique. Moreover, while all the DDs are interdependent, the idea of that interaction and continuous interface between the different DDs is not clear and visible in the DDF. Each DD is not a contained design category, but rather truly spaces to think about the specific design aspects defined by that DD, and, also on interactions with the other DDs, i.e., other design spaces.

In conclusion, the DDF allow the comparison between the DDF and other relevant frameworks in terms of consistency and comprehensiveness, and the DDs, as systemic design perspectives, but it does not provide the desired level of conceptual “granularity, ” detail and description of/for the WES. The contextualised seven DDs are supporting objects, “working models currently relevant now in this study” (Checkland 2000: S20, italics in the original) to achieve that higher granularity and claim a more permanent ontological status. In the absence of a clear research domain, these DDs and the contextualised information they hold, provide the research playground where one conducts further conceptual analysis to identify more stable and ontological design elements that will constitute the 2MW (§D). While the seven DDs are a coarse categorisation, they provide the seed from wherein the design elements, which define the core of the metamodel, emerge. In the following section that path will be described.

14.6 Defining The Design Elements And Layout Of The 2MW

In this sub-chapter, the design elements that form the targeted WES conceptual design metamodel for Mozambique (2MW) are defined, described and organised in a suitable layout. In the 2MW design strategy (§13.4), this is the intermediary stage between the definition of the Design Dimentions framework (DDF) and the test of the 2MW prototypes at Mozambique. However, (as with the DDF) defining the design elements and the 2MW layout was not a linear process, but an interactive and reflexive design process where prototypes have been tested and co-designed by the author and users until a version stabilised in the form of thirteen design elements, disposed in a simple-to-navigate layout. In relation with the DDF, the 2MW shares the same purpose: to be a non-normative and non-prescriptive conceptual design tool where designers with different backgrounds jointly describe and specify the conceptual design of WES in Mozambique. However, the 2MW is less abstract, more conceptually detailed and thus more practical and intuitive to use. Remarkably, the thirteen design elements are not more detailed versions or sub-categories (sub-classes) of the DDs, but truly design artefacts emerging for the conceptual

analysis and reflexive, co-design work integrating the DDs, insights from interviewees, and relevant similar metamodels.

Since the starting point to build the 2MW is to reduce the abstraction level in the DDF, an individual conceptual analysis emerges from the main design concerns on each DD (§14.1), which then, combined with insights from other similar ontological approaches and co-design with interviewees (§13.4.1) allows for identifying and describing of the thirteen design elements (§14.6).

14.6.1 Scoping The Design Dimensions

In order to derive the 2MW design elements as less abstract (in comparison with the DDs), essential building blocks useful to allow participants to elaborate detailed conceptual design descriptions or specifications of WES, the obvious starting point is to explore further the DDs. At this point, each DD is associated with related data from the semi-structured interviews conducted with experts and rural Mozambicans, and literature on WES in Mozambique and other DCs. Therefore, each DD is not only a main design issue or systemic design perspective of/for WES in Mozambique, it is also a repository of data that ultimately justifies and defines that same DD. Therefore, a further conceptual analysis on DDs means a conceptual analysis on the data that originated each DD. The conceptual analysis on the entire data originated in the DDs for the DDF, now a conceptual analysis on each DD will beget the design elements for the 2MW. However, the DDs are open and interdependent, meaning that any further conceptual analysis has to consider the possibility that some design elements could emerge from interactions between different DDs. In other words, this is not a hierarchical conceptual process where each new level of detail obtained by further analysis results in a level that is a more precise conceptual division of the initial level. The idea is to perform a conceptual analysis on each DD (see below) to produce the design elements.

Consequently, each DD identified in §14.1 will be analysed in order to derive the main design concerns that ultimately will support the definition of the design elements here. The conceptual analysis is only concerned with what design concerns there are within each DD, not with the reasons why or how they became manifested as these and not others. These analyses, while interesting, are outside the scope of this research. The data will be depicted using a constant representation which includes, fig. 14.15: the design concerns within each DD; the relative importance of each design concern expressed as a percentage of preference (from the total how much identified this design concern); the sources of those design concerns (rural, expert or literature): and the incidence of each source in each design concern (the relative weight of that design concern on each of the sources); and some exemplary sentences that capture some of the dominant ideas in that design concern.

Explanation

1. Design Concern A represents 33% of all incidences, i.e., from all data (documents and interviews), 33% indicate this concern as fundamental for the design from the perspective defined in this design dimension (the size of the design concern circle is proportional, but the Design Dimension circle is not).
2. Incidence: the design concern A was identified by 33% of all the rural interviewees, 77% of all the experts interviewed and 8% of all data considered.
3. For the design concern A, a representative sentence was "Charcoal is hard work!"

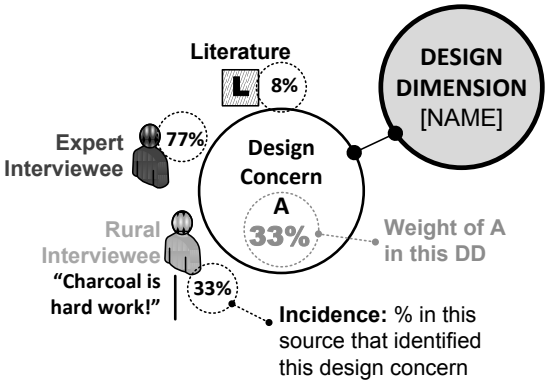


Figure 14.15| The blue-print for the representation conceptual analysis done in each DD [Source: the Author].

Before entering the conceptual analysis, note that, while presented as separated entities, the design concerns for each DD are In fact, linked in some way to each other. However, the purpose is not to define a precise and sharp classification, but rather to identify which are the major design concerns, their relative weight and how they can define the design elements that will constitute the 2MW.

14.6.2 Technological Design Dimension Conceptual Analysis

The technological DD (TT) was the most easily identified in the interviews and literature, which resulted in several design concerns according to the different sources, fig. 14.16.

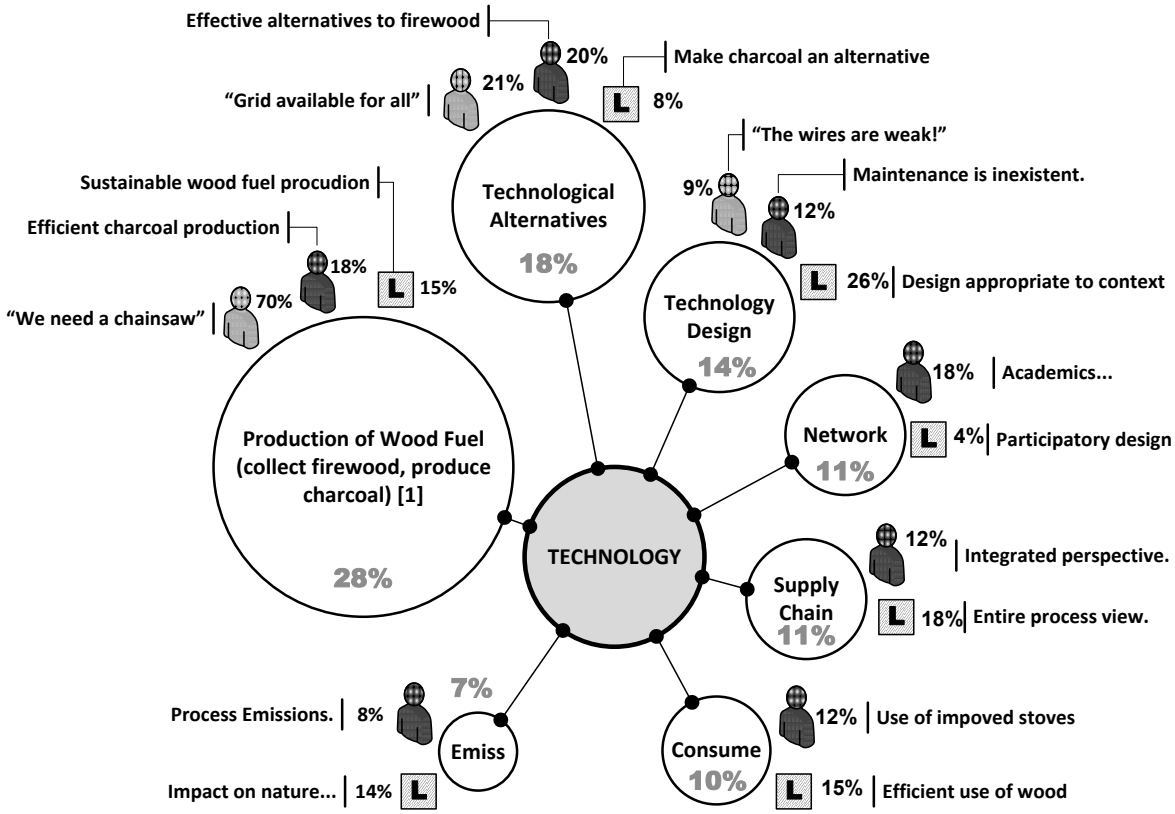


Figure 14.16| Main design concerns within the TT as defined by the interviews and relevant literature (Consume- Consumption; Emiss- Emissions) [Source: the Author].

However, a closer look seems to highlight the central relevance of the supply chain in the conceptualisation that different sources make of WES. In fact, while mentioned explicitly only in 11% of the cases, all design concerns refer to wood fuel supply chain in same way. The production (28% of preference) and consumption (10% of preference) are two possible poles in which the supply chain is normally confined. Technology design (14% of preference), technology alternatives (18% preference) and emissions (7% preference) concerns are all related with technological design of supply chains. Finally, networking (11%) refers to the possible cooperation and participation of the several actors in the supply chain in the design of technology and brings the social component of supply chains into the design of WES. This last concern was expressed by experts as an equipment design task constructed mostly around academics to study and develop alternative technological options, or as a form of participatory planning and design in some literature.

Therefore, the great outcome of this conceptual analysis on the TT is the central role played by the wood fuel supply chain in the conceptual design of WES, which includes the collection of wood, production of charcoal, distribution of the charcoal and selling and consumption for heat and cooking purposes. However, besides the relevance of the equipment and processes used, there is an important focus on the people using it and interacting with it. Both the interviewees and the literature identified the search for, or awareness/promotion of, technological alternatives as a design concern, while simultaneously pointed for the relevance of quality and appropriateness (fit to uses and culture) of that design. Thus another important outcome from this analysis is the importance of people in technology design. The networking design concern puts substantial weight on bringing the producers of wood fuel, consumers, experts and government officials to the design of supply chain technology. Moreover, it shows that while a charcoal maker can be open to technological changes if that makes sense and brings results and can be simultaneously a consumer of electricity, that is, the role played by different actors in the supply chain is quite fluid. Finally, the last issue with some relevance in the design of WES (8% incidence for experts and 14% for literature) is the impacts that supply chain technology (equipment and process) might have on the environment, in what can be seen as a rather subjective ecological cost difficult to quantify and/or qualify.

14.6.3 Institutional And Political Dd Conceptual Analysis

In the context of wood fuels, the main concerns expressed by the institutional and political dimension (IP) were, in order of relative importance (fig. 14.17 next page): legislation and regulation; political coordination and policy execution; networking; and land tenure laws and politics. With 36% of the preference, legislation and regulations proved to be a major component in WES definition in Mozambique. The majority of the rural interviewees (54% incidence) view local customary regulations and some governmental legislation as fundamental in the definition of their WES conceptual designs.

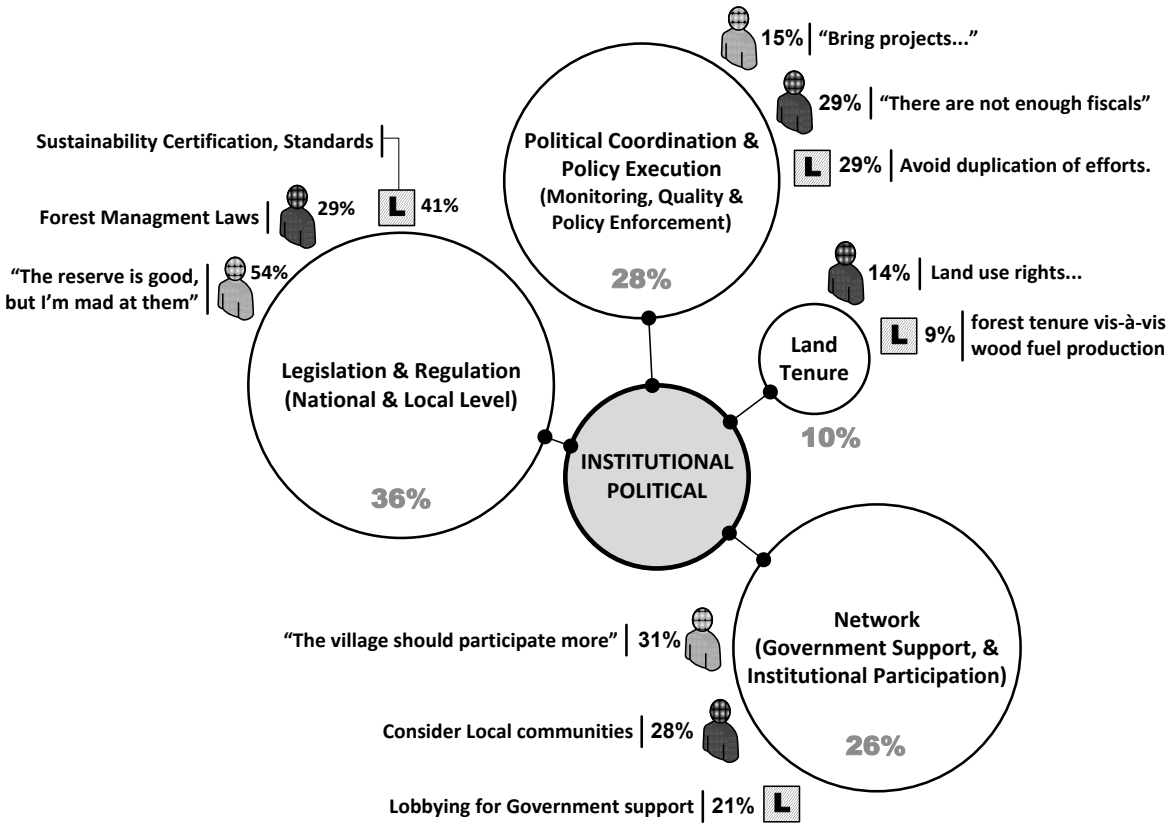


Figure 14.17| Main design concerns within the IP as defined by the interviews and relevant literature [Source: the Author].

These regulations are closely related with local knowledge and habits (§14.6.5) and include which trees to cut and which part of the tree to cut. The same concern is shared by the experts (29% of incidence) and literature (41% of incidence), However, from a technical and conservationist perspective, aims at the sustainability of the forest for a number of reasons including the economic. Related with regulation is land tenure which received 10% of preference and was identified by experts (14% incidence) and literature (9%). Despite the low values and absence of identification by rural interviewees, the fact that land tenure had emerged from the data as a singular individualised design concern reveals the importance of land in Mozambique[6]. In Mozambique the land cannot be owned, only used or explored with the State consent, However, "owning" the land does not necessarily means owning the trees above it, like owning the trees does not imply rights over the land where they stand. In Mozambique, land and resources ownership is a rather complex issue involving customary rights, community claims, legislation inherited from socialistic times and political and economic interest from a number of national and international powers. However, it is not possible to conceptualise a WES design in Mozambique without considering land and its institutional, political, legislative and

6 It is said that in Mozambique there are two laws, the Land Law and the others. The land belongs to the state and cannot be sold or owned, and yet, it is. The law recognises customary user rights to land and provides communities the legal rights to communally register land. However, the registration process is rather bureaucratic, complicated and expensive. ^Moreover the war made population move several times, to several different areas blurring the already ambiguous concept of "local".

regulatory (national and local) context. All this geographical and political dispersion of interests and reactions is also mirrored in the institutional level, where different ministries deal with the same wood fuel supply chain at different levels, at different points and form different political perspective. The lack of coordination is notorious and openly declared by most interviewees and also literature, this in a country where the ministry of environment is actually called ministry of environmental coordination. An example commonly presented is the lack of coordination between the MdE and the MINAG. Wood fuel is the most used energy source used in Mozambique (§1), However, it is mostly regulated by the MINAG, not the MdE which is actually defining and implementing most of the renewable energy policy and strategy. Remarkably, the same kind of dynamic and lack of coordination happens between charcoal makers in the rural areas (only recently were associations established, and even then with strong governmental support) or between official and customary authorities. Another relevant related concern is the quality of the policy making and the enforcement of legislation.

Mirroring the alternative and quality in TT (14.6.2), interviewees and literature alike complained of the lack of quality in decision making, local and national, and more insistently, on the effects that bad monitoring has on the WES. In terms of design, this complex political and legislative reality is translated into thee fundamental design considerations for the 2MW. First, the legislation and regulations (both national and official, and local and informal) that control the entire supply chain (§14.6.2), from the forest use and management to the commercialisation in the city is an element to be considered in any WES design initiative. Secondly, the first consideration should be extended to the land. That is, besides considering the legislation and regulation on the entire supply chain, the conceptual design of WES should also consider land and associated legislation and regulation. Thirdly, coordination and institutional policies (including monitoring) are considered relevant at all levels, which requires, in a participatory conceptual design, to make explicit which are the motivation and objectives of each designer, in order to understand the differences and similarities in the way problems and solutions are conceptualised, as well as, possible institutional policies. The last design concern identified in the IP is networking (26% preference) which hold different meanings for different actors. Experts and literature use think networking in terms of the declared benefits of institutional participation of “communities” in WES projects, while communities desire to have more influence in the design of WES in rural areas. Here networking also lobbies dynamics to include or exclude the government in the WES design. In all these cases, the relevance for the 2MW as an ontology is, like in the case of TT (§14.6.5) to clarify, at the institutional level, who participates and for what purpose, in the design of WES.

14.6.4 Economical, Financial And Business Dd Conceptual Analysis

The economical, Financial and Business DD (EC) of WES, includes five design concerns articulated around income, benefit, opportunity (27% of preference), cost/risk (24%), funding (19%), network (16%) and marketing (14%), fig. 14.18 (next page). Probably the income and cost would be an expected design concerns in the EC, However, the interviews and literature show a wider array of concerns and perspectives. Income, a pressing need for charcoal makers in rural areas (52% of incidence) is seen as a way (sometimes the only one due to low farm productivity) to raise money to buy goods and services now available in rural areas (e.g. phone credit, school books). However, within a view of charcoal as a possible profitable and sustainable business there are some experts (8% incidence) and literature (10% incidence) that see charcoal as an opportunity for rural producers and an ecological benefit for the whole socio-ecological system, if investment is made on sustainable forest management and high quality supply chain.

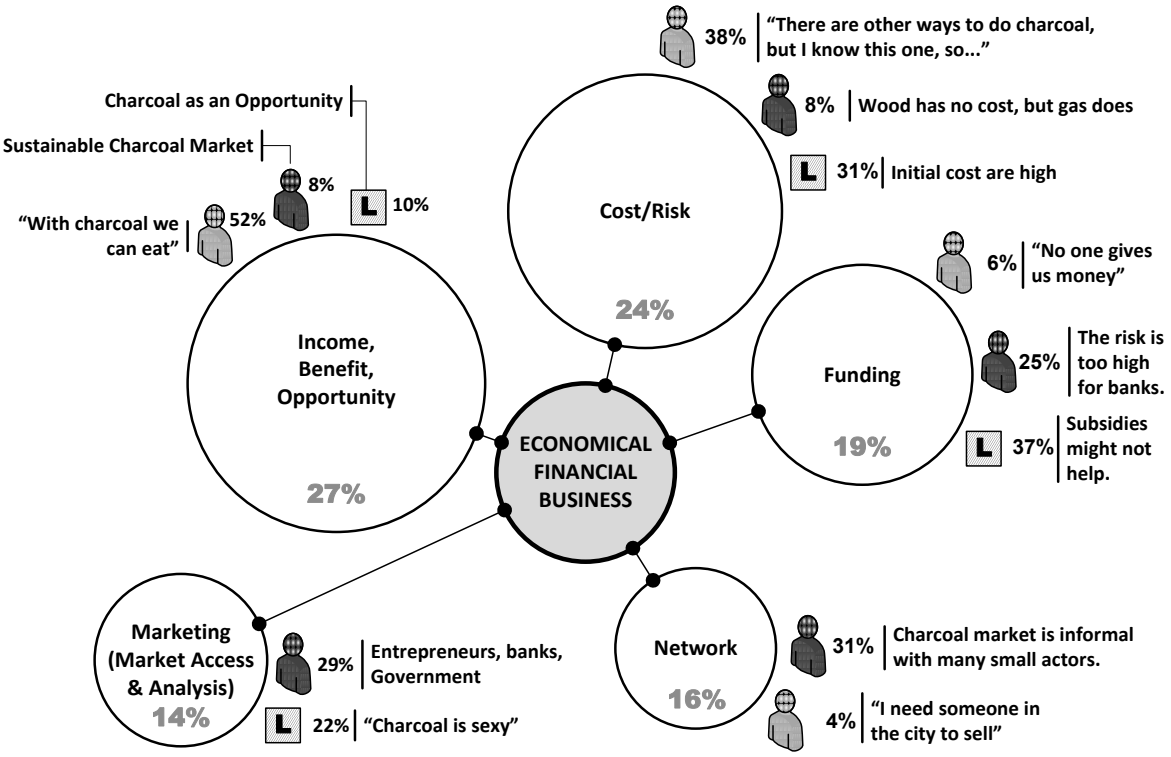


Figure 14.18| Main design concerns within the EC as defined by the interviews and relevant literature [Source: the Author].

The design outcome to emphasise here is the perception of income not just as monetary, but also as the less tangible terms, benefit and opportunity. Likewise, cost has some more to it than "payment due". From one side experts (8% incidence) and literature (31% incidence) claimed that free access, with no cost, to forest resources and high initial cost of most alternative energies (in relation with bad design as seen in §14.6.2) were two important reasons for the law dissemination, in rural areas, of alternative energies in contrast with the fast and widespread dissemination of charcoal making. From the side of the rural interviewees, cost was not measured on free access (that was considered a

right), but rather as safety, both in relation with forest resources and new technologies. Risk assessment was very conservative for new technologies, where future costs and past bad experiences (lived or known) were weighted high in the decision making process. This included new process of charcoal making that could be more effective and productive (higher yields), but had also a greater amount of unknown, untested possible consequences on income. On the other side, the forest was seen as eternal, and possible scarcity in the future was dismissed by the past experience that "there was always forest, there will be always forest." Therefore, in conceptual design terms, cost should come associated with risk. Funding was also associated with risk, but this time from the financial systems perspective. As mentioned by experts (25% of incidence), literature (37%) and rural interviewees (6%) there are no funding options for people interested in the implementation of WES in Mozambique, even from micro-credit entities or banks specialised in local development. The risk was considered to be too high due to the nature of the wood fuel business, rural society and financial systems in Mozambique. This image of risk, the difficulty to get access to formal markets and the lack of economical analysis on the wood fuel business was also seen as a marketing design concern by the experts (29% incidence) and the literature (22%). Marketing, as a design concern, has two perspectives: one is focused on the creation of a formal, regulated and monitored wood fuel market; and the second is on understanding charcoal as any other energy resource and marketing it as a valuable, interesting energy option. Wood fuel moves fabulous amounts of capital, even for developed countries standards , but the informal nature of the wood fuel systems, its dubious legal practices, the relevance, in terms of income that it has in several rural households, and the "dirty and smoky" image that wood fuel conveys seem to hinder any real effort for government or private sector intervention. For the 2MW, this insight stresses the relevance of marketing and commercialisation of wood fuel energy, linking the last stage of the supply chain (§14.6.2), some institutional policies and practices (§14.6.3), and users (§14.6.5). Finally, the participation of the private sector and government as economic actors alongside the multitude of small wood fuel producers brings about the importance of networking at different levels. For experts (31% of incidence) the entrance of the private sector (supported or not) by the government (§14.6.3) could bring economic, social and environmental advantages. The design concerns of the rural interviewees are far more practical, and related with the social network that should be created along the supply chain (§14.6.2). Once more, mirroring the network design concern in the previous DD (§14.6.2-3), the network design concern in the EC represent the importance of who to contact and for what purpose.

14.6.5 Livelihood Behavioural Socio-Cultural Dd Conceptual Analysis

According to the interviews and literature, three main design concerns assist the Livelihood Behavioural Socio-Cultural DD, BC, fig. 14.19 (next page): the socio-cultural context on energy (49%); energy consumption and cooking habits (30% preference); and social acceptance (21%). All three of the design concerns are intimately inter-linked and

the distinction made serves only to highlight different actors, focus and perspectives. In the socio cultural context on energy, the focus is on the WES related practices, including the array of traditional knowledge that guides which trees to cut, when and where. The socio-cultural context on energy was mentioned frequently by the rural interviewees (68%) and less so in the literature (18% incidence) as a major design defining factor of energy practices, and hence, conceptual design. This design concern is closely related with the local regulations, a IP design concern (§14.6.3), however, regulations express the way that knowledge is encoded, here the focal point is on the power issues and knowledge dynamics that define what is right and possible from what is wrong and forbidden. Therefore, the influence of rites, taboos, local beliefs and world views plays a major role on design of WES. Obviously, this matter is particularly important for rural people, since knowledge and beliefs define which trees are sacred or cursed, have other utility (fruit trees, trees that block the wind and sun) or are simply useless (low wood density, high humidity content). Moreover, these design concerns call attention to the fact that wood fuel is only one of many realities in rural contexts (as well as in urban). In rural areas, wood fuel is normally combined with farm activities, and many times the wood to make charcoal and/or firewood comes from clearing land for farming.

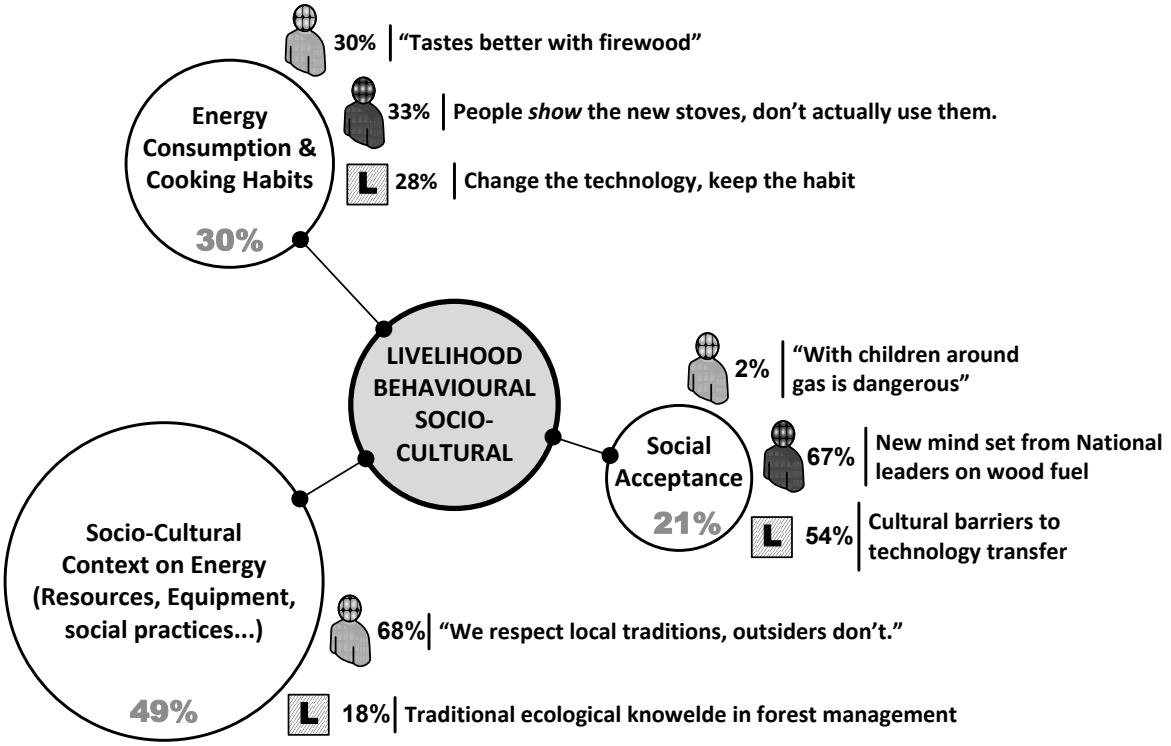


Figure 14.19| Main design concerns within the BC as defined by the interviews and relevant literature [Source: the Author].

Another issue raised was the gender dimension on household energy decision-making. While women are the mainly responsible for the wood collection, and many times for the entire charcoal production process, as well as, for most of the wood fuel management in the household, the decision-making on energy option and devices is mostly conducted by

males (e.g. fathers, husbands, sons). Therefore, it is not unusual to have a kitchen-hut[7] with a firewood three stone stove, but illuminated by a low consumption light bulb. Most of the energy consumed in households in Mozambique is for cooking, which makes the design of cooking technology particularly relevant. This aspect is reflected by the relatively high incidence of this design concerns in rural people (30%), experts (28%) and literature (33%). This design concern is closely linked with the technological design and alternative concerns in the TT (§14.6.2) and some of the experts interviewed are presently trying to design stoves that integrate socio-cultural practices with efficiency. Remarkably, the preferences, habits or behaviours particularly related with cooking are not easily transformed into design criteria. After encountering multiple problems with cooking with wood-fuelled three stones stoves, when women were asked to indicate which appliances they would buy if they had electricity and money, in less than 3% of the cases, the reply included cooking devices, ultimately, they preferred to buy TVs for information and refrigerators to keep food. Finally, the importance of socio-cultural aspects in the technology transfer process in general was also referred, particularly by the experts (67% of incidence) and literature (54%) and only marginally by rural interviewees (2%). In this wider perspective, the socio cultural aspects continue to be relevant, but what is really interesting in design terms is the fact that some authors and experts identify these as “barriers” (problems to be overcome, §14.4.1) while others directed the criticism towards governments and other organisations involved with energy issue in Mozambique and elsewhere. The conceptual analysis done on CB BC suggests three relevant conclusions for conceptual design of WES. Firstly, besides the “rules of the game”, i.e., the institutional and political DD (§14.6.3), it is necessary to consider the habits, behaviours, livelihoods and socio-cultural background of those playing and making them. This implies the recognition of these aspects as contextual infrastructural too. Secondly, this concern should be considered all along then entire supply chain: land, the charcoal makers and firewood collectors; and end users (§14.6.3). Thirdly, these socio-cultural aspects are also to be considered in the wider network of actors identified before (network in §14.6.2-3).

14.6.6 Nature Design Dimension Conceptual Analysis

Three design concerns emerged from the conceptual analysis on the Nature DD, NT, namely (by order of preference), fig. 14.20 (next page): forest & resource management (49%); land management (27%); and impacts (24%).

The management of the forest and other resources is a concern for the large majority of the experts (73% incidence) and still substantial for rural interviewees (41%) and literature (39%). Within the firewood collectors, forest management was basically related with the selective cut of dead branches from selected trees and the respect (not always

7 In most rural areas in the south of Mozambique, the house is In fact, a family compound, “Munti”, with the functionalities of the house (Cooking. Sleeping, hygiene) divided into different huts.

followed) for reservation land. On Inhaca Island, in particular, these practices had some ecological perspective behind them, mostly justified with the need to preserve the island from erosion. Charcoal makers where far less concerned with ecological issues than with finding species that produced good charcoal (high density species) easily accessible and close to cleared land where they make their kilns. The perspective taken from experts and most literature is more related explicitly with environmental and conservational purposes, however, a number of experts tried to conciliate charcoal production (or electric poles production) with a dedicated tree plantation either native or not.

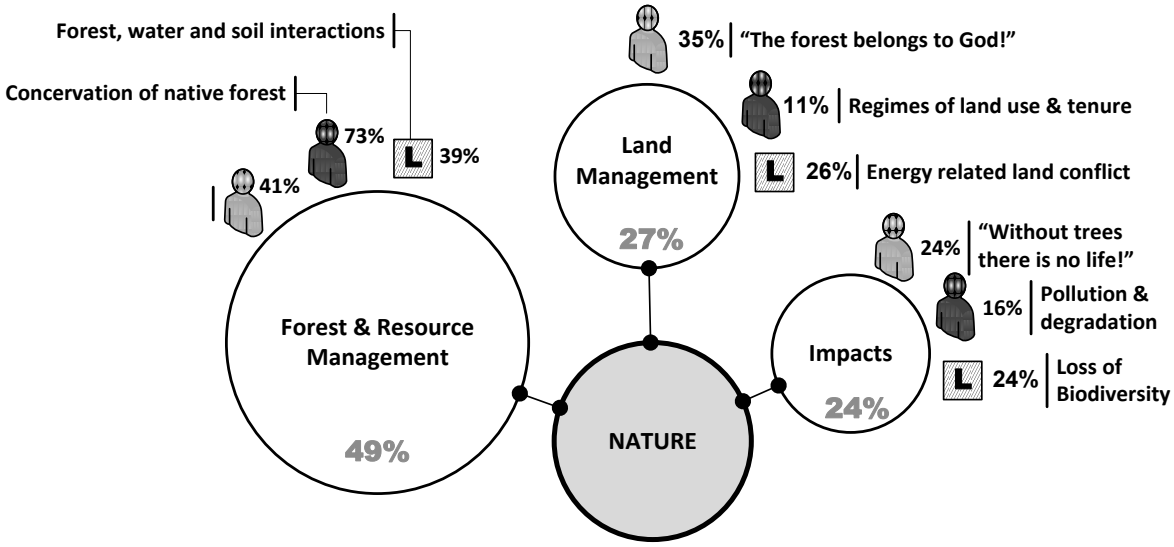


Figure 14.20| Main design concerns within the NT as defined by the interviews and relevant literature [Source: the Author].

The literature also registered a wider perspective on the forest ecosystem, trying to relate forest management with physical and chemical properties of soil and water, biodiversity and nutrient cycles (e.g. carbon, nitrogen). Therefore, forest and land management end up closely related. This relationship was already approached when analysing the institutional and political DDs (§14.6.3), however, in the NT the perspective is more related on the users and zoning implemented. There are several management schemes in place: on Inhaca Island, the zoning is mostly defined by a natural reserve, including protected bushes in the dunes and mangrove; in Goba a project set up by a natural resource management committee organised a plan of land use and exploration; and in Santaca the land management is mostly carried through traditional regulations and institutions. However, what is relevant in the context of design is the focus given to forest resources in conjunction with land resources as a crucial asset in the definition of WES in Mozambique. Finally the rural interviewees (24% incidence), experts (16%) and literature (24%) recognised the potential impacts on biodiversity, livelihoods and nature in general of the WES. These impacts were generally recognised as cost operational risks and measured against other values, e.g. survival of the household in the case of charcoal makers.

In conclusion, the conceptual analysis on the NT reaffirms the importance of forest and land management (scientific, professional, political, traditional) as fundamental design elements for those interested in design WES in Mozambique. Moreover, besides the several costs and risks identified in the EC (§14.6.4), impacts on nature, and therefore on livelihoods are also to be considered.

14.6.7 Knowledge, Communication & Skills Dd Conceptual Analysis

In the Knowledge, Communication & Skills DD, KI, four design concerns have been identified, all with very similar percentages of preference, fig. 14.21: skills capacitating and training (28% of preference); communication, information and research (26%); network (26%); and promotion and awareness (20%).

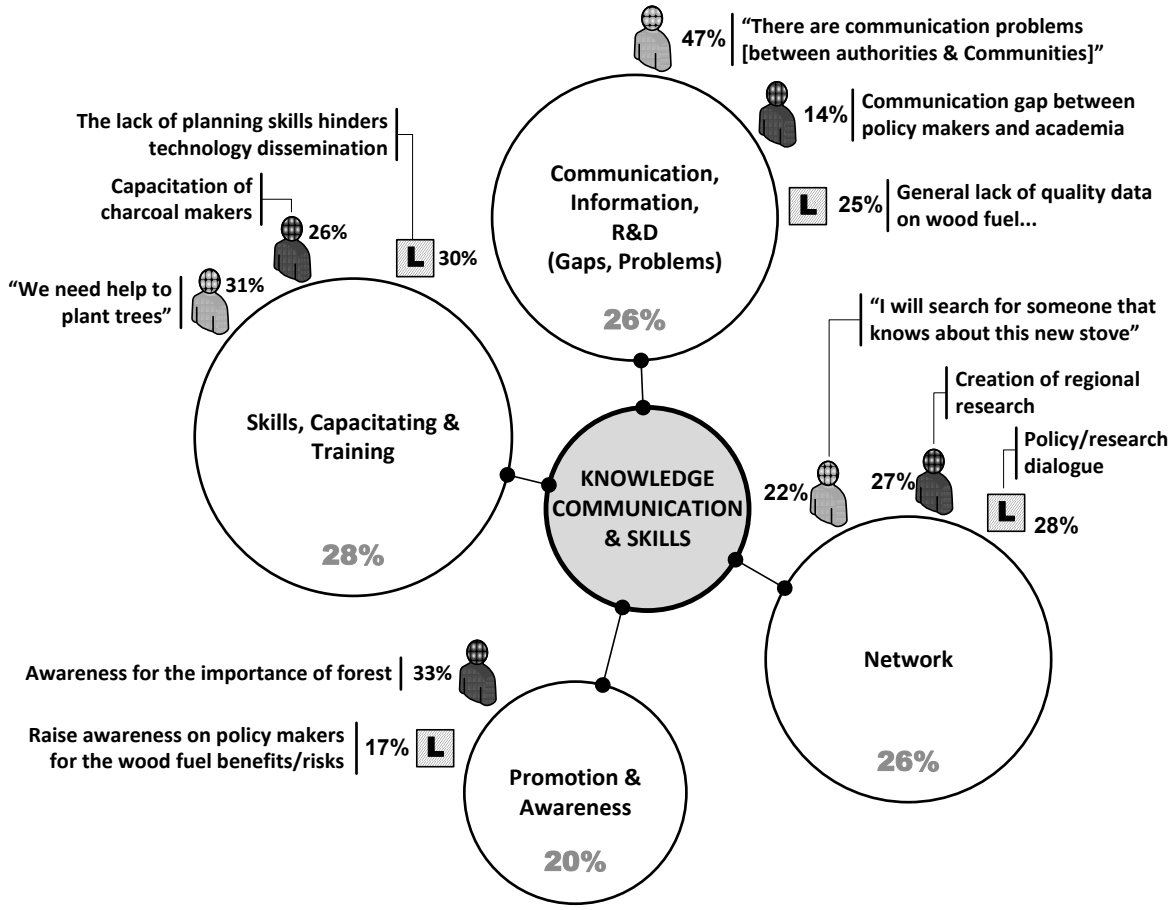


Figure 14.21| Main design concerns within the KI as defined by the interviews and relevant literature [Source: the Author]..

The lack or need of capabilities, both managerial and technical, was stressed by rural interviewees (31% of incidence), experts (26%) and literature (30%) as major barriers (§14.4.1) in the diffusion of renewable energy technology. In general, training, investment in education and/or capacitating are presented as necessary actions. Alongside these initiatives to increase the skills of users, producers and other actors in the WES supply chain, most literature (17% incidence) and experts (33% incidence) focus on the need to actively promote, and raise awareness on, modern and more sustainable technologies

and processes. The general picture emerging from this analysis on KI in Mozambique shows a knowledge transfer flowing in one direction, from policy makers and experts to users and producers of wood fuel. However, and remarkably, a substantial number of rural interviewees (47% incidence), experts (14%) and literature (25%) claim that some sort of communication problems or miscommunication prevails between authorities and rural communities, scientific communities and policy makers, and all other possible combinations. Indeed, not only reliable data is missing on most WES parameters (e.g. data on consumption, production, origin, cash flow), but there is a profound lack of funding and research on social, economic and technical aspects related with WES design (e.g. a truly comprehensive study on the socio-economic and environmental impacts of charcoal production in Mozambique is yet to be done).

There are four contributions to the 2MW definition from this analysis to KI. Firstly, the 2MW needs to consider which technical and managerial training, capacitating actions or skills are required (if any) to do the WES conceptual design. The 2MW aims to support the complete supply chain (§14.6.2) which might require technical and managerial skills not available or valued in specific socio-economic and socio-cultural contexts where the WES is to be designed. Secondly, the network design concern, like the previous similar design concerns in EC (§14.6.4) and TT (§14.6.2), point to the need to consider which are the other actors with the knowledge, skills and/or capabilities required to undertake the conceptual design of WES. Thirdly, in order to address the communication gaps and miscommunication, and mirroring the analysis done in the IP (§14.6.3), it is important to make explicit the motivations and problems, as well as the objectives solutions considered. The definition of these elements might be a starting point to define more aligned WES conceptual designs. Finally, the fourth contribution articulates the previous three by identifying the need for some sort of communication channels and relationship to link different networks with the training action through the participatory definition of problems and solution. Therefore, e.g., in the case where a lack of knowledge on a certain issue in the WES had been identified in a given community (network), a communication channel and a education relationship should be designed to raise awareness among that community.

14.6.8 Integrated Infrastructure & Networking Dd Conceptual Analysis

The WES, as any system, exists in, and co-evolves with, a wider socio-ecologic system (fig 14.22). The Integrated Infrastructure & Networking DD, SC, was defined to express that reality in terms of a main DD. Therefore, the conceptual analysis of the SC, fig. 14.22 (next page), was realised to identify the design concerns linked with the wider socio-ecological that could affect the WES conceptual design. The analysis identified three of those design concerns (in decreasing order of preference): the socio economic context (50%); energy as part of integrated approaches (34%); and supportive infrastructure network (17%).

The socio-economic context was considered by almost half of the rural interviewees (49% of incidence), experts (49%) and literature (44%) as a major defining design concern affecting the WES design. Poverty, unemployment, low farming production, urbanisation and other demographic changes, corruption, post-war instability, natural disasters and climate change are just some of the socio-ecological reasons presented to justify the existent WES design as well as their dissemination (or lack of).

Socio-economic contexts strongly condition what is possible to do, but also why to do it and how to do it (e.g. Amigun *et al.* 2008). A second design concern was the consideration of WES design as a component in wider approaches and/or initiatives at several levels. WES design could be included in the livelihood strategies of survival of a rural household, or included as a catalyst of rural development strategies with effects at the national level by a policy maker. Finally, another design concern on the SC was the effect that the existence (and above all nonexistence) of physical infrastructure (Amigun 2008; Porritt 2007: Valencia & Caspary 2008) not directly linked with the WES could have in the design of WES. A common example was given in Santaca, where a road that was seen as absolutely necessary for the charcoal business could be implemented with success. Moreover, the literature often indicates (40% of incidence) the lack of basic social (e.g. schools, medical centres), financial (e.g. banks), technical (e.g. repair shops) and communication (e.g. radio network, cables) and other infrastructures as blocking all possibility of a sustainable WES.

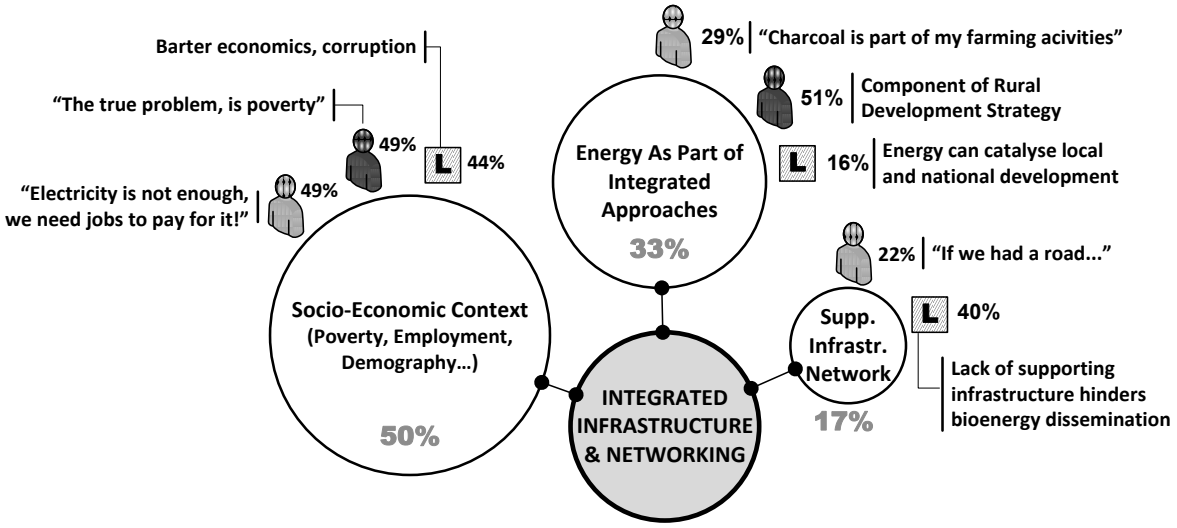


Figure 14.22| Main design concerns within the SC as defined by the interviews and relevant literature (Supp. Infrastr. Network- Supportive Infrastructures Network) [Source: the Author].

Naturally it is not the purpose of the 2MW to be a "theory of everything" encompassing the entire WES and context where it is embedded. However, the analysis provided two important outcomes. One is the relevance to make explicit which socio-ecological or infrastructural aspects, realities or contexts are relevant for the design of the WES. This could be done as part of the description of the problem/motivation or as part of the solution/objective(s) in the WES conceptual design, but could also be represented

separately as a infrastructural or contextual design element. Secondly, these design concerns could be aligned with the benefits, income and opportunity (§14.6.4) as a synergetic design element or with the costs, risks (§14.6.4) and impacts (§14.6.6) as a competing design element.

14.6.9 The Wood Fuel Energy System Conceptual Design Metamodel

In the sequence of the conceptual analysis on the several DDs performed in §14.6.2-8, it is now possible to use the outcomes to build a visual format for a coherent conceptual design tool: the WES conceptual design metamodel, the 2MW. The 2MW supports the participatory conceptual design of the WES conveying the "essentials" of what one needs to think about when doing WES conceptual design. These "essentials" are the design elements referred to earlier (§11), i.e., the essential building blocks with which it is possible to conduct informed dialogue/discussion, description, thinking and specification of WES conceptual design in Mozambique. The challenge is to produce a visual representation of the conceptual design of WES that is simple, useful for users with many different backgrounds, easy to understand (intuitive), non-normative, non-prescriptive, but not oversimplifying the complexities of WES and its conceptual design. From the analysis conducted so far, thirteen design elements emerged as the basic building blocks of the 2MW, covering all the DDs identified as fundamental for the conceptual design of WES, fig. 14.23.

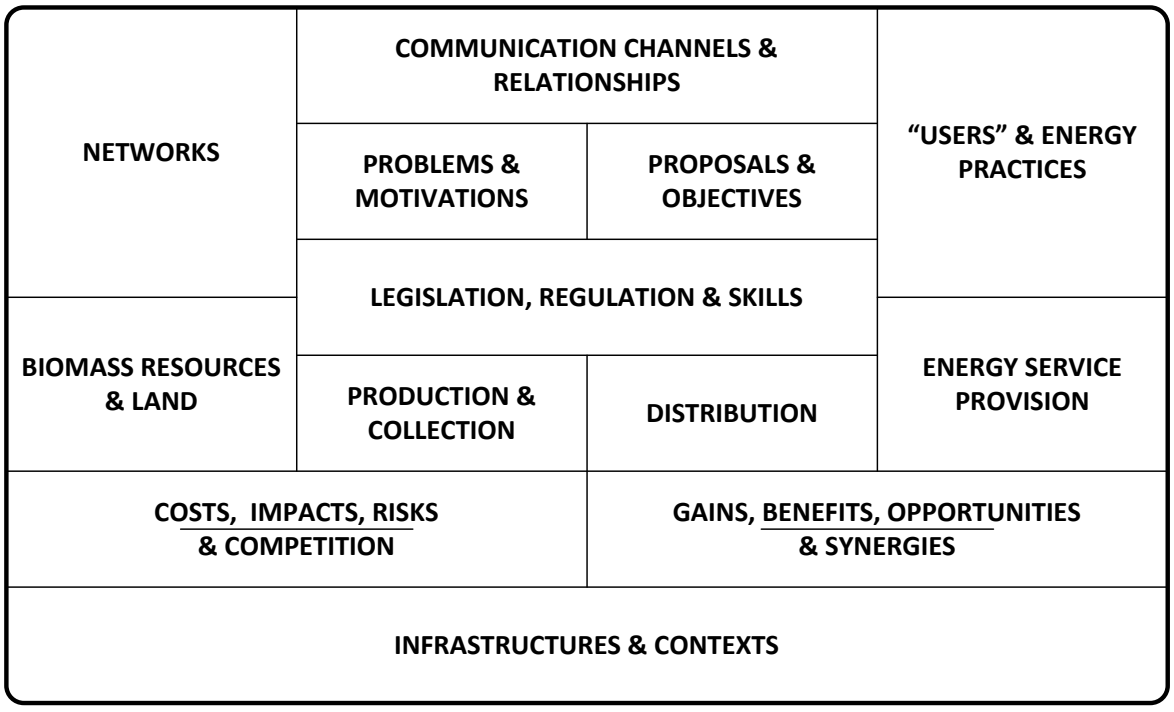


Figure 14.23| The layout of the 2MW [Source: the Author].

Being derived from the DDF (§14.1), the design elements that compose the 2MW also represents a set of interdependent basic building blocks, meaning that decisions or new information on one design element affects all others. Moreover, the layout of fig. 14.24 is the result of a continuous interaction between the author, the literature and the

interviewees, in a dynamic process of co-design. In the following, each design element will be defined and described and whenever relevant related to previous sections of the thesis. Moreover, exemplary questions related with the definition and purpose of each design elements are provided, as well as, some indications regarding the use of the 2MW.

14.6.10 Description Of The Design Elements

The **Problem & Motivations** design element intends to make explicit what is (are) the main problem(s) as well as the motivation(s) to address those problems, as felt by the designers (the group using the 2MW). Problems are recognised gaps or deviation from a norm or desired set of conditions (e.g. Cowan 1986; Märtensson & Westerberg 2007; Newell & Simon 1972; Watson 1976). Since those set of condition and norms vary between people and in time and are also socially and politically constructed (Cuppen 2009; Tsetse 2007) the problems are subjective, can be defined in different ways, at different times by the same person and a particular situation can be perceived as being a problem by one group but not so by another (§8). Indeed, this design element was identified in the conceptual analysis of the Institutional and Political DD in terms of lack of coordination (§14.6.3) and in the Knowledge, Communication & Skills as an issue of communication gaps between several actors (§14.6.7). A deeper inquiry of different interviewees revealed that besides the political issues (e.g. inter-ministerial mistrust) a common element for the lack of coordination and communication gaps was the different backgrounds and perspectives hold by different people on WES. Moreover, as a complex problem (§9.3), the WES design does not have a consensual formulation, cannot be stated in terms of performance measure(s), and action-consequence relations are not clear (Mingers & Rosenhead 2004). An approach to this is to structure the problem with suitable methods, the PSM already discussed (§9.3.5). For this design element, the relevant questions to be considered and used to define this design element are:

- What the existent or future problem(s) of the existent WES?
- What the possible problem(s) of the WES you want to design?
- What is(are) the motivation(s) to overcome the problem?
- What is(are) the motivation(s) to design the WES?

Therefore, the purpose of this design element is not to produce consensus or a “bullet proof” problem description, but rather to explore the problem by giving the participants the opportunity to shape and reshape, jointly, a certain individual perspective on “what is the gap bothering me.”

All design has an intention, even if the intention is to do nothing (Flusser 2010). This intentionality is represented by the **Proposals & Objectives** design element and is closely related with the Problems & Motivations since design could be defined as the interactive, creative, social and cognitive activity of problem setting and solution exploring that enables the generation of meaningfully distinct options (§9). Thus, this design element

aims to express ideas of a solution to be further explored as part of a continuous dialogue with the problem, shaping and being shaped in the process (§9.3.5). Relevant inquiring lines for this design element include:

- What do you want to achieve by designing this WES?
- What is the WES you would like to have? Why?
- If you were in charge, what would you do? Why?

The ultimate aim of the Problem & Motivations and Proposals & Objectives design elements is to provide some sort of proactive, flexible, but clear (temporary) guidelines that reflect the varying backgrounds, motivations and perspectives of the users and can be useful to address the remaining design elements. Instead of oversimplifying the design of WES as a process driven by a consensual set of non-revisited goals, fixed at the start of the analysis, the continuous dialogue between Problem & Motivations and Proposals & Objectives, and between both and the rest of the 2MW design elements, provides a learning opportunity that accrues through the process of redefining the problems and proposals. Moreover, it is expected, that this interactive Problem/Proposals dialogue helps to connect the WES conceptual design with the participants of different realities and backgrounds (Mårtenssona & Westerberg2007). Therefore, the definition of Problem & Motivations and Proposals & Objectives includes both creating a contextualised vision for the WES and identifying the central actors, processes and contexts.

Networks represent the set of actors (e.g. individuals, organisations and entities) and interactions that could affect, influence, collaborate with, facilitate, reduce risk on, guarantee or hinder the desired outcome of the WES design. From the conceptual analysis on then DDs three relevant networks have been identified:

- **Business/Financial Networks**-Resulting from the analysis on economical, financial and business DD (§14.6.4), refers to network of economical agents (e.g. suppliers, business partners, banks) that can fund the WES implementation and operation. It can also include business partnerships, i.e., a "network of suppliers and partners that make the business model work" (Osterwalder & Pigneur 2010: 38-39).
- **Knowledge networks**. Originated from the analysis done to the technological DD (§14.6.2) and Knowledge, Communication & Skills DD (§14.6.7) defines a network which connects actors or groups of actors to technology or knowledge (Seufert *et al.* 1999) or shared and related knowledge between members that relates to each other (Jones 2001). In practical terms, it defines who owns or has access to what technology or knowledge relevant for the implementation and operation of the WES.
- **Institutional Networks**. Derived from the analysis done on the institutional an political DD (§14.6.3), defines the net of local and national, formal and informal institutions that hold, or are perceived as having, some form of power (e.g. political) over some aspect of the WES, i.e., refers to who can decide on fundamental issues related with the operation and implementation of the WES design.

All these networks could be seen as particular cases of social networks, defined as a set of actors with some pattern of contacts, interactions or relationship between them (Brass *et al.* 1998; Newman 2003). In fact, social networks have been envisioned as enabling different actors to collaborate and coordinate management efforts in adaptive management based on different forms of participation and co-management of natural resources (Bodin *et al.* 2005) with particular incidence over forest (Colfer 1985; Hobley 1996; Grimble & Wellard 1996). Such collaboration in social networks constitutes both a form of social capital and a good medium to promote knowledge creation and transfer, mutual learning and sharing of resources and advice (e.g. Inkpen & Tsang 2005; Prell 2009). As Cross *et al.* (2002: 1) stated, "who you know has a significant impact on what you come to know". Finally, as one of the outcomes of the conceptual analysis on the Livelihood Behavioural Socio-Cultural DD (§14.6.5) indicated, these social networks do exist embedded in contexts which means that all these actors and interactions are considered to be contextually shaped (Schizas & Stamou 2005). Therefore, when doing the WES conceptual design, other design elements (aside from the "user" & consumption) should be inquired for "who" could support the WES design within one of these networks. Following the previous description, questions relevant here include:

- Which actors (institutions, people) are relevant for the proposal?
- Who can plan? Build? Construct? Manage? Maintain? Finance?
- Who authorises? Regulates? Legislates?
- Who can teach? Train?
- Who has access to the resources, technology and knowledge?
- Who can facilitate/hinder communication?
- Who can assist in the production, distribution and commercialisation (value chain)?
- Are these actors local? National? International?
- What interaction exists between the networks? Between you and the networks?
- Who can be an obstacle, impediment, adversary?

Answering these questions, designers should also reflect over the other design elements, or betters said, some of these questions might be posed while addressing other design elements, but should be included here for clarity of access to everyone.

"Users" & Energy Practices design element aims to focus on the people, group of people or organisation using and being affected by the WES energy services, products and artefacts as fundamental elements in the design-process. This design element arises directly from the all the design concerns identified in the conceptual analysis done on the Livelihood Behavioural Socio-Cultural DD (§14.6.5), representing thus the socio-cultural background, behaviours, practices, strategies and routines of users. Since these are also some of the strongest reasons expressed in the number of interviews and literature for the design failures observed in many energy technologies and, also, the search for alternative technology, the "Users" & Energy Practices implicates the "technological

alternatives, ” “technology design” and “consumption” found in the Technological DD (§14.6.5). In relation with these two main reasons, the “Users” & Energy Practices design element is also linked with the participatory design approach taken in this work, which privileges the human-centred design (§9.4.1). According to this approach, the user is not only the people who are targeted/identified as using the final energy product, service or artefact to accomplish a task or goal, but also people who manage those targeted/identified users and those persons who are affected in some way by the use of the WES product, service or artefact (Abras *et al.* 2004, Gasson 2003)[8]. Therefore, here, the focus is on relating WES conceptual design with those “routinised, culturally embedded patterns of behaviour relating to fulfilling human needs and wants” (Foxon 2011: 2263). The WES is designed to provide energy products, services and artefacts to the “users, ” but the users exist in a variety of shapes and sizes, with differing expectations, attitudes and cognitive skills embedded in specific socio cultural backgrounds. Defined this way, practices, e.g., cooking, are conceptualised as ways of meeting social needs, using particular technologies, enacting in individual agency constrained by social structures (Spaargaren 2003). Ultimately user practises and technology/energy provision co-evolve, since user practices may be enabled and constrained by prevailing WES and related technology and business strategy (Foxon 2011; Ropke 2009). In conclusion the “Users” & Energy Practices design element invites designers to explore:

- Who is the user? Who is affected by WES products and services? And how?
- What are their energy needs? What are their expectations? What do they want from those WES products and services? Do they really want them? (e.g. energy consumption patterns, willingness to pay)
- What are the risks they are prepared to take?
- What relevant information do you have about the household/”Users?” (e.g.: income level; size; gender; age: composition; educational attainment; particular skills; food tastes; cooking practices; lifestyle.
- What is their degree of knowledge and experience with the technology?

Note that besides these endogenous aspects other exogenous aspects (Kowsari & Zerriffi 2011) to the household might affect the “users” preferences and energy consumption habits, e.g.: geographic factors; political instability; natural disasters; climate; policies and regulations; supply factors (availability, affordability, method of payment, access) and; equipment characteristics. As exogenous, these factors should be explicitly included in other design elements deemed appropriate.

Communication Channels & Relationships design element describes the strategies to communicate and the dialogue with people, group of people or organisations identified

8 The term “user” is considered here to facilitate prompt understanding and a wider consideration of what is a “user”. But does not indicates any kind of enforcement of user-centred design (§9.4.1).

both in the Networks and the "Users" & Energy Practices design elements in order to raise participation, collaboration, mobilisation, awareness for the WES designed, and to conduct assessment and marketing for the WES and associated products, services and technology. These strategies entail the definition of the content and kind of relation to be made with the Network and "Users" & Energy Practices, as well as, the type of channels to convey that content and enact that relationship. These are crucial decision for the WES implementation and thus should be considered in the conceptual design. This design element is explicitly presented as a "communication, information & R&D" and "Promotion & Awareness" design concerns, but is also implicit in the design concern "Network" identified in the conceptual analysis of the Knowledge, Communication & Skills DD (§14.6.7). Considering a marketing communication approach to the WES, this design element is also explicit in the "marketing" design concern in the Economical Financial Business DD (§14.6.4). Indeed, communication gaps, between different actors in terms of WES objectives, solutions, purposes and perceptions and/or reality have been identified by many interviewees. In more generic terms, communication and dialogue is increasingly being recognised as a fundamental aspect of ESy design, implementation and monitoring in DCs (e.g. Tufte & Mefalopulos 2009). For instance, awareness and information dissemination regarding available and appropriate technological options is often perceived as the single most important factor affecting the deployment of those technologies (Ölz & Beerepoot 2010; Painuly 2001; Werner & Schaefer 2007). Knight *et al.* (2008), labelled as "research-implementation gap" the consistent "failure to adequately exchange knowledge and understanding with local [populations]" in Developing Countries. Likewise design projects can fail "because of the different ways in which non-technical and technical design participants communicated and evaluated the knowledge about the design" (Gasson 2003: 32). Consequently, several development organisations have related communication, energy and development[9] (e.g. Anyaegbunam *et al.* 2004; Mefalopulos 2008; Tufte & Mefalopulos 2009; UNESCO 2007; WB *et al.* 2007) and developed and used several methodologies and approaches accordingly, e.g. Development Communication or Participatory Development Communication (e.g. Mefalopulos 2008; Morris 2001), Communication for Development (Mefalopulos 2008), Participatory Rural Communication Appraisal (e.g. Anyaegbunam *et al.* 2004) and Risk and Energy Communication Studies (e.g. Flüeler 2006; Minsch *et al.* 2012: 307; Renn & Levine, 1991).

Channels of communication can include a wide range of techniques and media, from simple conversation to global campaigns supported by mass media. The relationships to be established between the designers of the WES conceptual design and the members of the networks and "users", in general, tend to be defined by the communication approaches which, in turn, are dependent of communication strategies, tab. 14.15:

9 Other UN organizations promoting communication for development can be found in www.c4d.undg.org/.

Table 14.15| Relationships between WES designers and "Users", channels and methods according to usual communication approaches in WES design (products, services and technologies) [Source: the Author].

COMMUNICATION APPROACH IN WES DESIGN[1]	CHANNELS & METHODS (e.g.)	POSSIBLE RELATIONSHIPS	
		WES DESIGNERS	NET & "USERS"
Inform and raise awareness on the WES	Mass media, Media,	Informants & Mobilises	Recipients
Dialogue on the WES	Conversation, meetings, social networks	Collaborator, Co-Designer	Collaborator, Co-Designer
Marketing the WES	Mass media, Media, social networks	Seller, Lobbyist	Consumer, Decision & Opinion Maker
Assessment for/of the WES design	Interviews, Sketch map, Problem/solution tree	Data Collector	Data Provider

Note that the communications approaches and relationships presented tab. 1415 do not represent mutually exclusive closed or qualitatively hierarchical positions, but rather reference points is a network of possibilities. People can interchange positions (e.g. data provider could become a co-designer and informant) and communications strategies could co-exist, be used or dropped according to the communication strategy chosen (e.g. start with assessment for WES move to marketing WES and return to assessment of WES). Moreover, to be effective, the communication strategy needs to be based on the stakeholders' knowledge, perceptions, and practices (Mefalopulos 2008).

Communication for awareness and information is centred in new legislation, regulation and training possibilities related with WES design and/or encourages and motivates people to: consider, pay more attention to, certain energy practices and WES design aspects; highlights, with the right appeal, perceived advantages and disadvantages of the WES design proposed and competitors; and "fill[s] the gap between what the audience knows and what they need to know" (Mefalopulos 2008: 123). The information should be useful, relevant, appealing and trustful (Litvine & Wüstenhagen 2011; Nannen & van den Bergh 2010; Roy *et al.* 2007). Communication channels for this approach could normally include mass media campaigns targeting specific audiences, e.g. campaigns on new fees for charcoal transport, or awareness on deforestations risks, Edu-tainment[10] on wood fuel.

In the communication for assessment approach, the communication channels are used to investigate, explore, and assess various aspects of the WES design or related with the WES design, implementation and operation, including, e.g., quality, usability, accessibility, suitability, impacts, degree of satisfaction. This approach could also be used to probe socioeconomic and political factors affecting the WES design, identifying priorities, assessing risks and opportunities, assess the range and level of people's perceptions and attitudes regarding WES. Communication channels might include dialogue, door-to-door

10 As the term indicates, edutainment is a way of applying educational messages in popular forms of entertainment, such as television soap operas, radio programs, and even music (Mefalopulos 2008).

assessment or assessment meetings and other inquiring methods common to participatory approaches, but aiming at the assessment of/for WES.

The Communication for Marketing target is persuasion to make people buy, acquire or sponsor (economically or politically) the WES design or some of its associated products, services or technologies. This approach focuses on the commercial/business and political side of the WES design looking to attain a competitive or differential advantage by successfully positioning the WES design at a favourable location in the market space and political sphere. Typical examples are lobbying action by policy makers and advertisement campaigns through mass media, e.g., TV commercials featuring new ethanol stoves in urban households in Maputo.

Communication as dialogue was already approached due to its importance in participatory design and development (§9.2). Here the purpose is to create communication possibilities between the various actors ("users", members of the networks) making the WES conceptual design visible and accessible for all to participate, e.g., through the creation of working groups.This approach to communication opens up new spaces for participation and exchange of different knowledges, which could contribute to empowering people, and increase the quality and effectiveness of the WES conceptual design (Mefalopulos 2008; Stoll-Kleemann & Welp 2006).

With this general description of the objectives and possible approaches, the Communication Channels & Relationships design element could be described through a number of questions:

- How do the "users" and networks want to be contacted?
- How to communicate (inform, raise awareness, market, dialogue) with the "users"?and with the networks?
- What channels can the "users" and network exploit to know, affect, participate in and assess the WES design, e.g., decision making on production technology?
- What types of channels are better suited to deliver the previous points?
- How are the communications approaches integrated and aligned with the socio-ecological context of "users" and networks?
- How to assess the communication strategy?
- What problems could generate communication breakdowns, gaps or miss communication?

The **Biomass Resources & Land** design element, expresses the need for land and wood fuel resources in any WES. In Mozambique, while consumed in urban centres, the forest, and hence wood fuel resources, exist mostly (if not entirely) in rural areas. Therefore, in the context of 2MW, "Land" means essentially land in rural contexts. While "Forest & Resource Management" had been identified as a design concern in the conceptual analysis of the Nature DD (§14.6.5), "Land" was detected both at the Institutional & Political DD (§14.6.3) and the Nature DD (§14.6.6). This situation can be explained by the

fact that laws and regulation affecting the use and exploitation of forest are dependent on the Mozambican Law of The Land. This conclusion reinforces the need to consider a design element comprised of both Biomass Resources and Land.

Kolers (2012) synthesised four main conceptions of natural resources (from which biomass resources are a type). The first definition states that "Natural resources are physical objects that are economically valuable to someone or other, and hence, to whoever controls them" (Kolers 2012: 6). According with this view, "having a natural resource" is itself a resource, which is exploited not by extracting but by leveraging it. Therefore, the entire landscape can be constituted by natural resources (the wind, the water, the soil) and valued as such, that is, Natural resources are the essential material building blocks of all economic value. The second definition, advanced by Tim Hayward (2005, 2006) defends that natural resources neither come into existence when exploited, nor go out of existence when burned; they merely change state, e.g. from solid wood to gaseous carbon and waste heat. It follows that, for Hayward, the only significant physical resource is ecological space (or ecospace). i.e., "the total amount of bio-productive capacity sustainably available on Earth each year, based on all energy inputs (the sun), natural capital (stored energy), and ecosystem services (processes, cycles, and so on)" (Kolers 2012: 10). The third conception presented by Dworkin (2002) follows a constructivist stand and contends that the value of the natural resources are in the eyes of the beholder. By valuing, each person pursue their own conception of the good with which decides the relative values of all resources. Finally Kolers advances its own definition, stating that of a natural resources is "a resources to the extent that it is a type-fungible means for the group that holds a territorial right covering it" (Kolers 2012: 27). Fungible is something replaceable by other means to the same end, or convertible without loss into money. Moore (2012: 3) has a similar definition, but described in simpler terms: natural resources refers to "anything, derived from the environment, that is, instrumental to satisfying human wants and needs."

The purpose here is not to conduct a debate on natural resources, but to gain insights from all these definitions to support the designers using the 2MW while dealing with this design element. Therefore, it should be noted that what counts as a resource is not constant, but varies according to socio-ecologic contexts and interactions. Resources "to an overwhelming extent, are not natural resources" (Zimmerman 1951: 7, emphasis in original), since "everything is neutral (or perhaps even a resistance) until humankind learns what to do with it", and that "resource is a term of appraisal […] reflects human judgment as to want-satisfying capacity, utility" (Vargo & Lusch 2006: 7). Hence natural resources, though constituted by physical entities, are not In fact, physical entities in their own right. Natural resources are rather "intention-dependent" phenomena (Baker 2002). Another aspect to consider is that the valuation of nature, related to its exploitation and control has an impact, a physical cost. Moreover, there are power dynamics in play in the definition of what is a resource or not. Differences of power between groups with

different perspectives on what constitutes value or could be evaluates could (and normally do) engender impositions of a favoured perspective against another. The first definition of natural resources clearly indicates this point, focusing on the wealth gained by control of both the stream of benefits of exploitation and the spigot for turning that stream on and off. In this sense, natural recourses have alternatives, which might be valued differently by different people in different contexts. Finally, besides the resource and context, some sort of capability should exist to value, exploit and manage the resource (Campbell *et al.* 2012).

While conceivable as a resource, a site of production or a tool for realising economic potential, land should not be isolated from a wider social and cultural context (Haaland 2008). On the other side, seemingly "free" or unoccupied land might host significant socio-cultural values and be providing water and firewood or serving as a buffer in case of community expansion (Hanlon 2004). The local way of seeing and interpreting the landscape differs radically from "outsiders." In a study conducted in Madjadjane (an area close to Santaca) Haaland (2008) realised that residents might confer emotional and cosmological meaning to land and to their environment creating embedded relation with the land making a "separation between humans and nature, or humans and land, difficult for people in Madjadjane (Haaland 2008: 347)." Land does not only have economic value, but is also significant to local residents in terms of identification and for their sense of belonging (Haaland 2008). Property should be seen as a social relation vested with power (Berry 2001), but also with knowledge. Following these considerations, in this design element, relevant questions to be addressed and used to describe this design element include:

- Which wood fuel resources are valued as such by local people?
- Which wood fuel resources are available? Accessible?
- Are there alternative wood fuels resources not valued so far by local producers?
- What are the impacts of forest and land management?
- What different version of forest, resource and charcoal exist?
- What land is available? Where? How far from the Village/City?
- What properties should fuel resources have to produce energy?
- What properties should land have to produce energy?
- What strategy to use for the access, use and management of land & wood fuel resources?

Land and landscapes are also valuable resources which, like the forest, have many purposes and uses besides energy, and interact with socio-ecological systems and dynamics beyond the WES. However, those competing purposes and uses and interactions with wider contexts affect dramatically the WES design, particularly in Mozambique. Access to land and forests are the basis of survival in rural Mozambique. The way in which access is structured in cultural norms and rules is essential to the way in

which such a society is organised and will reflect the different normative repertoires and economic possibilities that exist within a certain society (e.g. Brouwer 1998; Haaland 2008). Therefore, the WES design should consider land, resources, capabilities and cultural and institutional contexts when defining the wood fuel resource and land to use.

The **Production & Collection** design element intends to describe the production process that the WES design intend to implement. This is a fundamental technological aspect in the WES: the conversion of the biomass from resource into an energy carrier. Besides the "production of Wood Fuel" design concern, some significantly associated design aspects have been identified in the analysis of the Technological DD (§14.6.2), namely: "technology design"; the "technological alternatives"; and the "Supply Chain." These design concerns are translated into the present design element as a number of suggestive questions that draw attention to three aspects: the choice of processes and/or technologies for production and collection of wood fuel; and the management and operation of the production and collection of wood fuel.

As many of the interviewees and literature analysed suggested, most of the failures in WES in Mozambique and other Developing Countries can be directly linked with the disconnection between the technology design and people's practices. Technology is imbedded in the socio-ecological context where it is designed and used. Every technological system has a set of norms embedded into it as well as coming with a set of norms on usage. In other words, some decisions are already made long before the user ever gets a choice. Conversely, technology in use also interacts with the reality and users, changing both in the process. This game of mutual embedment justifies the idea of co-evolution of technological systems with socio-ecological systems (e.g. Norgaard 1994), which highlights the importance of local cultures, knowledge, practices, social arrangements and contexts in the design of systems, as well as, the effects on technology transfer in those contexts. In simple terms, the choice of a technology for wood fuel production should be aware that technology is not neutral, and definitely not just technical. This design element provides a space to inquire technology in these socio-ecological terms.

This design element also deals with the management and operation of the production and collection of wood fuel considering in advance aspects related with the acquisition of the equipment, operation of the equipment and disposal of the equipment. Likewise, some aspects of the operation of the equipment or process could be questioned, in order to obtain ideas or raise awareness for the possible impact of the production.

Therefore, relevant questions that might be considered in this design element include:

- What technology to use in the production and collection of wood fuel?
- Was that technology already used in rural areas of Mozambique? Any other developing Country?

- Which technology could be more easily accepted? Cause the least cultural confrontation? Why?
- How much is the production and collection expected?
- What is the degree of innovation to introduce? (create new, adopt, adapts...)
- What is the production strategy to be considered? (local, large scale, ecologic...)
- What is the period and frequency of production/collection? (continuous, seasonal...)
- How will purchasing be done? In what conditions? (subsidised, rental…)
- What is the management regime? (communitarian, private…)
- Is there maintenance?
- Who will own the process/technology for wood fuel production and collection?
- What to do with the end of life of the process/technology used in the production and collection of wood fuel?
- What strategies for recycling, reduction, remanufacture and reuse of technology and possible by-products of the production and collection of wood fuel?

The presence of the **Distribution** design element in the 2MW is a direct consequence of the recognition of "supply chain" as a design concern in the conceptual analysis of the Technological DD (§14.6.2). Inspired by the same design concerns (except for the "Production of Wood Fuel"), distribution is a supply chain stage and an important element is the WES design, since it establishes the connection between rural contexts and urban contexts, between production and consumption, and, at least in Mozambique, between the realm of the Ministry of Agriculture and the Ministry of Energy. In current literature on wood fuel supply chains the distribution has been presented as the stage in the supply chain where the accumulation of capital was higher (Brouwer & Magane 1999; Ribot 1998) for making the wood fuel distributer one of the most influential actors in the supply chain due to its coordinating and financing role (e.g. Sem 2004). Within the 2MW, the Distribution design element represents the possible ways in which the production in rural areas could arrive to the markets. Since most of the process could be influential in, and influenced by, the technological choice for distribution. Therefore, the suggestive questions for this design element are similar to the ones presented for the production & collection of wood fuel that are only applied to the distribution.

The **Energy Service Provision** design element represents the interface between the wood fuel supply chain and the consumption by the "users". More specifically, this design element represents the bundle of WES products and services made available for the "Users" to consume as well as the possible relationships to be established with those same "users." Therefore, Energy Service Provision design element has design concerns similar to the distribution (and other design elements in the supply chain) and to the "users" & energy practices design element. Like the distribution design element, the Energy Service & Commercialisation design element is explicit in the "supply chain" design concern as well as in the "technology design" and "technological alternatives" of the Technological DD (§14.6.2). Moreover, it is also explicit in the "energy consumption &

cooking habits" design concern in the Livelihood Behavioural Socio-Cultural DD (§14.6.5). Considering the cases where WES is designed to make profit, this design element is also directly related with the "income, benefit, opportunity" design concern in the Economical Financial Business DD (§14.6.2) since it is the selling (provision with revenue) wherein income is generated. Due to its interface nature, the energy service might be seen as constraint by the characteristics of the "users" and their consumption patterns, but could also be a strong point to influence changes in those habits. In this sense, Energy Service Provision design element is also implicit in the "promotion & awareness" design concern of the Knowledge Communication & Skills DD (§14.6.7) and in the "marketing" design concern of the Economical Financial Business DD (§14.6.4). In any case, the Energy Service Provision grants the design space for designers to align the WES products and services with the characteristics of the "user" and its energy practise. Note that the non-normative and prescriptive nature of the 2MW prevents any design element, including this one, to imply a business perspective in the WES conceptual design, that is, the provision of the WES energy product and service does not have to occur on a business environment involving the exchange of same form of value. However, if it does occur, the Energy Service Provision aligned with the WES energy product and service with the "users" & energy practices design elements could also have inputs from a more business-oriented perspectives[11]. Thus, considering "users'" practices, WES products and services from a business perspective, and conditions similar to the supply chain, indicative questions for the Energy Service Provision include:

- Which energy service and/or product is the WES design providing to the "Users"?
- Which of the energy practices, socio-economic/cultural contexts, consumption patterns or need of the "Users" is the WES design responding and/or satisfying?
- How to pack the WES design in a way appealing to the "Users" and aligned with their energy practices, and socio-economic and cultural contexts?
- What previous experience with these WES products and services exists?
- What is the period and frequency of commercialisation? (continuous, seasonal...)
- What type of relationship to establish with the "users"?
- How will the selling be done? In what conditions? (subsidised, rental…)
- What is the management regime? (communitarian, private…)
- Is there maintenance?

The **Legislation, Regulation & Skills** design element represents both "the rules of the game" (North 1990), including its monitoring and execution, and the capabilities required to implement the WES design. The legislation and regulations are derived from the design concern with the same name and detected in the conceptual analysis done on the Institutional & Political DD (§14.6.3), but has also contributions from the "land tenure"

11 Indeed, all field tests revealed that people did favour income over any other possibility. However, the final decision is always of the designers and their creativity and intensions.

and “political coordination & policy execution” design concerns obtained in the same analysis. Likewise, the Skills have been determined by the skills, capacitating & training design concern that emerged from the Knowledge Communication & Skills DD conceptual analysis (§14.6.7). This design element, combining institutional, political and capability tries to cover two design aspects essential for the implementation of any WES design in Mozambique, namely: the knowledge of the several set of rules, legislation and mix of entitlements that regulate the use and exploitation of wood fuel resources and land, as well as, the entire wood fuel supply chain; and the combination of managerial, technical and negotiation skills to deal with a number of institutional contexts. By institutional contexts it is meant both the organisations and the set of formal and informal social rules that structure and give meaning to social relations (Giddens 1984; Hodgson 2006; North 1990: 3; Ostrom 2005: 3). Moreover, most of the capacitating initiatives, training and programmes aiming to improve skills are defined, sponsored and/or conducted by many of the organisations responsible for those same regulations.

In the Mozambican case, it is impossible to conceive any WES design without considering the Law of the Land, as seen before in the description of the Biomass Resources & Land design element. The Mozambican Land Law recognises the cultural value of land and assigns room for customary institutions and knowledge (e.g. Haaland 2008; Sitoe & Tchaúque 2007; de Wit & Norfolk 2010). The recognition of the term “local community” also provides a legal basis for common property arrangements (Norfolk *et al.* 2003). While in practical terms, land tenure is “both a legal framework and a set of customary practices” (Galaty 1994: 198) in Mozambique this is exacerbated by deep historical roots (e.g. Brouwer 1998) which makes the Mozambican Land Law to be considered quite progressive in the southern African context. (e.g. Haaland 2008; Tanner 2002). However, several interviewees and related literature (e.g. Sitoe & Tchaúque 2007) have criticised strongly the application and regulation, with impacts on most WES. This fact uncovers again the importance of the organisational and institutional skills for the WES design. Finally, the wood fuel supply chain and associated social networks require a number of technical and managerial skills (e.g. operate and manage technology, manage supply and demand flows) whose absence might seriously compromise the WES design (e.g. Parawira 2009). Thus, relevant questions to trigger the debate in this design element include:

- What procedures, conditions, regulations, rules and laws should be followed regarding the property, access, use, exploitation and management of land, wood resources and forests?
- What procedures, conditions, regulations, rules and laws should be followed regarding the property, operation and management of the wood fuel production and collection, distribution (transport) and provision (commercialisation)?
- What skills, capabilities, knowledge are necessary to access, use, exploit and manage the land, wood resources and forests?

- What skills, capabilities, knowledge are necessary to own, operate and manage the wood fuel production and collection, distribution (transport) and provision (commercialisation)?
- What are the community regulations regarding the use and exploitation of the forest and land in the area of the production/collection site?

The **Costs, Risks, Impacts & Competition** design element describes what can prevent success, jeopardise and/or create damage in the WES design. This design element is the result of the congregation of the ideas of damage, loss and risk, that express the three design concerns that emerged in the conceptual analysis on the three DDs, namely: the "emissions" from Technological DD (§14.6.2); the "cost/risk" from Economical Financial Business DD (§14.6.4); and "impact" from Nature DD (§14.6.6). However, other more implicit sources could be named. The "network" (Political & Institutional DD, §14.6.3, Technological DD §14.6.2, Knowledge Communication & Skills, §14.6.7) can be seen as risk management and aversion strategies in the WES design. Likewise, the search for "technological alternatives" can be a diversification of solution to minimise risk by "users", and "technology design" a risk for the promoter (in the case where there is no social acceptance or commercial failure).

In economical terms, most of the activities included in the several design elements imply financial costs (e.g. inform the network or the "users" about the WES services or products, buy a technology, distribute WES products and services). For designers aiming to design profitable WESs, these costs should be minimised, which could be accomplished by combining four extremes of cost management (Osterwalder & Pigneur 2010): reducing cost whenever possible (cost driven approach); focusing on certain values of the WES that might provide higher returns (value driven approach); produce in large quantities (economies of scales); and/or produce many different products targeting wider sections of the "users" (economies of scope). The really old half broken lorries transporting gigantic quantities of charcoal on Mozambican highways are an example of a cost driven business focusing on an economy of scale. On the other hand, proponents of the sustainable charcoal production might be aimed at value driven economies of scope. However, WES might comprise other social, environmental and cultural cost, not so easily classified. Deforestation, soil degradation, accumulation of toxic substances, loss of ritual sites, or cultural values are just some of the immense list of indicators of socio-ecological costs and impacts possibly associated to the WES (e.g. Lattimore *et al.* 2009; Rose *et al.* 2009; Stupak *et al.* 2011). Since WES are complex, adaptive and co-evolving socio-ecological systems (§9.2) there are a number of unpredictable issues that might occur in several levels and dimensions of the WES. In design terms, this equates to the possible risks in each of the DDs or in their interaction. A particular point of concern is the risk that is associated with the existent WES or the risks inherent to the acquisition of new technology. For instance, rural household survival strategies are highly dependent on the forest, and therefore WES might jeopardise that ecological safety net. On the other side,

diversification of income through WES might be an ex-ante risk management. Sensitive to this complexity, a number of tools and approaches have been developed to assess, minimise or manage risk in WES (e.g. Pimentel 2008; SEI IUCN 2009; Yousefpour *et al.* 2012). Finally, this design element also provides an indication of possible WESs, ESy and/or business competing for the same resources, land, and supply chain serving the same ”users” with the same or similar WES product and services.

In resume, this design element invites the designers to think and consider what is negative, or might become negative (or go wrong) with the WES design when affecting other socio-ecologic contexts interacting with the WES. These considerations can be illustrated by the following questions:

- What are the expected costs, risks, impacts from WES design to the land and resources?
- What are the expected costs, risks, impacts from WES design to the networks?
- What are the expected costs, risks, impacts from WES design to the “users”?
- From the WES design, which design elements represent a higher cost, risk, impact?
- What other WES or activities could compete with your WES for land, resources and supply chain?
- From the WES design, which design elements represent a higher possibility to be used, exploited or allured by competing WES, ESy or businesses?

The **Gains, Benefit, Opportunities & Synergies** design element represents the counter-part (or vice versa) of the previous Costs, Risks, Impacts & Competition design element and describes what gains could be accrued from the WES design. As a design element it originates from the conceptual analysis on the Economical Financial Business DD (§14.6.4), from which emerged the “income, benefit, opportunity” and “funding” design concern. However, it is also implicit in the benefits and qualities people see in the “technology alternatives” design concern in the Technological DD (§14.6.2). In essence, the Gain, Benefit, Opportunities & Synergies represents all the positive aspects, or possible positive aspects that WES can provide. The word “gains” was selected instead of the suggestive “revenue” to highlight the possibility that such “gain” could be in all sorts of forms, including monetary revenue from business operation, other less-financial currency or value or in monetary form, but not from business operations. For instance, in Mozambique some initiatives on WES operate with funds and subsidies. However, for business-driven designers, like the generality of the interviewees in Mozambique, the “gains” could be the revenue from selling WES products and services (e.g. charcoal and firewood). For more social driven designers it could be the possibility of job creation, which effects to the overall economy (e.g. Domac 2002; Kammen *et al.* 2004; Openshaw 2010; Stupak *et al.* 2011), or reduced greenhouse gas emissions and risk of lung deceases (e.g. Torres-Duque *et al.* 2008; Bailis *et al.* 2005). Furthermore, this design element provides a space to think about the possible synergies that could be achieved with the

WES design, i.e., the possibility to use the same resources, land, and supply chain serving to generate benefits for the same or diverse ”users” and the networks. This might include, e.g., combination of agriculture, sylviculture and herding with mutual benefits in food production and energy. Suggestive questions that could further specify this design element include:

- What are the expected gains, benefits, opportunities from the WES design to the land and resources?
- What are the expected revenues, benefits, opportunities from WES design to the networks?
- What are the expected revenues, benefits, opportunities from WES design to the “users”?
- What value are the users really willing to pay for the WES services and products? How much do they pay now for the same or equivalent services? How would they like to pay those services?
- From the WES design, which design elements represent a higher revenue, benefit, opportunity?
- What other WES or activities could be integrated or create synergies with your WES for land, resources and supply chain?
- From the WES design, which design elements represent a higher possibility to establish synergetic relations with other WES, ESy or businesses?

Note that both the Costs, Risks, Impacts & Competition and the Revenue, Benefit, Opportunities & Synergies design elements are rather subjective evaluations of concrete situations, or conceptualisations. While some examples have been presented, the purpose of the 2MW is not to conduct the designer through a certain path of evaluation, but instead provide the due space of cooperative thinking and exploration on the overall picture of the WES design, provided by the 2MW and use the best criteria and experience to assess the WES positive and negative aspects.

The **Infrastructures & Contexts** design element describes generic socio-ecological aspects that might affect the WES design. This design element is completely derived from all the design concerns identified for the Integrated Infrastructure & Networking DD (§16.4.8) through conceptual analysis. However, considering the open nature of both the WES and the DDs considered as sub-systems (§9.2), every DD has an implicit linkage with the wider socio-ecologic context where it is embedded. In many senses, this design element corresponds to the impacts and synergy aspects described in the Costs, Risks, Impacts & Competition and in the Gains, Benefit, Opportunities & Synergies design element respectively. However, while impacts and synergies departed from the WES design to assess positive and negative outcomes in the context, the Infrastructures & Contexts design element makes the opposite movement from the context to the WES design. Note here that the issue is the interaction flow and not the outside/inside nature of the design

element in relation with the WES design. They are both design element in the 2MW, only with different dynamics in relation with the WES design. This design element is also inspired by the confluence of two crescent perspectives on ESy in Developing Countries (and not only there). From one side policy makers have progressively realised over the last few decades that energy is fundamental catalyst for development (§5). From the other side, there is among energy specialists a growing conviction that energy is only a component in development (e.g. Cai *et al.* 2009). In design terms, this confluence of perspectives can be described in the three design concerns that originated in this design element and, thus, exemplified in questions such as:

- What socio-economic aspects can benefit/hinder the WES design?
- What infrastructures exist (or should exist) to facilitate, justify or burgeon the WES design? (roads, bridges, universities, health centres...)
- What infrastructures are hindering the WES design?
- What existent initiatives exist where the WES design could be a useful addition?

Naturally, the objective of this design element is not to produce a detailed socio-economic report on the conditions of the region where the WES design could be implemented, but rather to situate the design and link it with the pertinent socio-ecological reality. For Instance, many of the interviewees started the description of the WES by saying: “because Mozambique is a poor country…”

14.7 Linking The Design Element With The Design Dimensions

In order to have a graphical representation of the relation between the design elements defined and characterised above and DDs identified in §14.1, the tab. 14.16 was elaborated. Several conclusions can be drawn from this graphic representation. First, every design concerns identified for the DDs have been used to derive one or more design elements. Since the seven DDs (and respective design concerns) were already quite comprehensive and totally derived from interview and literature, those properties are still preserved with the design elements. Secondly, while there are same scattering of design concerns over the design elements, the majority of the table is composed by blank spaces, which suggests a high degree of consistency between the two conceptual analyses, the first, from data to the DDs, and the second, from DDs to design elements. Thirdly, while keeping the comprehensiveness from, and the consistency with, the first conceptual analysis and DDs, the design elements operated a remarkable synthesis. From seven abstract DDs characterised by twenty nine design concerns, useful for analysis but not design, the 2MW emerged with fourteen explicit and intuitive design elements useful to conduct a detailed description and specification of WES conceptual design in participatory groups. Therefore, more than a reorganisation of data, the design elements keep the richness of the data gathered in the interviews, the comprehensiveness and consistency, but have also tuned into a participatory conceptual design tool.

Table 14.16| Relation between the DDs and the design elements. The black cells represent an explicit relation while the grey cells represent an implicit relation (DDs are as in §14.1; Comm.- Communication; Legis.- Legislation; Regul.- Regulation; Opp.- Opportunity) [Source: the Author].

DESIGN DIMENSIONS	DESIGN ELEMENTS / DESIGN CONCERNS	PROBLEM & MOTIVATIONS	PROPOSALS & OBJECTIVES	NETWORKS	"USERS" & ENERGY PRACTICES	COMM. CHAN. & RELAT.	BIOMASS RESOURCES & LAND	PRODUCTION & COLLECTION	DISTRIBUTION	ENERGY SERVICE PROVISION	LEGISL. REGUL. & SKILLS	COST RISK IMPACT & COMPET.	GAIN BENEFIT OPP.& SYNERGY	INFRASTRUCTURE & CONTEXTS
TT	Production of Wood Fuel							■						
	Technological Alternatives				▒			■	■	■		▒	▒	
	Technology design				▒			■	■	■		▒		
	Network			■								▒		
	Supply Chain							■	■	■				
	Consumption				▒					■				
	Emissions											■		
IP	Legislation & Regulation										■			
	Political Coordination & Policy Execution	■	■								■			
	Land Tenure						▒				■			
	Network			■								▒		
EC	Income, Benefit, Opportunity									■			■	
	Cost/Risk											■		
	Funding												■	
	Network			■										
	Marketing					■				■				
BC	Socio-Cultural Context on Energy				■									
	Energy Consumption & Cooking Habits				■					■				
	Social Acceptance				■									
NT	Forest & Resource Management						■							
	Land Management						■							
	Impacts											■		
KI	Skills, Capacitating & Training										■			
	Communication, Information, R&D	■	■			■								
	Network			■								▒		
	Promotion & Awareness					■				▒				
SC	Socio-Economic Context													■
	Energy As Part of Integrated Approaches													■
	Supportive Infrastructures & Network													■

14.8 THE FINAL 2MW LAYOUT

After all the previous consideration developed in this chapter, the final layout of the 2MW is presented in the fig.14.25. Note that this layout is not exactly the same that was used in the field test, but the outcome of the results and suggestions collected during that testing period.

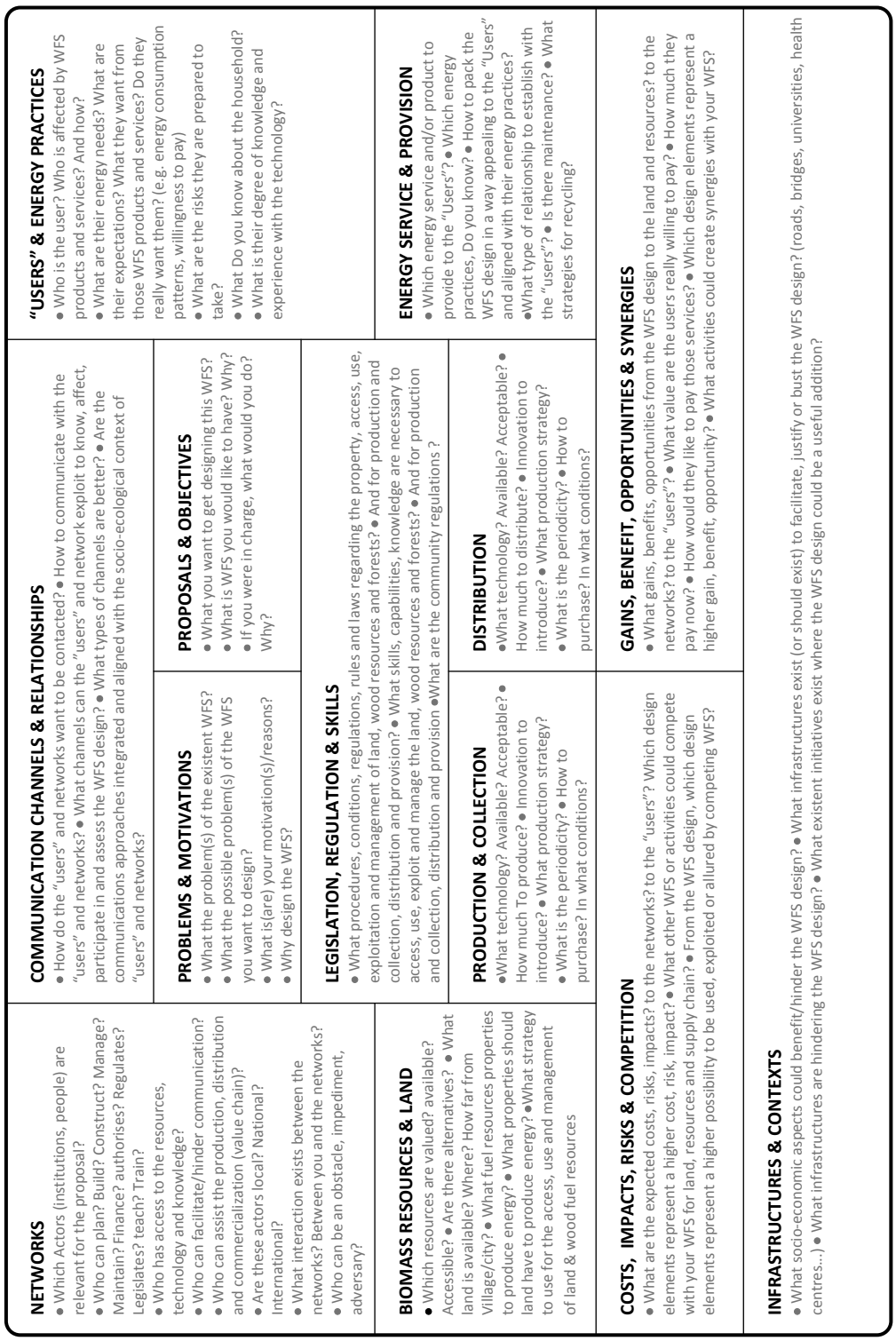


Figure 14.24| The final layout of the 2MW. In the real 2MW used on practical work, there was plenty of space for writing or drawing [Source: the Author].

However, the differences are minimal: Competition and Synergy were a separated design element; Objective, Proposal, Problem and Motivation were four separated design elements; and some design elements have been renamed, e.g. Users & Consumption, become “Users” & Energy Practices.

14.9 Comparison With A Similar Ontological Design Approach

Before describing and analysing the 2MW testing in Mozambique (§15), it is relevant to compare and/or relate the 2MW with other similar models in the same or similar context and/or approach. A comparison performed earlier in this thesis (§10) suggested that available models and tools in the field of wood fuel modelling (or even energy related models) do not fulfil the design criteria used to build the 2MW. These criteria included: support of WES (or other ESy) participatory conceptual design; dialogue facilitation; simplicity, intuitiveness; be presented in a visual format; be non-computer based; non-normative and non prescriptive. A more extended search including models from other research fields found one model that complied with all the criteria, but was not suitable to support the WES conceptual design: the business model ontology by Osterwalder (2004). The business model ontology, besides being an interesting reference for comparison, was also a remarkable source of inspiration for this thesis, which makes this comparison all the more necessary.

Like this work intends to defined by a metamodel composed by a set of essential building blocks that allow designers to describe and specify the conceptual design of WESs, Osterwalder (2004) proposed a rigorous conceptual model of business models, the business model ontology (BMO), which allows managers to “accurately describe the business model of a firm” (2004: 42) or describe “the logic of how an enterprise earns money” (2004: 9). As seen before (§11), a metamodel, a conceptual model, a reference model or an ontology are equivalent concepts since they refer to an “explicit specification of a conceptualisation” (Gruber 1993), i.e., they represent a description of the essential concepts (building blocks) and relationships in a specific domain. Therefore, both research share the same ontological approach to their respective domains. Scoping the domain of business model with such ontological approach (essentially conducting a conceptual analysis), Osterwalder identified a set of nine interrelated building blocks that allow conceiving a business model. These nine building blocks are normally organised as in fig. 14.24, forming the basis for a handy tool, the Business Model Canvas (BMC), defined as “a shared language for describing, visualising, assessing, and changing business models” (Osterwalder & Pigneur2010: 12).

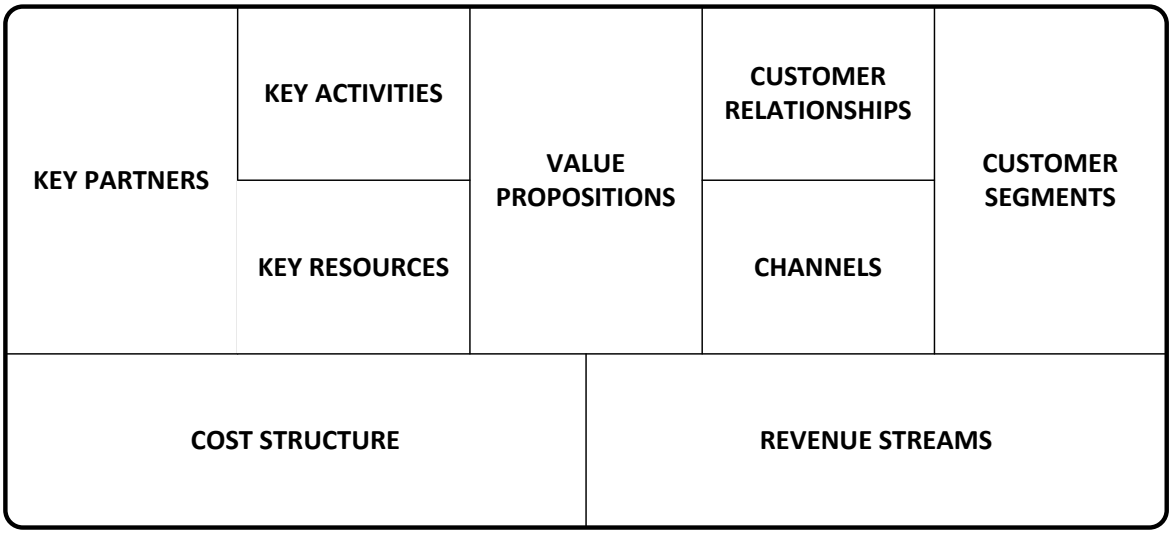


Figure 14.25| The business model ontology, also called business model canvas [Source: Osterwalder & Pigneur2010].

As for the building blocks, here is a brief definition (Osterwalder & Pigneur2010):

- The **Customer Segments** building block defines the different groups of people or organisations an enterprise aims to reach and serve. Customers comprise the heart of the BMO. Costumers are grouped into distinct segments with common needs, common behaviours, or other attributes. An organisation must make a conscious decision about which segments to serve and which segments to ignore. Once this decision is made, a business model can be carefully designed around a strong understanding of specific customer needs.
- The **Value Propositions** building block describes the bundle of products and services that create value for a specific Customer Segment. The Value Proposition solves a customer problem or satisfies a customer need by offering a Customer Segment an aggregation, or bundle, of benefits.
- The **Channels** building block describes how a company communicates with and reaches its Customer Segments to deliver a Value Proposition. Communication, distribution, and sales Channels comprise a company's interface with customers. Channels serve several functions, including: Raising awareness among customers about a company's products and services; helping customers evaluate a company's Value Proposition; allowing customers to purchase specific products and services; delivering a Value Proposition to customers; providing post-purchase customer support.
- The **Customer Relationships** building block describes the types of relationships a company establishes with specific Customer Segments. Relationships can range from personal to automated and may be motivated by: Customer acquisition; Customer retention; Boosting sales.

- The **Revenue Streams** building block represents the cash a company generates from each Customer Segment. A company must ask itself, for what value is each Customer Segment truly willing to pay? Successfully answering that question allows the firm to generate one or more Revenue Streams from each Customer Segment.
- The **Key Resources** building block describes the most important assets required to make a business model work. These resources allow an enterprise to create and offer a Value Proposition, reach markets, maintain relationships with Customer Segments, and earn revenues. Key resources can be
  - Physical- physical assets such as manufacturing facilities, buildings, vehicles, machines, systems, point-of-sales systems, and distribution networks;
  - Intellectual- brands, proprietary knowledge, patents and copyrights, partnerships, and customer database.
  - Human- Human resources, in the common sense of employees.
  - Financial- financial resources and/or financial guarantees, such as cash, lines of credit, or a stock option pool for hiring key employees.
- The **Key Activities** building block describes the most important things a company must do to make its business model work. Like Key Activities, they are required to create and offer a Value Proposition, reach markets, maintain Customer Relationships, and earn revenues. And like Key Resources, Key Activities differ depending on business model type
  - Production- refers to designing, making, and delivering a product in substantial quantities and/or of superior quality.
  - Problem solving- refers to coming up with new solutions to individual customer problems.
  - Platform/network- refer to business models dominated by platform or network-related Key Activities. Networks, matchmaking platforms, software, and even brands can function as a platform.
- The **Key Partnerships** building block describes the network of suppliers and partners that make the business model work. Companies create alliances to optimise their business models, reduce risk, or acquire resources.
- The **Cost Structure** building block describes the most important costs incurred while operating under a particular business model. Costs can be calculated relatively easily after defining Key Resources, Key Activities, and Key Partnerships.

With these building blocks in place, the BMC allows the participatory creation of "a shared and common understanding of the domain and facilitate communication between people and heterogeneous and widely spread application systems" (Osterwalder & Pigneur 2002: 78) and a "way to systematise business model invention, design and implementation" (Osterwalder & Pigneur 2010). These are clearly objectives also for the 2MW (§A).

Comparing the BMC visual format and the definitions of the BMO, a number of parallelisms could be identified. Visually, both the 2MW and the BMC are presented in a similar simple visual format composed by squares (boxes) with tag names[12], each representing a well defined essential building block (design element in the 2MW) and organised symmetrically. In terms of the content, it is reasonable to point a number of parallelisms between the two tools, as presented in the tab. 14.17:

Table 14.17| Possible similarities between the 2MW and the BMO in terms of content [Source: the Author].

2MW DESIGN ELEMENT	BMC POSSIBLE EQUIVALENT
Networks	Key Partnerships
"Users" & Energy Practices	Costumer Segments
Communication Channels & Relationships	Channels & Customer Relationships
Proposal & Objectives	Value Proposition
Biomass Resources & Land	Key Resources
Production & Collection & Distributions	Key Activities
Costs, Impacts, Risks & Competition	Cost Structure
Gains, benefit, Opportunities & Synergies	Revenue Streams

Before starting to analyse each of the possible similarities (each line in tab. 14.17), it is relevant to state three important points. First, similarities are not a drawback per se. Both tools present an ontological approach to the design of human activities in different fields (even if related) and thus it is possible that both design activities have the same constituent, essential (i.e. ontological) building blocks. In the comparison between the DDF and other resources or capitals frameworks, natural capital/resource (Nature in the DDF, Ecosystems in Foxon's co-evolutionary framework) appeared very consistently, even if with slight differences, in all the frameworks, probably because while producing an explicit specification of the conceptualisation of each domain of interest (i.e. build the ontology) all the authors found very reasonable (it made sense) the existence of "Nature" as an essential concept. The consistent appearance of "Nature" only shows that, probably, it has to be considered as an essential building block if the purpose is to describe a human activity dealing with "nature." Therefore, in this regard, both the 2MW and the BMO can be seen as independent research confirming the ontological relevance of the same, or similar elements (that, as it will be seen below are not that similar). Secondly, and quite importantly, there is no equivalent in the BMO for the 2MW Legislation, Regulation & Skills and Infrastructures & Contexts design elements. There is a good reason for this absence to specify a business model, these are contextual aspects already assumed in the

12 The final version of the 2MW, for each design element besides the tag defining name, also presents a set of suggestive questions. Some versions of the BMC also do the same.

contextual grounding of the BMO. The BMO was built from other less comprehensive ontologies and data available in the literature on Business Model in DCs, where capitalism prevails, hence an ontology of business models built in such context should mirror the essential principles of such context (that is exactly the definition of ontology), i.e., capitalism. In other words, the BMO was built in/for a capitalist, European and well regulated (at least in principle) society as model of that same capitalistic way of doing business. Since in those societies, the business context is in general stable from the institutional point of view, this context does not have to be modelled. While the surrounding context (expressed as Infrastructures & Contexts in the 2MW) affects (or could affect) the business model, for the BMO these are only adversities that are not to be considered as essential building blocks, since the system it tries to ontologically model (capitalist business), is quite the same with or without those adversities, i.e., the business environment in a capitalist society. Therefore, unless it would be legislated that profit is illegal, that is, that capitalism is illegal, the BMO would not have to conceptualise contextual aspects outside the "logic of earning money." For the 2MW, as seen above, these contextual aspects are fundamental to set the design scenario and keep design close to the reality. The purpose is to facilitate design based on contextualised perspectives designers express while using the 2MW. This is only possible, because the 2MW was co-designed and makes explicit diverse contextual realities, providing thus, not a model of a specific form of making design, but a space for creative expression of design capabilities. Thirdly, and as a consequence of the two previous points, in the Problem & Motivation design element in the 2MW, have no equivalent in the BMO. Significantly, the BMO is only concerned with one thing, Business, and with only one perspective on that Business, the economic. While very well concern with social aspects[13], Osterwalder does not consider other fundamental aspects in the design of Human artefacts (like what a business model In fact, is). Therefore, for the BMO there is only one problem, lack of value creation (measured as profit) and only one objective, to make profit with innovative business models. This is quite obvious by the title of the recent book by Osterwalder & Pigneur (2010), Business Model Generation, A Handbook for Visionaries, Game Changers, and Challengers. The purpose is to be an innovative entrepreneur or business person, again considering the innovation as an important leverage in the capitalist system, even if that entrepreneurship and innovation serves social causes. The 2MW clearly considers a different dimension of design (seven to be more exact §14.1) and allows for the definition of different problems and motivations, which interact with different proposals and objectives.

In resume, the BMO is a remarkable ontological approach, consistent and integrating other existing ontologies, that provides an ontology of capitalism business modelling focused on innovation, considered as a leverage factor to succeed in a capitalist business

13 His PhD Thesis was dedicated to "To all those people out there fighting poverty in the world" (Osterwalder 2004) and he does champions disruptive social innovation (Osterwalder & Pigneur 2010)

environment. In this formulation, the BMO has the scent of a normative approach, formulating the idea of change, improvement, innovation through/in business accepting and making explicit a set of rules assumed to be unchangeable.

Based on these basic differences, each element of the tab.14.17 will be briefly analysed.

In the Networks vs. Key Partners, the basic principle is indeed similar: have a person, or group of persons to help you with your objectives. However, this is also a basic component of most frameworks for design that consider social networks or human capital (e.g. Fuad-Luke 2009). Moreover, while for the BMO the network is made of Key Partner, that is, the nature of the relation is basically positive and business driven, in the Networks, besides the economic, financial and business perspective there are social, knowledge and institutional networks which might support or hinder the WES design.

In the "Users" & Energy Practices vs. Customer Segments, the principle might look similar: there should be someone or some organisation for which the design is oriented. However, as the literature on co-design or participatory design establishes, the human-centred design used in 2MW, is quite different from the user-centred design, used in the BMO (see description of "users" above). Moreover, the BMO is only concerned with "costumers, " a very limited business view of what are indeed the possible "users" of the WES. For instance in non-monetary remote areas, a WES could be designed to promote the use of available alternative not usually considered biomass sources, e.g. coconuts shells, and the "users" could have them for free. Moreover, the Costumer does not explicitly consider the idiosyncrasies and practices of such a costumer, only the ones that fit into the value proposition (a typical user centred approach), while by including energy practices, the 2MW clearly acknowledges the multiplicity of complexities of the "users'" possibilities and relates them to the design.

The Communication Channels & Relationships vs. Channels + Customer Relationships, there are two possible situations to compare. If the WES design is business driven, then these building blocks become all involved as Marketing, and the BMO becomes a useful and interesting model to be used with the 2MW. However, outside that business logic the Channels and Customer Relationships are again narrower in scope and completely distinct in approach. While both the Channels and Costumer Relationships admit feedback from Costumers, the purpose is always to gain business advantages. The Communication Channels design element considers the "user" in a wider range of perspectives including the user engaged in collaborative dialogue. Many of the Communication Channels, strategies and approaches might be focused on social and ecological (perceived) gains, not on gaining costumers or selling ideas. Moreover, in the 2MW, the Communication Channels serve to link the WES design with the both the network and the "Users" & Energy Practices, trying influence, captivate and engage in fruitful dialogue the entire web of actors around the 2MW design. The Channels in the BMO is only directed towards the

costumer as a buyer with opinion, assuming the Key Partner relationship to be based on common interests.

The Proposal & Objectives and the Value Proposition are very similar. They both make clear the overall design goal(s) to facilitate political and design dialogue among designers. Besides, both essential building blocks create some sort of value for those proposing it. The only differences are: the specification of objectives in the case of the 2MW which might clarify some political issues important to analyse the WES design; and the simplicity of "proposal & objectives" in relation with a somewhat more abstract "value proposition."

Considering the Biomass Resources & Land design element in the 2MW as an instantiation of the Key Resources in the BMC, would made the Key Resources have a higher degree of "essentiality" as an ontological building block. However, Biomass Resources & Land does not fit in any of the types of Key Resources presented in the BMO (Physical, Intellectual, Human & Financial). There is an obvious reason for this, it is not possible to "easily" quantify the value of nature, especially in Mozambique, where the land cannot be owned. But even if there was natural key resource in the BMO, how would it account for the peculiarities of the relation between land, forest and people (e.g. in cultural and ownership issues)? Wood is not like oil that is presented in drums; wood comes from living forests serves many purposes, has many values, requires land and is regulated by many cultural systems and principles. Hiding the natural resources and the land in a bundle of "resources" would prevent design dialogue in one of the most important design elements in the definition WES.

The Production & Collection + Distributions could indeed be considered Key Activities and was considered the creation of a design element called Supply Chain key Activities mirroring the Key Activities building block. However, there is a strong consensus regarding the definition of the supply chain as composed by production and distribution and eventually designers would end up dividing the possible Supply Chain key Activities into production and distribution. Moreover, making the supply chain stages facilitate a higher degree of design creativity and analysis on these design elements, while making the issue accessible for those who are not familiar with the concept "supply chain." However, the building block Key Activities does have a higher degree of "essentiality."

Both the comparisons Costs, Impacts, Risks & Competition vs. Cost Structure, and Gains, benefit, Opportunities & Synergies vs. Revenue Streams, follow the same line of argument followed before regarding the differences of scope and approached between the 2MW and the BMO. In essence, both design elements mean "positive aspects, gains" or "negative aspects, losses", however, the BMOI considers only one kind of objectively quantifiable gain/loss for the business model. On the other hand, the 2MW considers a range of possible types of subjective gains/losses in relation with the WES, but also with the possible impacts (negative and positive) on systems or contexts interacting with the WES. In other words, the 2MW considers gains/losses for/in/from the WES design.

Finally, besides differences (an some similarities too) in the philosophical approach to the design in the contents of the 2MW and the BMO, there are also some discrepancies in relation with the tool designing methodology.

Osterwalder started from a more or less well defined and recent domain in management, the business modelling, that he helped to clarify and specify further. Scoping that research domain and applying an ontological approach (conceptual analysis), it was possible to derive the essential building blocks that eventually compose the BMO. Subsequently the BMO was tested in interviews with business experts to check the usability, relevance and comprehensiveness, and with case studies to evaluate the capacity to describe business models. His research could not start from a limited more or less well defined research field. There is not a “wood fuel energy systems conceptual design” field of studies, but there is a huge literature on design, wood fuel, and systems modelling. Moreover, while business is a well circumscribed concept, energy On the other side, is definitely not. Therefore, the 2MW was defined through a continuous work of reflexive co-design between the author, the literature and relevant actors in the WES in Mozambique and elsewhere. The 2MW was co-designed and finally tested in Mozambique both by experts and rural communities. In this regard, the BMO is more expert driven, than the 2MW.

In conclusion, while the BMO belongs to the set of remarkable, interesting and inspiring works for this thesis, the 2MW is not a version (instantiation) of the BMO in the energy design field, and differs remarkably in terms of philosophical approach, scope, contents and methodological genesis. As a result, if the BMO was used to define a WES based on firewood to a rural household consumption, it would have a lot of empty boxes, and a lot of missing boxes. This been said, from the field of business, the BMO and BMC provided relevant insights and clarification useful for this thesis.

15 TESTING THE 2MW

As specified in the methodology (§13.4) the testing of the 2MW was performed through seven participatory design workshops (PDW) in rural and urban settings. The data and outputs collected in these workshops were then analysed and evaluated in terms of: the process of design using the 2MW, i.e., the WES conceptual design modelling (§15.1); the actual output of the workshops, the WES conceptual designs (§15.2); and workshop site (urban, rural) specific analysis (§15.3). The purpose is to compare the 2MW outputs and design process performance and quality against criteria defined in the Methodology (§13) and in the modelling/design purposes (§3). These criteria includes practical functionality of use (workability; relevance, utility, applicability; interactivity; and ease of understanding and use) in the Mozambican context (§15.1), conceptual attributes including: relevance/appropriateness of the design elements; logical structure (parsimony; comprehensiveness; coherence); and knowledge extension possibilities. All these attributes are always explored in relation with the 2MW's effectiveness to support sense making, learning and dialogue dynamics, which are the main modelling objectives of this research (§3).

15.1 CRITICAL ANALYSIS ON THE DESIGN PROCESS USING THE 2MW

All the workshop processes were carefully designed to obtain the maximum of good quality data. Therefore, in all the workshops, prior to the participatory design exercise, a small explanation adapted to the audience was given on the 2MW and the actual exercise. As much as possible, the design elements within the 2MW were presented randomly to avoid "replication" effects during the design exercise. Moreover, rather than explain in detail each design element, the participants were invited to consider the suggestive question introduced in the 2MW (see fig. 14.24 for a version of the 2MW with those questions). This low level of information was necessary to avoid any possibility of influence on the participants while addressing the proposed design exercise. The design exercise was in reality a design challenge adapted to the local WES in each site. In the participatory design workshops in Maputo (PDW), the challenge was to develop a WES to supply Maputo with wood fuel for 101 years. In Inhaca, where there is no charcoal production and the natural reserve (dune bushes and mangrove) is actively and effectively protected, the exercise was to guarantee that wood would still be available in the same quantities as today in 101 years without affecting the reserve. Finally in Santaca, a charcoal producing area, the challenge was to create a WES design that could produce charcoal for 101 years. In physical terms, the 2MW was provided as an A2 piece of paper with the several design elements with its suggestive questions organised according with the layout of exposed in fig. 12.24 (but with plenty more space to write and draw). An exception to this presentation was the first workshop (also the first in Maputo with experts, PDW1) where the design elements were provided as unstapled A5 paper sheets.

The purpose was to get input regarding the possible layout, but that did not happen. In any case, the author was always absent in the urban workshops and in the rural workshops serves as compiler and reader of the design elements, never interfering (in any of the workshops) with the course of events or emitting any comments or value consideration.

With this simple and prompt information and without any other kind of additional support, the 2MW proved to be easy to use, understand, manipulate and "move around." The large blank spaces in each of the design element were used to write and draw ideas that later were erased and written again. Moreover, the 2MW was able to effectively promote the dialogue between participants of different backgrounds and facilitated the definition and communication (in a relatively short period of time) of complex ideas on the conceptual design of WES for Maputo in a more integrated and complete form than provided in the individual interviews. Also, judging by observation of the several workshops, the comments received in the questionnaire and verbally in the end of each workshop, the 2MW did produce the surprise effect necessary for the reflexive, reassessment of assumptions that assist learning dynamics on collaborative (trans-disciplinary) work (e.g. Groß & Hoffmann-Riem 2005).

However, there were two process limitations in the use of 2MW: time required and reading skills required. The number of design elements (sixteen at the time) were probably excessive to some users. The teams took between 4 hours and 4:30h to produce a WES conceptual design for the design challenge presented. This time periods could increase if there is presentation and debate between groups (as it was considered in the conception of the workshops). However, it should be noted that participatory conceptual design is a slow and complex "learning by doing" process based on a gradual and interactive clarification of initial ideas, trial and experimentation supported by discussion and debate (e.g. Pohl & Hadorn 2008). The individual interviews from where the 2MW design tool was derived took always more than one hour (sometimes two) even considering that it was basically the direct and immediate explanation of the interviewee experience and personal opinion. Moreover, despite its simplicity, the 2MW was a design tool (and experience) completely new for the participants, requiring thus a learning period before effective use. This discovery aspect of the tool could also be amplified by the design proposal posed: as an ideal situation, without any constraints and with total freedom of action (within reason).

Therefore, crucial to the success of the 2MW usage seems to be the motivation and time availability of the participants. Nevertheless, the usage of the 2MW requires always some sort of explanation, which should be short, appropriate to the audience and quite sharp on what is the meaning and linkage of each design elements.

The requirement for the reading (the tool is not computer based, but still is presented as written) might be an impediment in areas where few (in any) of the potential WES

designer, entrepreneurs or decision makers can read and write. Therefore, the presence of a facilitator with good knowledge of the 2MW and with experience on participatory design might be necessary in contexts of low literacy. The facilitator, could, indeed, also be useful in expert or multidisciplinary contexts where all participants are literate. Despite the fact that, as seen in the previous paragraphs, the 2MW is basically self-explanatory and intuitive, professional bias and power issues can limit the usefulness of the design tool. These two aspects will be discussed in the next paragraphs.

The 2MW supports the interactive design since as all design elements are considered interdependent. Therefore, every design element is a potential initial point to start the conceptual design, and decision and changes in every design element condition changes and decision in all the other design elements, fig. 15.1A. However, the participants preferred a design approach that is essentially sequential with some interactive loops, and strongly dependent on the design elements Problem & Motivation, and Proposal & Objectives, fig. 14.6.3. In the urban workshops (PDW1, PDW2) this mode to address the design elements was confirmed by the questionnaires where three participants (18%) used the 2MW other three (18%) in randomly, while four (24%) did it sequentially and finally seven (41%) used a mix of these modes. In the rural workshops, the design elements were also addressed in fig. 15.1B, with the participants stating the Problem & Motivation, and Proposal & Objectives and then addressed the issues of greater concern, returning occasionally to add or remove some problem and/or proposal.

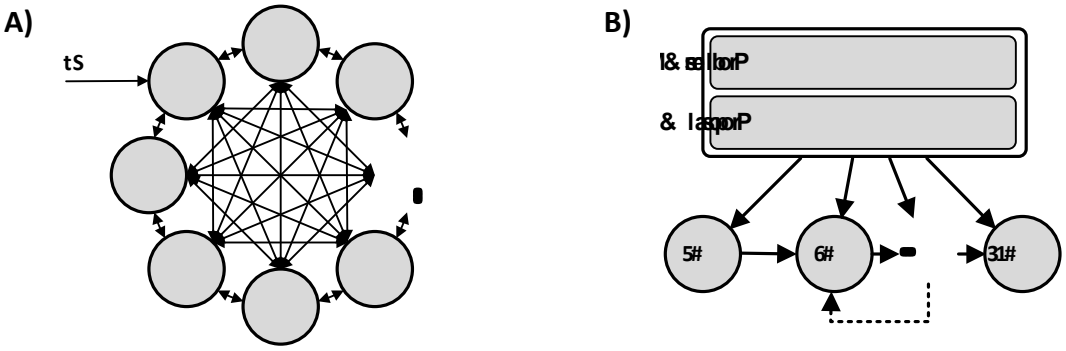


Figure 15.1| A) Pure interactive design with all design elements interdependent**, B)** Sequential design with interactive loops strongly dependent on two design elements [Source: the Author]

The sequential design is not a fault, however, the interactivity tends to generate and identify innovative and unexpected ideas and linkages, while promoting a wider view on the big picture of energy systems. The essentially sequential design selected by the teams in the expert PDWs can also be the result of a professional bias. Most of the participants on the workshops are professionals in elaborate project proposals and one of the participants actually identified the design exercise as “set up a project.” Indeed, all the four teams dedicated much more time to define Problem & Motivation, and Proposal & Objectives design elements than in any other, and none mentioned any change or refinement to those Design Elements motivated by others design elements. Therefore, a

facilitator with a strong knowledge of the Design Elements and 2MW usage could be useful here. Such facilitator could identify gaps and highlight the linkages between Design Elements.

Regarding the power issue, it is rather complex to deal with. In Mozambique, from the author's experience, in contexts marked by strong traditional leadership, in academic contexts where a senior professor is present or in contexts where a political authority with some influence is present (just to mention a few examples) it is difficult to have a real collaborative effort. The 2MW, while mute and ontological, serves contextualised design (the design is meaningful for the designers in that context) and as such cannot bypass those power logics. In this regard, once again a good facilitator and a suitable choice of groups could be helpful. Both in the rural and urban workshops, the formation of the groups was a carefully designed process (see §13.4) that revealed to be rather useful in terms of the interesting results obtained.

In resume the 2MW is an intuitive, easy to understand and to work with, facilitating dialogue and learning and realisation dynamics, but requires a well prepared facilitator in rural or low literacy contexts, to serve as reader/writer and possibly also with more literate groups, to produce more interactive results. Moreover the 2MW, as most reflexive design of complex issues, requires time and continuous reflexion and reframing of issues. This is a rather time consuming activity, to which the designers should be motivated. Finally, regarding utility, besides the generally positive comments (verbal and written) it is relevant to inform three remarkable outcomes. One senior official with more than thirty years of experience at the Ministry of Agriculture (MINAG), who participated in one of the PDW in Maputo, stated that the 2MW is now being used by him to organise projects with multidisciplinary team in the field of WES. Another consultant is actively using the 2MW in a bilateral project between the Belgium Government and Mozambican MICOA in relation with charcoal production and Clean Development Mechanisms (CDM) projects in the Mozambique. Finally, the most enthusiastic comment on the utility of the tool was probably from a charcoal maker after 4 hours of conceptual design: "My head is three times bigger, I never thought we could make so much more."

15.2 Analysis On The Team Conceptual Design Using The 2MW

To make clear, this is not an analysis on the quality of the WES conceptual design produced by each team, but rather an exploration of the potentialities offered by having a 2MW completely filled with ideas, that is, a WES conceptual design described and specified. And this is the first great outcome of this work, the actual production of complete description and specification of a WES conceptual design with the Problems, Motivations, Proposal and Objectives clearly presented, the indication of the "users" and respective interesting attributes in relation with the Problems/proposal, a network supportive (or not) identified, the biomass resources also explicitly indicated as well as the supply chain (production & Collection, Distribution and Energy Services Provision) all

the way to the "users." A communication strategy defined, with channels and relationships defined, the legislation to follow (or to be created) acknowledged, as well as, the risks, costs, impacts & Competitions alongside, the gains, benefits, opportunities & Synergies. Finally, embracing all these, are the infrastructure and networks existent, or possibly suggested. In other words, the 2MW fulfils its main purpose, to describe in a formalised way the conceptual design of a meaningful WES defined in a participatory process.

Naturally this is only the first design inspired by an intellectual design challenge, and this it was not expected to get a perfect and fully described version of the WES conceptual design. Besides there was no final debate, in any of the workshops and therefore it was not possible to further refine, interact and play around with the conceptual designs proposed by both teams. However, here resides another conceptual design advantage embodied in the 2MW: the refinement and reflexivity opportunity given by explicit knowledge. Being simple, open, non normative, and non prescriptive the 2MW is in permanent dialogue with the designer. The 2MW works more like a prototype, an embodiment of ideas, knowledge and experience (much of these normally tacit, or implicit in experts) made available for continuous refinement and reflexion. The purpose is not to correct the design done, but rather to test the capacity of the 2MW to communicate participatory conceptual design to others and the ability of the 2MW to be in itself a "design in the making" allowing thus the manipulation, questioning, analysis and even further design by others or the same group. From this analysis or manipulation a number of gaps and question can be identified which, in turn, could possibly trigger or lead to the refinement of new ideas or even new conceptual design proposals. In other words, by making knowledge explicit, what the 2MW once worked on (i.e. once a WES conceptual design is produced) became a design prototype, or what Coughlan *et al.* (2007) defined as "learning tool." This further design exercise over the conceptual designs produced in the Workshops also provide very good indication on the capacity of the 2MW to stimulate the creativity, ease the understanding of others ideas in conceptual design of energy systems and provides a quick overview on the big picture of a complex design problem. With a minimal number of design elements defined in simple terms (the suggestive questions), the author could promptly understand the basic design logic that guided the conceptual design of each team and consequently work on the proposal presenting questions, identifying gaps and proposing links and ideas for those gaps.

Note however, that like the physical limitations of a prototype, the 2MW also has conceptual limitation to the changes and designs allowed. WES conceptual designs produced with the 2MW must be meaningful, i.e., they must make sense. The design elements are open, but are also interdependent, meaning that changes in one design element affects the others. Therefore, the analysis and further design over the initial design produced by each team is only possible within the conditions established by the team. The 2MW, while favouring the continuous reflection on conceptual design, has also

a formal structure that makes sense. Therefore, not only design produced by the 2MW makes sense, they also keep some sort of "design DNA" literally printed in the design element (graphically these are the boxes in fig. 14.24). For instance, when the Black Team states as one of the proposals to create an "Energy Systems that considers energy crops", provisions have to be made in all the boxes to promote this proposal. When the Yellow Team claims an "integrated forestry resources system, " the expected consequences or specification of these must be inquired within all boxes. Likewise, when the Red Team mentions "poverty" in the motivations, what does that mean in term of Communication Channels and Relationships? The "certification" mentioned by the Green Team in its Proposal & Objectives affects and is affected by what other design elements? Naturally any designer wishing to work with the Black team would have to consider "energy crops" or, if not, erase the item from the Proposal & Objectives, i.e. change radically the design DNA idea from the Black Team. In other words, 2MW has a strong internal coherency and consistency, and any further design has the freedom to work and modify the designs, as long as it respects that consistency and coherency. It can be said therefore, that the 2MW produces coherent WES conceptual designs because the 2MW is coherent and consistent, or that designer can produce coherent consistent WES design because they see the coherence of the 2MW. In simple words, the 2MW makes sense and assist the sense making of WES conceptual design. To exemplify, imagine that next to the Legislation, Regulation and Skills design element there was a design element saying "favourite song." Probably designers would not consider this house in their WES conceptual design, that is they would make sense of the "favourite song" concept in a conceptual design exercise. However, all the teams (except the Black Team with the previous Competition & Synergies) filled all the design elements and no one in the questionnaires could identify more besides the ones presented. Therefore, it seems that beside coherent and consistent, the 2MW is comprehensive.

Finally, analysing the WES conceptual design produced by experts and by rural people, two major conclusions arise: there are not much qualitative differences; and they can all be compared with each other. The first conclusion is probably the single most important outcome of this research work and the most solid evidence of the potentialities and usefulness of the 2MW. For members who, a few couple of weeks before, could not articulate any other WES than the production to sell on the road, to be able to define an entire WES from the production to the provision with all the other design elements in accordance is definitely an achievement. With the simple support of a A2 piece of paper with some boxes printed with names and the dynamic (sometimes too dynamic) dialogue and discussion, people in rural areas could present interesting, valid and useful ideas for the WES conceptual design. While the author read the questions and wrote the replies, there was no influence in the conceptual design presented. The second conclusion presents one of the biggest advantages of the 2MW. Constituting a formalisation of the conceptualisation of the WES conceptual design, the 2MW works as a common ground to

make sense and, simultaneously provide a consistent form of comparison across different backgrounds and ideas, because the design elements are the same, meaningful, necessary and sufficient.

15.3 ANALYSIS ON URBAN PARTICIPATORY DESIGN WORKSHOPS

The participants in the two participatory design workshops conducted in Maputo (PDW1 and PDW2, see invitations on Annex 4) were all Mozambican and selected from a sample of 36 national and foreigner experts in WES (academics, governmental officials, senior consulters) interviewed between March and July 2012. Furthermore, there were five participants (two in PDW1 and three in the PDW2) which had not been interviewed before the Workshops[14]. Since, aside from those five participants, all the participants in the workshop had been interviewed individually in previous occasions to address a similar design exercise, it was possible to establish a comparison between that previous individual WES conceptual design without the 2MW and the participatory WES conceptual design done in group with the 2MW. Besides this comparative analysis done by the author, the workshops participants also provided their personal evaluation through an anonymous questionnaire.

The participants in the workshops have been divided into four teams (red, green, yellow and black), which composition tried to maintain the wider diversity of perspectives and disciplinary backgrounds while keeping some equilibrium between experience and innovative ideas. Therefore, the participants in the PDW1 were divided into the Green and Red Teams, and the participants in the PDW2 were divided into the Black and Yellow teams. With these considerations in mind, the results produced with the 2MW in the PDW1 and PDW2 were evaluated in terms of (§13.4.2):

- The 2MW comprehensiveness, parsimony & creativity stimulation;
- The 2MW stimulation of design innovation;
- The participants feedback

15.3.1 ANALYSIS ON COMPREHENSIVENESS, PARSIMONY & CREATIVITY

To be effective as a design tool the 2MW should have the necessary and sufficient design elements and stimulate the creative thinking of users (§9.3). To have the necessary and sufficient design elements means that 2MW should be simultaneously comprehensive and parsimonious, that is, the 2MW design elements are the minimum necessary to effectively describe all aspects of the WES conceptual design. The stimulation of creative thinking, on the other hand, is expressed by new ideas or perspectives in one or several design elements. Therefore, comprehensiveness and parsimony are related with the

14 With the exception of one of these "not interviewed before" participants, all the other were include by suggestion of formally invited participants. It was motivating to see how a workshop on WES with no benefits (no projects or meals attached) attracted so much interest.

2MW design, that is, the 2MW is (or is not) comprehensive and parsimonious by design. On the other hand, creativity (besides the obvious subjective nature) might be stimulated by the contact (dialogue) with the 2MW design elements or by dialogue with others while using the 2MW (§9.3.4). These attributes have been simultaneously measured by combining (triangulating) the information provided in the Workshop questionnaires filled by the participants and by comparing the WES designs from the previous individual interviews done without the 2MW and the group WES design done with the 2MW.

The results of the questionnaire are summarised in tab. 15.1, and refer to the seventeen participants in PDW1 and PDW2 (almost all known experts in this field working in Mozambique have been present):

Table 15.1| Workshop questionnaire results on 2MW parsimony, comprehensiveness and creativity stimulation [Source: the Author].

ATTRIBUTE MEASURED	QUESTION MADE IN THE QUESTIONNAIRE	RESULTS	
		YES	NO
Parsimony	Are there irrelevant design elements	0%[1]	100%
Comprehensiveness	Are there design elements missing?	0%[2]	100%
Stimulation of Creativity	Are there never thought[3] about design elements?	47%	53%

NOTES: 1- There was a participant that suggested the combination of two different design element into one, which was actually done for the last 2MW version; **2-** Two participants proposed that socio-cultural aspects should be included in all the boxes, and indeed they are through the philosophical background of the 2MW (§3; §C); **3-** … but still makes sense in the context of WES design.

The results presented (even considering the notes) are quite revealing. Based on the opinion of experts, most with several decades of experience in WES, the 2MW is quite parsimonious and comprehensive, that is, the design elements presented are necessary and sufficient to describe and specify a WES conceptual design in Mozambique. Moreover, while making sense, a number of design elements were never considered, or thought about, by some participants in the WES design, and thus, the 2MW "forced" the participant to look into the WES design from a wider perspective, opened more doors and possibilities for creativity.

Besides the questionnaire, the presence in the 2MW of the three attributes considered in Tab. 15.1 can also be tested using directly the results of the individual interviews and the data produced in the workshop using the 2MW. Comparing the individual WES designs without the 2MW and the WES designed in group, it is possible to see if the 2MW had the necessary and sufficient design elements to cover all the aspects in the individual description (parsimony and comprehensiveness). Moreover, for each Workshop participant it is possible to see how coincident in the aspects mentioned are in relation to each design element by him/her, and the aspects mentioned by his/her group for the same design element, i.e. it is possible to check for the presence of new ideas, taken as an expression of added creativity. There are two ways to see this testing. On one hand, the test is equivalent to check the degree of overlapping between the individual design and

the group designs. On the other hand, the test relies on the 2MW capability to make explicit each of the individual descriptions to be compared with the explicit description provided by the group. In other words, it is possible to translate the oral description made by the workshop participants of his/her WES design into an individual 2MW and then compare design element by design element that individual's 2MW with the group 2MW produced by his/her team, fig. 15.2.

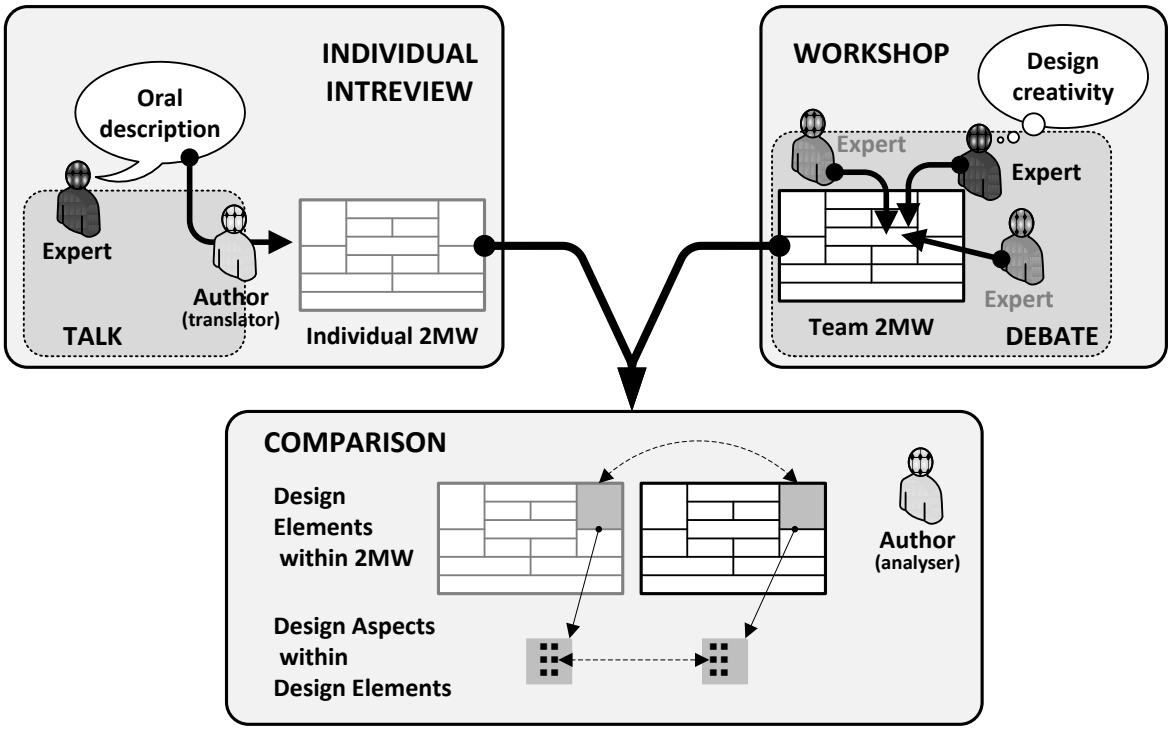


Figure 15.2| Graphical description of the process used to compare the WES design produced individually and as part of the Team using the 2MW as a common platform [Source: the Author].

In simple terms this comparative analysis intends to quantify the degree of conceptual overlap between the individual WES design and the team design using the 2MW as a common comparative ground. The outcome of the comparison can give an indication of how much the 2MW is comprehensive, parsimonious to describe both individual and team WES conceptual design, as well as, how useful the 2MW is to assist designers to expand their design thinking and creativity. This comparison is only possible because the 2MW can actually provide that common ground of comparison and because the individual interview with experts explored a design challenge (§13.4.2) similar to the one offered to each team in the PDW1 and PDW2 (§15.1). To quantify the degree of overlap, it was possible to establish a five-point scale measuring systems, tab.15.2. Note that there are five participants (two in PDW1 and three in the PDW2) which were not interviewed before, and thus will not be considered in this comparison.

Table 15.2| Types of possible overlapping between the individual and group conceptual design [Source: the Author].

SCALE	IN RELATION WITH THE DESIGN WITH THE 2MW THE INDIVIDUAKL DESING:
0	*Does not mention* the 2MW design element (*Overlapping null*)
1	Mentions the 2MW design element, but in a *implicit or indirecta way*
2	Mentions the 2MW design element *directly*, but with a *secondary importance*
3	Mentions the 2MW design element *as rather important*, but *does not refer to all design aspects* identified by the team for that same design element or refer *to other design aspects*
4	Mentions the 2MW design element *directly as rather important* and *refers all the design aspects* identified by the team for that Design Element *(total Overlapping)*

Using the scale of tab.15.2, this comparative analysis shows which Design Elements of the 2MW have been identified (or not) by each respective group member, and further, for those design elements clearly identified, the comparative analysis shows the degree of overlap between the ideas and perspectives proposed (the design aspects) for that Design Element by the individually and while working as a Team. With this scale it is possible to show how each expert scores in terms of conceptual overlap in the WES design, however, it is more interesting to see how those scores added compare with the Team. In this comparison for each 2MW design element, if all the members identified that design element and all (or more) design aspects within that design element, that represents a 100% overlapping. The results for the two Workshops (PDW1 and PDW2) and four Teams are presented in fig. 15.3. In other words, 100% of overlapping in fig. 15.3, represents what each team actually achieved, while the colourful lines represent the sum of the individual scores using the tab. 15.1 scale.

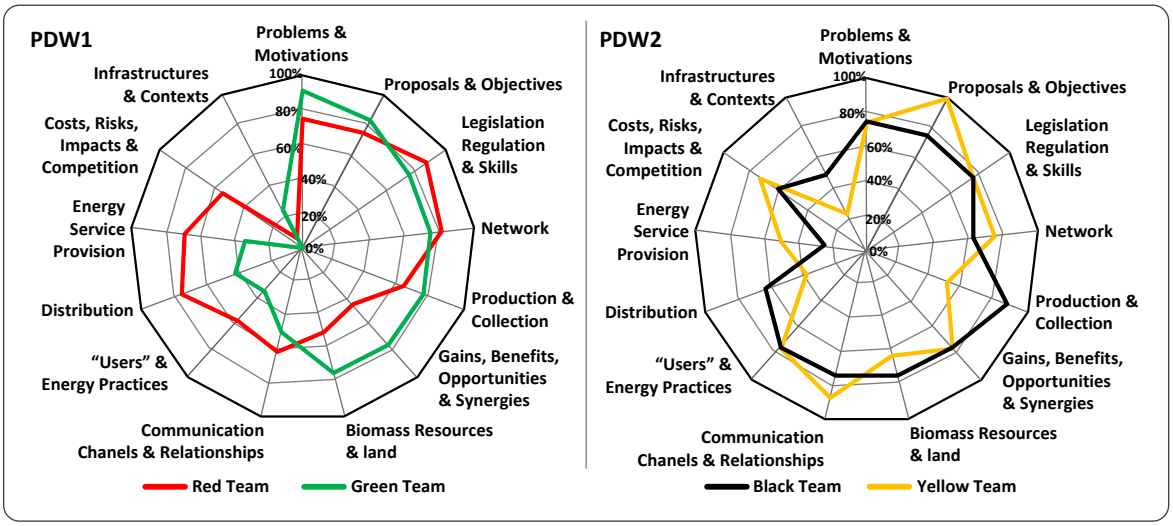


Figure 15.3| Percentage of overlapping between individual WES conceptual designs and team WES defined in participatory designs workshops (PDW) using the 2MW for the Red and Green Teams (PDW1), and for the Black and Yellow Teams (PDW2) [Source: the Author].

The results presented in fig. 12.28, are quite elucidative, except for the design element Problem & Objectives in the PDW2, each Team WES design produced with the 2MW is more comprehensive and with more aspects of design than the sum of the individual WES designs produced by the members that compose that Team. Moreover, analysing the overlapping values it is possible to quantify four groups of results with clear identifiable meaning:

1| 0% overlapping- None of the group members identified the design element without the 2MW design tool, i.e., this is a new design element not considered in his/her individual conceptual design, as in the case of Infrastructures & Contexts for the Green Team.

2| 0% < overlapping < 16%- None of the group members identified the design element in a direct explicit way and possibly one or more, but not all members, simply did not identify the design element, as in as in the case of Infrastructures & Contexts for the Red Team.

3| 84% < overlapping < 100%- All the members of the group directly and explicitly identify the design element as relevant and defines design aspects to it, but at least one member of the group did not consider all the design aspects for that design element as identified by the respective team. Examples are the Problems & Motivations for the Green Team, Legislation, Regulations & Skills for the Red Team, Production & Collection for the Black team, and Communication Channels and Relationships for the Yellow Team.

4| 100% overlapping degree - All the group members clearly identified the design element and all the same respective design aspects using the 2MW design tool and in his/her individual conceptual design. This only happened with the Problems & Objectives design element in for the Yellow Team.

The results presented in fig. 15.3 clearly show that between the two extremes of overlapping. 0% and 100%, there are always one or several members of the Teams that ignore, overlook or consider only implicitly or indirectly some design element of the design aspect. These results could indicate that the 2MW design tool facilitates a clear and easy view over the WES conceptual design big picture, meaning, a more comprehensive and parsimonious perspective revealing new design elements, or highlighting design elements not explicitly or directly considered previously, which could also facilitate the participatory creativity of team members.

This comparative analysis also works in the opposite direction, i.e., from the 2MW structure of design elements to the individual WES designs. Arranging all the Team results into maximum and minimum values, fig. 15.4, it is possible to see that practically all the design elements are greater than 20% and vary in a relatively coherent band of values over 50%, meaning that in some form, even if implicitly, all the design elements are considered meaningful for the experts in their individual WES conceptual design for

Maputo (Mozambique). Hence, the 2MW design tool is truly coherent with, and expresses accurately, the conceptual design models of these participants.

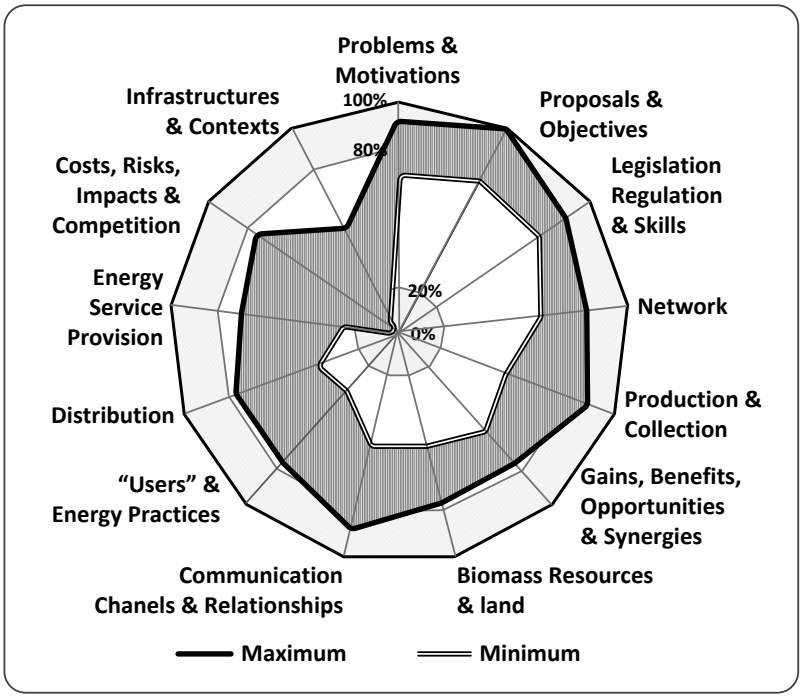


Figure 15.4| Band of variation between the maximum and the minimum values of overlapping between individual WES conceptual designs and team WES defined PDW using the 2MW considering the results of all the Teams [Source: the Author].

To further support the conclusion presented above, a combined analysis of all teams was performed considering the frequency of scale of the overlapping scale value (tab. 15.1) for each team and in total, fig. 15.5:

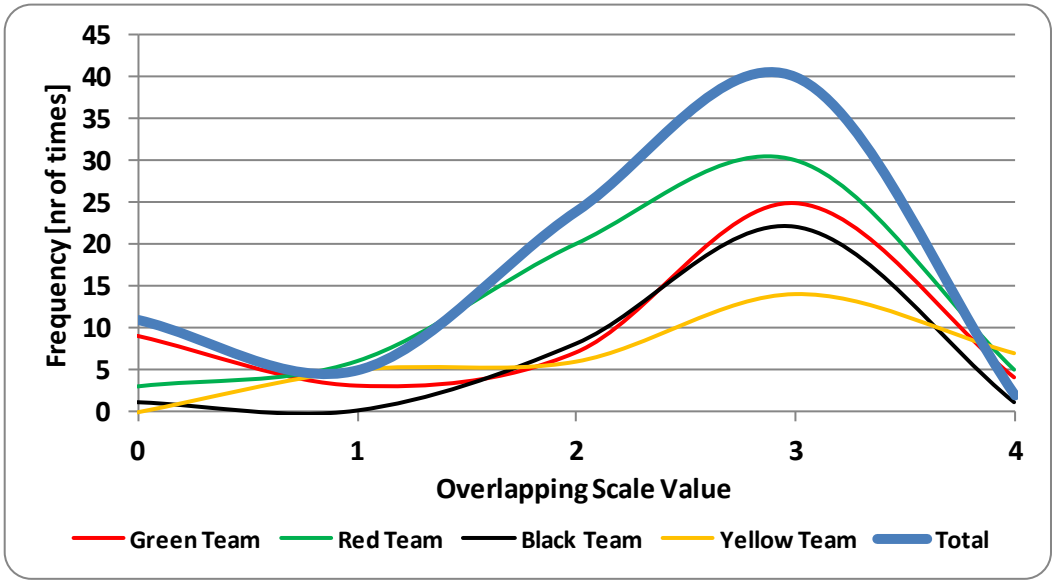


Figure 15.5| Cumulative number of times (frequency) that a certain overlapping scale value (tab. 15.1 to evaluate all the 2MW design elements for each and all Teams [Source: the Author]..

As presented in fig. 15.5, the distribution clearly favours the scale value 3, i.e., the majority of the 2MW design elements is explicitly mentioned by the experts and can even be characterised with design aspects, only not as much as the design aspects identified by his/her team for those same design elements. These results point to a high degree of familiarity or meaningfulness for most design elements among the participants, or, that the 2MW design tool structure effectively and coherently makes explicit the design logic and design mental models of the experts. Moreover, there are still several scale value zero and one, meaning that some design elements are indeed new or were never considered in the individual WES design. Likewise, the frequency of scale four of overlapping is quite reduced, which is in accordance with the conclusion that the team design did produce innovation and creative results in comparison with the individual WES design. Remarkably, these tendencies and trends are followed more or less equally in all the teams.

In resume, this comparative analysis indicates that the 2MW design tool provides a means to simultaneously see and think about in a clear, prompt, meaningful, creative and informed way, the big picture for the conceptual design of WES in Maputo (Mozambique).

15.3.2 The Wood Fuel Energy System conceptual design innovation analysis

The comparative analysis performed in §15.3.1 offers a good indication on the degree of agreement between the individual WES design and the design elements defined for the 2MW design tool, but says little on the integrative capacity of the 2MW at the level of the design element. Therefore, an analysis similar to the one conducted in §15.3.1 will be considered, but this time for each design element considering the design aspects considered by the Team and by the individual expert. The design aspects are what each Team wrote or drew in each design element of the 2MWl, i.e., the description of that design element made by the Team. The purpose is to identify if the contents defined by the group for each design element (the design aspects) in the 2MW are just the conjugation of previous ideas or perspectives held previously by each group member or if the 2MW actually facilitated the creation of new ideas and perspectives. i.e., design aspects, for that design element. While simple conjunction of ideas to produce a whole as the sum of the parts is appreciated in design, the true benefit of participatory design (§9.4.1) is the creative integration, that is, the generation of synergies, where the whole is bigger than the sum of the parts. Therefore, to know how much overlapping exists between the ideas developed individually and the ideas defined in groups for each design element, a Design Innovation Analysis was conceived, as explained in fig. 15.6:

With the definitions provided in fig. 15.6 (next page), and once again translating into 2MW the several WES conceptual design description produced in the individual interviews it is possible to compare the design aspects of all the design elements both in the individual WES design and the team design using the 2MW, fig. 15.7 (next page).

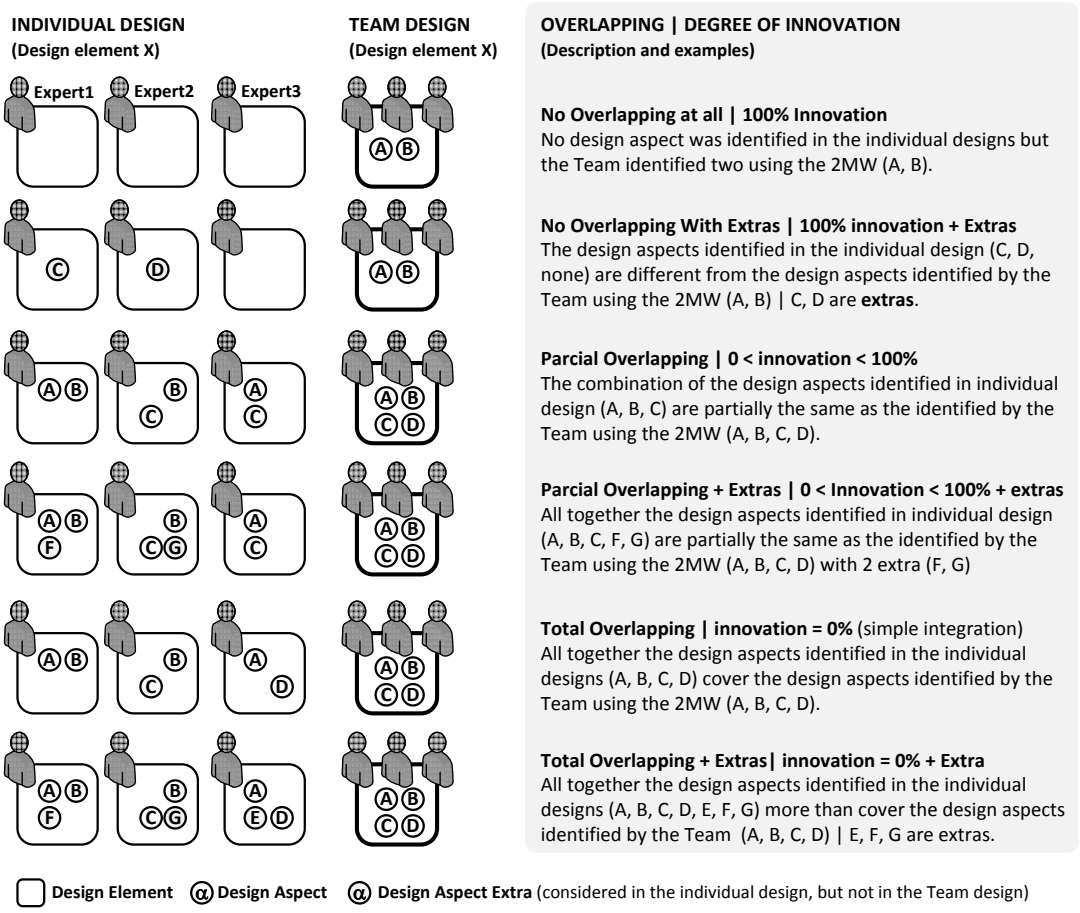


Figure 15.6| Description and examples for each of the three design aspects overlapping possibilities in a generic design element "X" in the 2MW [Source: the Author].

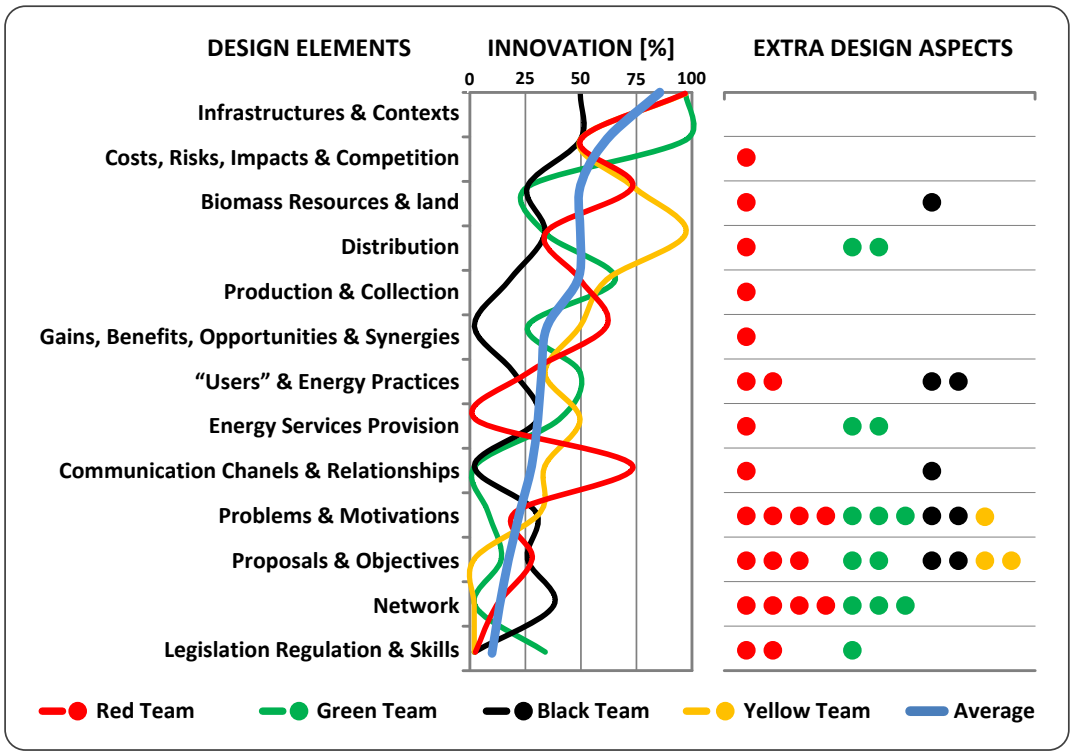


Figure 15.7| Degree of innovation in each design element and number of team members that identified extra design aspects for the four teams in the PDW1 and PDW2 (see fig. 15.6 for definitions and the following text for explanation) [Source: the Author].

The fig. 15.7 reveals the potential of the 2MW design tool as a facilitator of innovation in participatory design, since most design elements present an innovation way over 0%. Therefore, compared with the designs generated individually, each team produced designs with completely new aspects for most design elements. However, these results should be taken carefully, since there are a number of design aspects considered “extra” in the individual WES designs for more than one design element. Consequently, in order to evaluate the possible interaction between innovations values and the presence of the extra design aspects four possibilities were identified:

1| 100% Innovation, e.g. Infrastructures in the Red, Green and Yellow team- situations where the design element was never considered by the any of the team members. Basically the team members are stimulated to create design aspects for this element.

2| Innovation between 0% and 100% and design aspects extra absent, e.g., Problems and motivations for all Teams- the most clear case of innovation, since there was a total integration of design aspects identified in the individual WES designs and, furthermore, new design aspects were created by the Team to the design element.

3| 0% Innovation and design aspects extra absent, e.g., Communication Channels & Relationships in the Green Team- there is no innovation, but simple integration, being the WES design done in group the combination of the individual design aspects of respective team members.

4| Innovation between 0% and 100% and design aspects extra absent exist**,** e.g., Proposals & Objectives in all Teams - there are several possibilities. It could also mean that integration was not complete, and that some ideas where not shared, leaving therefore, more space to further enrich the Team design with design aspect from individual perspectives. However, this could also be the result of conscientious choices from the Team members that might change their design aspects or perceive their design aspects as conflictive with or incompatible with the Team conceptual design.

15.3.3 FURTHER EVALUATION BY THE PARTICIPANTS

The evaluation of the 2MW design tool by the participants was done through an anonymous questionnaire provided at the end of each Workshop. The input from the participants is fundamental to directly assess subjective and otherwise difficult to quantify intensions, values and feelings in relation with the modelling main objectives: to assist WES conceptual design through dialogue, learning and knowledge sharing on WES conceptual design across different actors. Therefore, the questionnaire complemented and enhanced the 2MW assessment by addressing conceptual and practical functions of the design tool, such as: Relevance/appropriateness; logical structure in terms of consistency; parsimony; comprehensiveness; utility and usefulness; applicability and implementability; interactivity; and ease of understanding and use (§13.4.2). The questionnaire data related with comprehensiveness and parsimony was already used in

§15.3.1, and the interactivity approached in §15.1, thus in the following, the remaining of the data is further explored.

In relation with the major objectives defined for the 2MW, the participants valued rather positively the usefulness and utility of 2MW as a WES design tool that facilitated leaning, dialogue and creativity (tab. 15.3):

Table 15.3| Average and mode (most frequent values) results for the participant evaluation of the 2MW utility, usefulness and relevance in relation with the major learning, dialogue and objectives of 2MW (original values on a 1-5 scale, being 1= nothing; 5= very much; AVG- Average) [Source: the Author].

2MW IS USEFULL & RELEVANT FOR…	BY FACILITATING…	RESULTS [%]	
		Avg	Mode
Design/Dialogue	**The WES participatory design**	85.9	80
Dialogue	**The dialogue on WES design**	90.6	100
Communication	**The communication of design ideas on FWES**	88.2	80
Learning/Dialogue	**The understanding of other's WES conceptual design**	82.4	100
Learning	**The organisation of thinking on WES conceptual design**	81.3	100
Creativity/Learning	**Thinking creatively on WES conceptual design**	77.6	80
Learning/Creativity	**A more informed strategic planning of WES**	82.4	80
Learning/Dialogue	**The analysis/vision of FWES *big picture* & interactions**	85.9	100
Dialogue/Learning	**The participatory WES design with rural populations**	80.0	100

The evaluation results provided by the participants indicate that the 2MW design tool does fulfil its objectives rather satisfactorily, facilitating effectively the creative and participatory WES conceptual design, as well as, dialogue and learning dynamics. Even the lowest ranked property, thinking creatively on WES conceptual design, was evaluated rather positively (77.6% average and 80% mode), which is remarkable, considering that none of the participants, regardless of their immense experience, had never used a design tool with these characteristics.

Regarding the simplicity, ease of understanding and familiarity (intuitiveness) of the 2MW, three questions were made to the participants. In the first, the participants were asked to identify the design elements they had difficulties with. In the second, the participants were asked to rank the design elements by order of importance. Finally, in a third question, the participants were asked to rank the design element according with time spent. The objective was to cross information (triangulate) on the relationship the participants established with the 2MW and find out how intuitive and familiar the design elements were or how difficult it was to understand the use of the 2MW. While the fist question could relate to the first contact with the tool where novelty could be an obstacle, the ranking exercises would help to clarify those issues requiring more consideration of the meaning and purpose of each design element in the WES conceptual design.

Starting with the first question, from seventeen respondents, five (29%) had difficulties to understand a total of eight design elements, tab. 15.4:

Table 15.4| Design elements identified as difficult to understand by the participants in the PDW1 and PDW2, according to *FREQUENCY* of identification (number of times identified) and total percentage in the number of possible identifications, *% IN TOTAL* (seventeen, i.e., the total number of participants) [Source: the Author].

DESIGN ELEMENT DIFICULT TO UNDERSTAND	FREQUENCY		% IN TOTAL
	PDW1	PDW2	
Gains, benefit, Opportunities & Synergies	1	2[1]	17.6
Biomass Resources & Land	2		11.8
Problems & Motivations	2[2]		11.8
Production & Collection	1		5.9
Communication Channels & Relationships		1	5.9
Legislation, Regulation & Skills	1		5.9
Costs, Impacts, Risks & Competition		1	5.9
Proposals & Objectives		1[3]	5.9

NOTES: 1- Only Synergy, at the time of the questionnaire an independent design element; **2-** Only Motivation, at the time of the questionnaire an independent design element; **3-** Only Objective, at the time of the questionnaire an independent design element.

Eight design elements out of thirteen possible (sixteen at the time when the questionnaire was made) where participants had difficulties to understand might be considered high percentage, it is worth noticing that in total these are relatively marginal values which did not prevent the use of the 2MW design tool and worked as recommendations for further versions of the 2MW, including, for instance, clearer and more precise suggestive questions. However, overlooking the suggestive question might be the origin of some of the identification. There is a possibility that "difficult to understand design element" might have been confused with "what is intended to do on this design element", since it is believed that "Production & Collection" (at the time simply Production) are simple to understand concepts, but could have several meaning depending on the participant. Also, as mentioned by some participants in conversation, in a first contact, some participants relate "new" with "difficult to understand." The possibility of this confusion was in the origin of the conception of the two other ranking questions mentioned above. Therefore, knowing that all design elements had been considered as relevant, tab. 15.1, the participants identified also a hierarchy of importance for the 2MW design elements tab. 15.5, and the time spent with each design element, tab. 15.6.

Table 15.5| Hierarchy of importance for the design elements of the 2MW aggregating the participants (Points attributed as 1st = 13, …; 13th =1) [Source: the Author].

#	2MW DESIGN ELEMENTS	POINTS	NR OF TIMES AS		
			1ST	2ND	3RD
1	**Problems & Motivations**	378	11	5	2
2	**Proposal & Objectives**	347	4	6	6
3	**Profit, Benefits, Opportunities & Synergies**	306	3	3	3
4	**Production & Collection**	203	4	2	1
5	**Biomass Resources & Land**	199	3	4	2
6	**Network**	195	5	2	0
7	**Distribution**	189	2	4	2
8	**"Users" & Energy Practices**	182	1	4	2
9	**Legislation, Regulations & Skills**	178	3	4	0
10	**Energy Services Provision**	174	1	4	2
11	**Costs, Risks, Impacts & Competition**	168	1	4	1
12	**Infrastructures & Contexts**	164	2	4	1
13	**Communication Channels & Relationships**	161	0	3	1

Table 15.6| Design elements ranked in function of the number of times (FREQUENCY) they have been identified by participants as being more time consuming (ordered from more time consuming to less time consuming) [Source: the Author].

#	2MW DESIGN ELEMENTS	FREQUENCY		
		PDW1	PDW2	TOTAL
1	**Problems & Motivations**	9	5	14
2	**Proposal & Objectives**	8	3	11
3	**Production & Collection**	1	6	7
4	**Distribution**	2	4	6
5	**Profit, Benefits, Opportunities & Synergies**	1	4	5
5	**Costs, Risks, Impacts & Competition**	2	3	5
5	**Network**	3	2	5
6	**"Users" & Energy Practices**	2	1	3
6	**Biomass Resources & Land**	1	2	3
7	**Energy Services Provision**	2	0	2
8	**Legislation, Regulations & Skills**	1	0	1
8	**Infrastructures & Contexts**	1	0	1
8	**Communication Channels & Relationships**	1	0	1

The results from tabs. 15.5-15.6 are very consistent, which might indicate that participants allocated time not according to difficulty to understand, but rather in function of perceived relevance in the WES design. By understanding or perceiving the relevance it means that the participants either were familiar with the design element or

either recognised through the 2MW its relevance for the WES design. In any case, both results suggest the intuitive and easy to understand nature of the 2MW as a design tool to support WES conceptual design. It is also notorious the dispersion of ranking values given by the participants to the relevance of the design elements. While this is a consequence of the different background and perspectives, which translate in different ways to value the same situation, it is interesting to see that the design elements Problems & Motivations, Proposal & Objectives, Profit, Benefits, Opportunities & Synergies, Production & Collection, are consistently (higher points and presences in the first position of preference, tab. 15.5). This result is in agreement with the notion indicated before (§15.1, fig. 15.1) that the Teams in PDW1 and PDW2 tended concentrate first in the definition of the problem/solution and only then focus on the other design elements. Confronting these results with the ones presented in tabs. 15.4, it seems that while some understanding problems might have been felt by some participants with some design elements, the team rapidly dealt with them effectively. Remarkably, the first four design element mentioned as "difficult to understand" by the participants (Gains, Benefit, Opportunities & Synergies, Biomass Resources & Land, Problems & Motivations, Production & Collection) also rank high on the preference, and time spent by all teams.

Finally, comparing the tab. 15.5 and tab. 15.6 similar trends with the degree of innovation (fig. 15.7), it is difficult to find a relation of rankings, which is quite revealing that the lower values for innovation and overlap in some 2MW design elements are not the result of those elements being considered irrelevant but rather because they have not been considered thoughtfully by the participants in their personal conceptual designs. In other words, the combined analysis of these results seem to indicate that the 2MW does provide a wider view of the WES, favouring thus the creativity and learning by "forcing" participants to think outside their professional and disciplinary boundaries.

15.4 PARTICIPATORY DESIGN WORKSHOPS IN RURAL SETTINGS

The particular conditions prevailing in rural areas of Mozambique forced some changes in the way the 2MW was tested, but the overall assessment and modelling objectives continue to be the same: test the ability of the 2MW to effectively and efficiently assist the participatory WES conceptual design through the promotion of dialogue, learning and sense making mechanisms. Therefore, with slight differences in relation with the participatory design workshops (PDW) conducted with experts in Maputo City, five rural participatory design workshops had been organised and carried out in Santaca (Tinonganine, PDW3 and PSW4) and Inhaca Island (Ribjene, PDW5; Nhamkene, PDW6; and Inguane, PDW7). Unlike the case in urban setting, there were not individual interviews before the testing of the 2MW and it was not possible to make individual and anonymous questionnaires in the end of each workshop. The rural interviews made to co-design the 2MW were all group interviews for which only some members were in the PDWs, and thus it was not possible to relate the individual WES designs before the use of

the 2MW with the ones produced with the 2MW in groups, as it was done in the urban settings. The final questionnaire was not possible to do because few could read or write and by the end of the workshops, most had to leave promptly. The nonexistence of someone able to write or read fluently in Portuguese was also the reason why the author had to serve as reader and writer of the 2MW in the workshops. Finally, a major difference with interviews with experts was the technique used for knowledge elicitations. In rural settings, the design knowledge was made available through storytelling (see §13), where the group of interviewees was stimulated to tell the story of a typical charcoal production cycle or firewood collection day, like if they were professors and the author a student. Therefore, in order to access the 2MW through the comparison of the WES designed with and without the 2MW, it was necessary to translate this storyline into a WES described in terms of the 2MW design elements (a process similar to the one on fig. 15.2). Remarkably, this translation was only possible for two reasons. First, because a rather consensual and consistent storyline on making charcoal and collecting wood emerged from the group interviews, which will serve as a "standard" of comparison against the multiplicity of designs produced with the 2MW. Secondly, because the 2MW can effectively describe those story lines in terms of design elements, which constitutes another evidence of the 2MW usefulness as a design descriptive tool.

Therefore, in the following for each rural setting, an initial WES story would be described using the 2MW and then compared with the actual WES design produced in the respective PDWs. To facilitate comparison, a colour code will be used in the description of "standard storyline." The design elements explicitly mentioned in the group interviews are in dark gray (■), the design elements mentioned implicitly or indirectly are in light grey (■); the design elements not mentioned are not marked. Moreover, semi-transparent, red double arrows mark the interactions between the different design elements when necessary.

15.4.1 Tinonganine Charcoal Storyline

Two workshops were carried at Tinonganine: the PDW3 with six participants; and the PDW4 with eleven participants. The participants had been selected among the most active and participative members in the several group interviews performed previously. In those group interviews, it was found that in Tinonganine, charcoal is produced by virtually all members of the locality at different degrees, but according to a common charcoal storyline (WES description) composed by three basic elements: poverty; easy access to forest resources; and a road. Poverty and the recent monetization of rural areas is the major motivation to produce charcoal. All the interviewees complained of the hard work required to do charcoal, which continues to use traditional methods extremely demanding in terms of time and effort. However, to provide education and buy most of the otherwise full time farmers, turn to charcoal as a source of income. Only one interviewee mentioned that besides goods, she was interested in use the charcoal money

to start a chicken farm side-business. Some, few, mentioned the possible damage to forest that charcoal can produce, but in general the forest was taken as free common-use resources with free access, except for sacred tress, fruit trees or otherwise useful trees. Restrictions were also recognised on sacred land (essential burial sites or "bad luck" areas) and some areas that had an "owner, " possibly some local authority. Charcoal can also be considered as an integral part of traditional land management, since the opening of areas to make farms generates the wood necessary to make charcoal. Finally, charcoal makers deposit the charcoal bags brought from the woods into the side road and wait for the occasional buyer informal, retailers, the "guevas", to buy the gags. Since the road is not very busy there is a high risk that charcoal is not sold at all, or sold at a very low price to "gain at least something." Some innovations are possible, e.g. rent a chain saw, generally as group to share the expenses, work load and profits, or renting a truck to deliver the charcoal in city markets. However, this was not the general rule and lack of income to pay the rent fees is a problem. Translated into the 2MW, this standard Tinonganine charcoal storyline is described as depicted in fig. 15.8. Note that this standard version is the most complete possible, that is, it represents what most charcoal makers described in the group interviews, but adds as explicit and clearly marked design aspects that would be implicit or indirect to some of the interviewees.

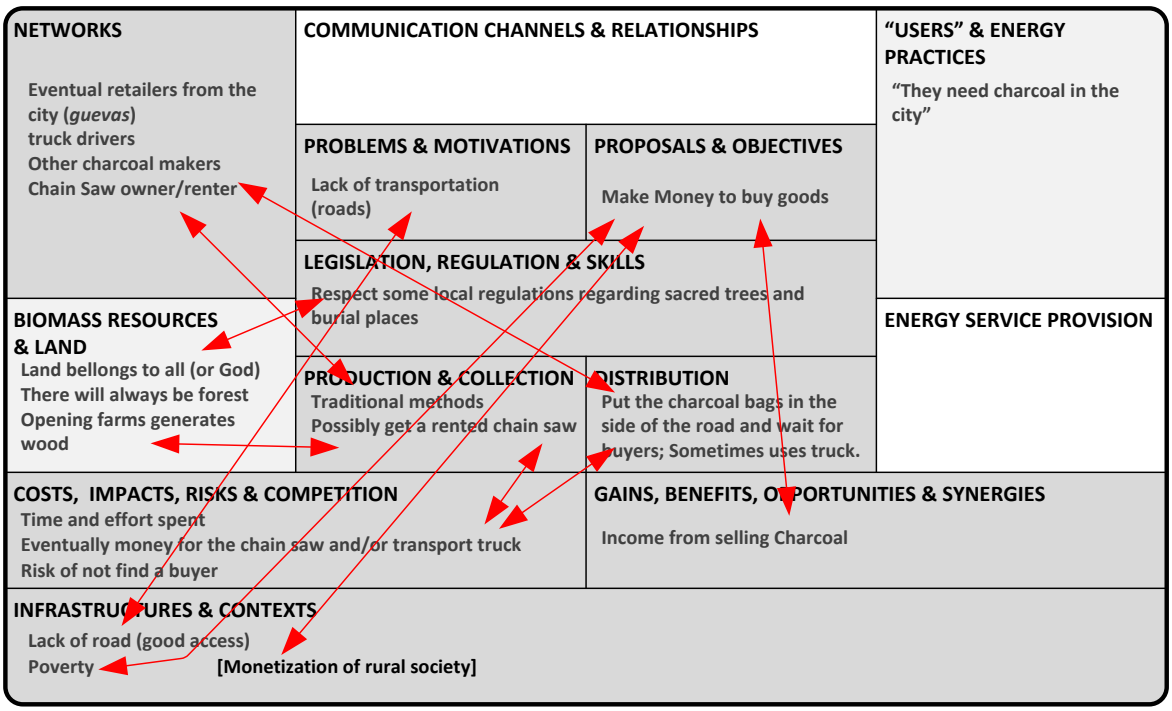


Figure 15.8| The Tinonganine Charcoal Storyline as described by the 2MW following input from rural group interviews in Tinonganine also showing the multiple interactions (transparent double arrowed lines) between design elements. ([TEXT] a conclusion observed by the author) [Tinonganine Actors & the Author].

Using this "standard storyline" as a "general standard picture" of the WES prevailing in Tinonganine, the two rural workshops in Tinonganine were defined using a similar design challenge as the one proposed in the urban settings: "How to keep producing charcoal in Tinonganine in the next 101 years." The outcomes are presented in fig. 15.9 and 15.10.

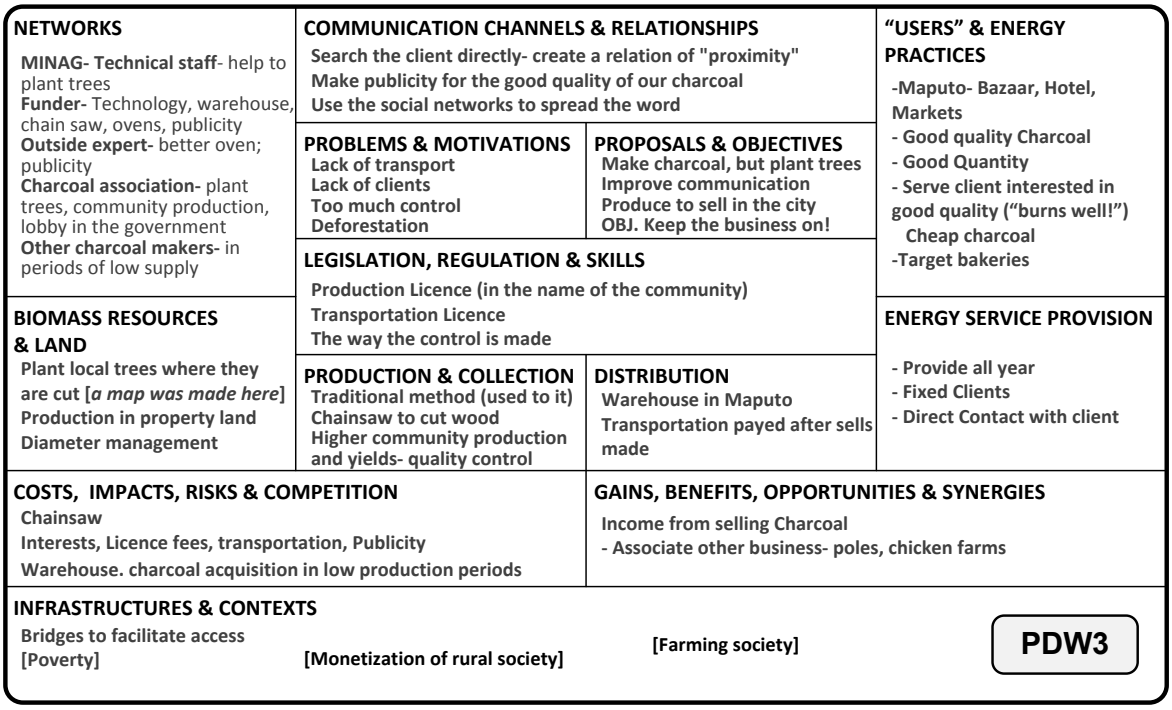


Figure 15.9| The WES conceptual design described using the 2MW in the PDW3 at Tinonganine ([TEXT] a conclusion observed by the author; MINAG- Ministry of Agriculture)) [Tinonganine Actors].

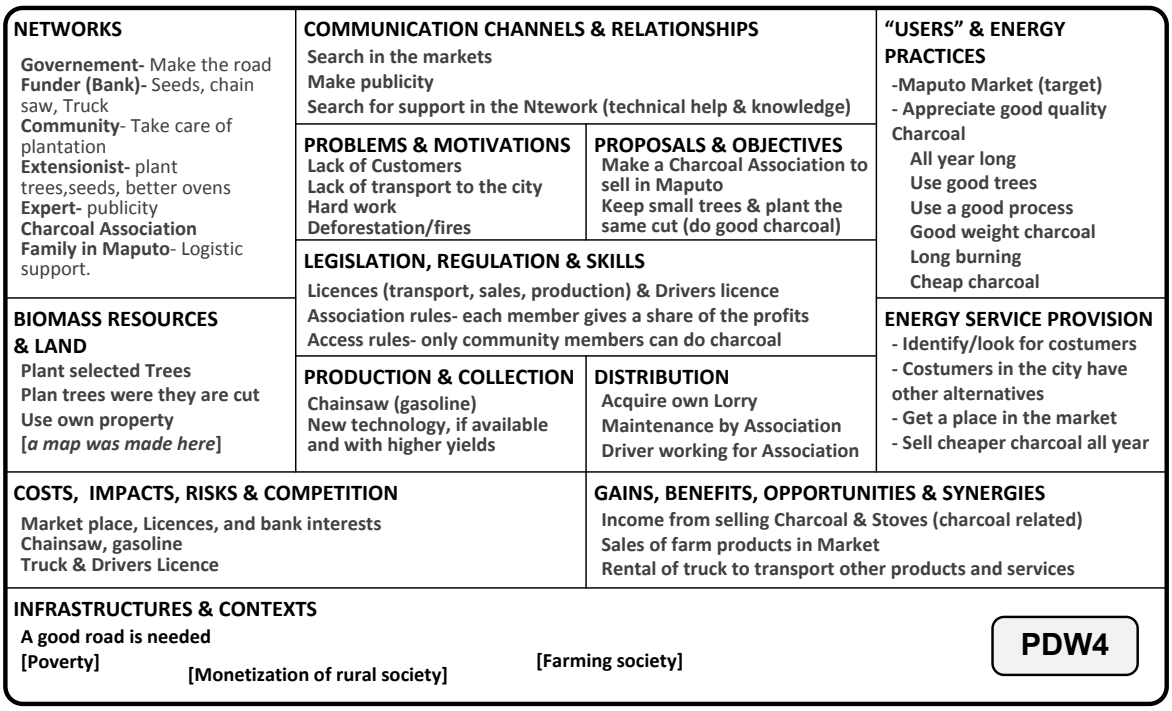


Figure 15.10| The WES conceptual design described using the 2MW in the PDW4 at Tinonganine ([TEXT] a conclusion observed by the author)) [Tinonganine Actors].

The two PDW in Tinonganine (PDW3 and PDW4) fallow a relatively business driven approach supported by the plantation of trees, funding and some technological improvements. The group in PDW3 is probably more concerned with using the charcoal business to fund other business, while the PDW4 group opted to improve technology (truck) to fuel other farm related businesses. However, what is relevant for this research

is the fact that by using the 2MW, both PDWs produced a far more complex, interlinked, integrated, informed and extended WES conceptual designs than what was offered by the standard charcoal storyline.

In order to get a visualisation of the impact of 2MW in the WES design for Tinonganine the standard charcoal storyline depicted in fig. 15.8 can be compared design element by design element with the WES produced in PDW3 (fig. 15.9) and PDW4 (15.10). However, some consideration should be made before the comparison. First, note that the objective is not to produce a precise quantification of ideas or design, but to establish a reasonable comparison between WES design after and before the use of the 2MW. Secondly, since the participants in the Workshops were also actively involved in the group interviews from which the standard charcoal storyline emerged, it is natural that some of the design aspects mentioned in fig. 15.8 are still in place even if not mentioned in figs. 15.9 and 15.10, e.g. traditional and religions regulation will be obviously in place. Thirdly, all conceptual design aspects (the description inside each design elements), are considered equal and granted the value of "1" when they are mentioned explicitly and directly in the standard storyline (design aspects in the dark grey design elements), and the value of "0.5" are only mentioned implicitly and indirectly in the standard storyline (light grey boxes in fig. 15.8). Likewise, each new design aspect generated in the workshop for each design element will be granted the value of "1." With these considerations in mind, taking 100% as the design provided by the Workshops it is possible with a simple ratio to make a quantitative relative evaluation between the standard storyline and the WES designs for each design element, fig, 15.11.

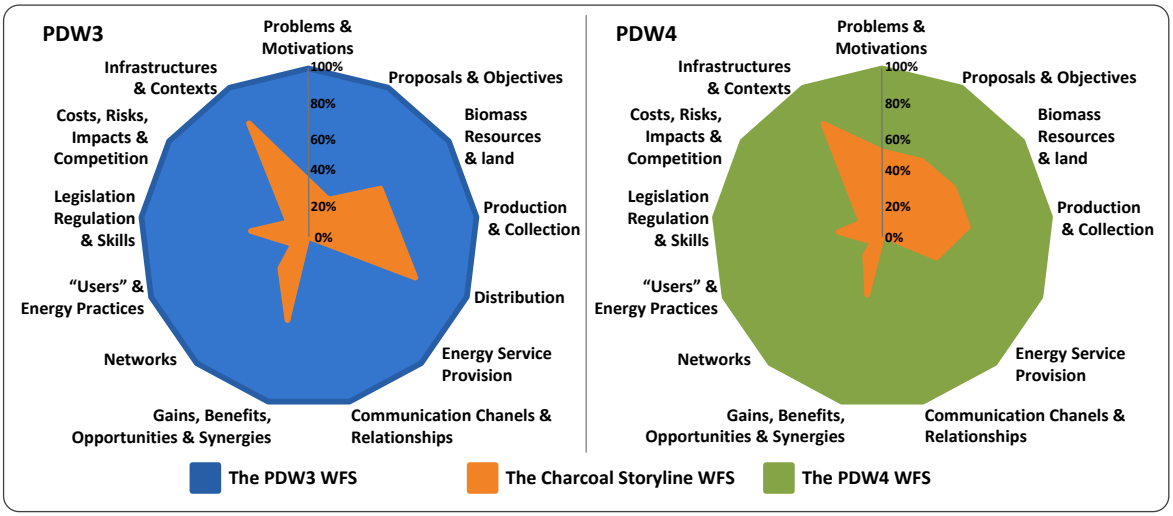


Figure 15.11| The relative position of the WES design obtained by translating the charcoal story line into the 2MW WES and the WES designs obtained in PDW3 and PDW4 [Source: the Author].

The fig. 15.11 only makes visible what is already clear comparing figs. 15.9-10 with fig. 15.8: the WESs produced with the 2MW are more comprehensive, informed and detailed than the description encapsulated in the standard storyline. There are more design elements used (hence the two 0% in each of the WES designs in fig. 15.11) and for each

design elements new and more design aspects are used (hence there is not any design element ranking 100% in fig. 15.11). In graphical terms, in fig. 15.11, the qualitative difference is between the WES produced in the Workshops and the WES represented in the storyline is the transparent blue and green space between the orange line (the limits of the storyline) and blue /green 100% line (the definition of each Workshop WES). Also relevant are the number of new interactions and linkages identified and explored by each group in the Workshops, the transparent red double arrowed lines in fig. 15.11. Comparing with the fig. 15.8, the interactions identified more than doubled clearly showing a more integrated, informed and robust WES. This higher number of interactions also shows the capacity of the 2MW to generate interactive and iterative design. Also stimulated by the author/facilitator, the participants in both workshops started from an initial definition of the problems and proposal and then went to other design elements returning to redefine the proposal whenever necessary.

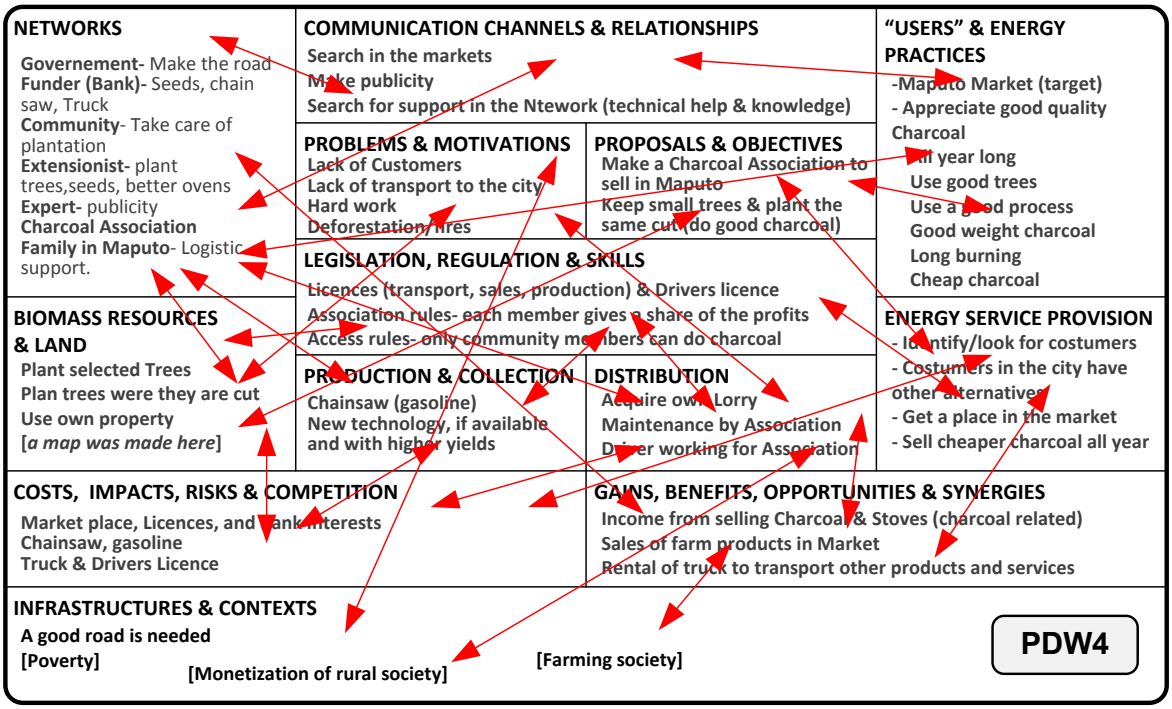


Figure 15.12| The WES from the PDW4 with the representation of interactions (transparent red double arrowed lines) between design elements (similar figures could be produced for the WES design from the PDW3) [Source: the Author].

In resume, the 2MW facilitated in both PDWs an increase in the quality of the WES design by considering a wider number of relevant design elements, generating more design aspects for each design element and interactions between the design elements. These improvements were motivating and motivated by an active dialogue/debate between the participants stimulated mostly by the suggestive questions and the willingness to address them. During the 3:30h to 4:00h debate/dialogue it was possible see how each new design element inspired creativity, inquiring and learning. Triggered to go "beyond the road", the participants considered forest management to address their living conditions, learning more about the WES with the support of the 2MW. This was clearly stated in a

number of occasions by the participants verbally and through surprise expressions. For instance, in the PDW4 when questioned by the Costs, Impacts, Risks & Competition design element, the participants were surprised to realise that (after some basic arithmetic with candies) the major cost was not in the rental of the chainsaw, but transport. Eventually, this realisation led to the idea of acquiring a truck and trying to make it profitable, both for distribution of charcoal and other farming products (synergy and integration with local farming reality). This evidence strongly suggests the effectiveness of the 2MW to facilitate informed and wider understanding of the WES.

15.4.2 Inhaca Firewood Storyline

Inhaca Island is a rural area almost fully covered by electrical grid[15] where charcoal is not produced[16] and a natural reserve prevails with intense monitoring with environmental and conservationist campaigns in the communities. Following the administrative division of the island, three participatory design workshops (PDW) were carried out: the PDW5 in Ribjene (the more urbanised area) with a group of five participants including a bakery owner, firewood collectors and firewood users; the PDW6 in Nhankene with a group of seven participants, all firewood collectors and a member and an Induna (a traditional institutional rank); and in Ingwane (the least urbanised) with a group of nine participants all firewood collectors, some also sellers and the Regulo (the local Leader). Like in Tinonganine, these participants had been selected from the most active and creative members in the several group and individual interviews performed previously during the 2MW design stage (§13). Since some of the previous interviews (i.e. the interviews without the support of the 2MW) were individual, in principle it would be possible to perform with the data collected in Inhaca the same analysis done with the experts. However, the dispersion of ideas and perspectives revealed to be very small, and thus, in agreement with the assessment process done in Tinonganine, the standard basis for comparison is the common firewood storyline that pervaded was the WES descriptions offered by the firewood collectors in Inhaca.

The firewood storyline of Inhaca, fig. 15.13 (next page), is the tale of a living dilemma involving: the access to resources; livelihoods and cultural habits; and recent socio-economic changes. “Trapped in a land boat” amidst poverty and low farm production, the Inhaca inhabitants have to make a daily choice between protecting the island and cooking food, eating bread, opening farms, building houses, constructing fishing boats (a main activity for men in the island) or open roads. Cooking should be made with wood. It is cheap, there is plenty (still) and it tastes better. However, grid electricity (the energy

15 EdM (Electricidade de Moçambique) the National electricity provider claims coverage of 98%, and indeed the wires run all along the roads everywhere in the Island. Moreover the prices charged for installation and use are lower than in the rest of Maputo City, where Inhaca belongs administratively.

16 Actually, in what could be considered a relevant local discovery, during the realization of this research it was found that charcoal was indeed produced in the Island at least three times. Although authorities promptly stopped the activity, there is not one single document on the subject.

option available, i.e. known), presents a number of problems: is too expensive; the quality of supply not constant; and the installation quality weak (wires burn easily). As a result, there are high costs and risk of burning wires associated with the use of electricity to make it a not viable replacement to the traditional means of cooking food, which "tastes better with firewood anyway". On top of this, the demographic growth is accelerating and with it, the pressure on the resources. A number of bakeries opened, supplying the most desired bread, but demands large quantities of big trees with high energy content. Incidentally, these are the same preferred to make boats due to their resistance and shape. Within these pressures, people do have to make a living and are daily designing energy strategies that respect the regulations imposed by the Natural Reserve (do not collect within the reserve) or accepted by culture (collect outside sacred areas) while bringing home or selling selected tree species (dead brunches) known for their fire quality to cook. This is hard work, done with traditional methods and tools three times or twice a week for private consumption or daily to sell to bakeries and/or private households in Ribjene. Definitely, there is a strong acknowledgement of the essential work of the natural reserve, the institutionally established entity that keeps, through a series of strict prohibitions, the line of bushes and mangrove that protects the coast along a number of jobs. However, with the scarcity of wood, low income and lack of real alternatives, many interviewees reclaimed controlled access to the Natural Reserve, an ease in the present firewood constraints. In all the interviews conducted in Inhaca, the dilemma here described was made visible in the immanent conflicts between the recognised importance of the reserve and the need for resources available.

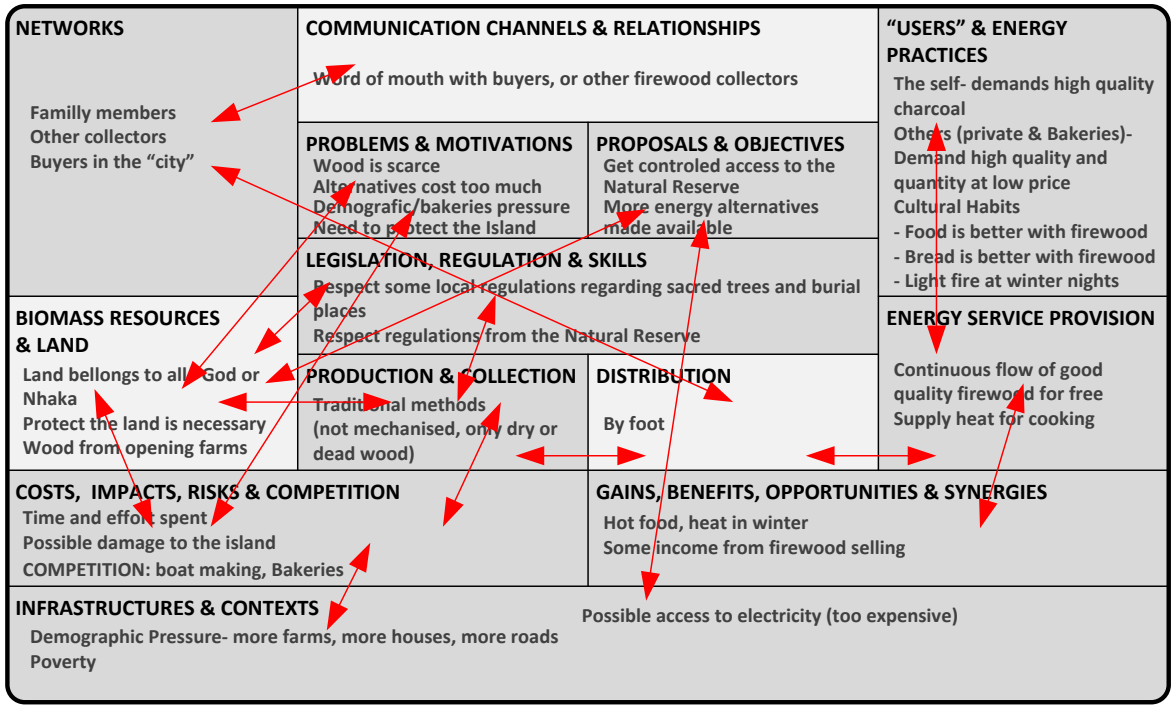


Figure 15.13| The Inhaca Firewood Storyline as described by the 2MW following input from rural interviews in Inhaca also showing the multiple interactions (transparent double arrowed lines) between design elements) [Source: Inhaca Actors & the Author].

Like with Tinonganine, fallowing the "standard" WF storyline for Inhaca WES presented as a conceptual design on 2MW (fig. 15.13) the three outcomes from the PDW are also produced, fig. 15.14-16.

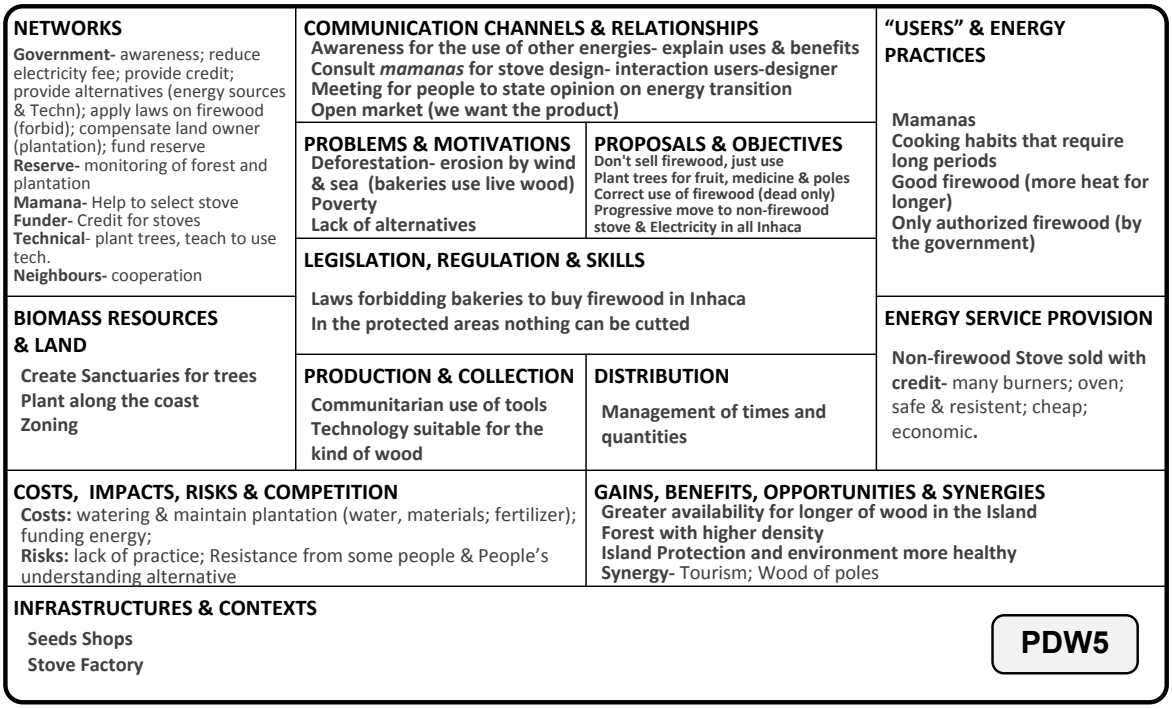


Figure 15.14| The WES conceptual design described using the 2MW in the PDW5 at Inhaca (Tech.- Technology; Mamanas- Female head of the household, loosely translatable as "Mothers"). [Source: Inhaca Actors]

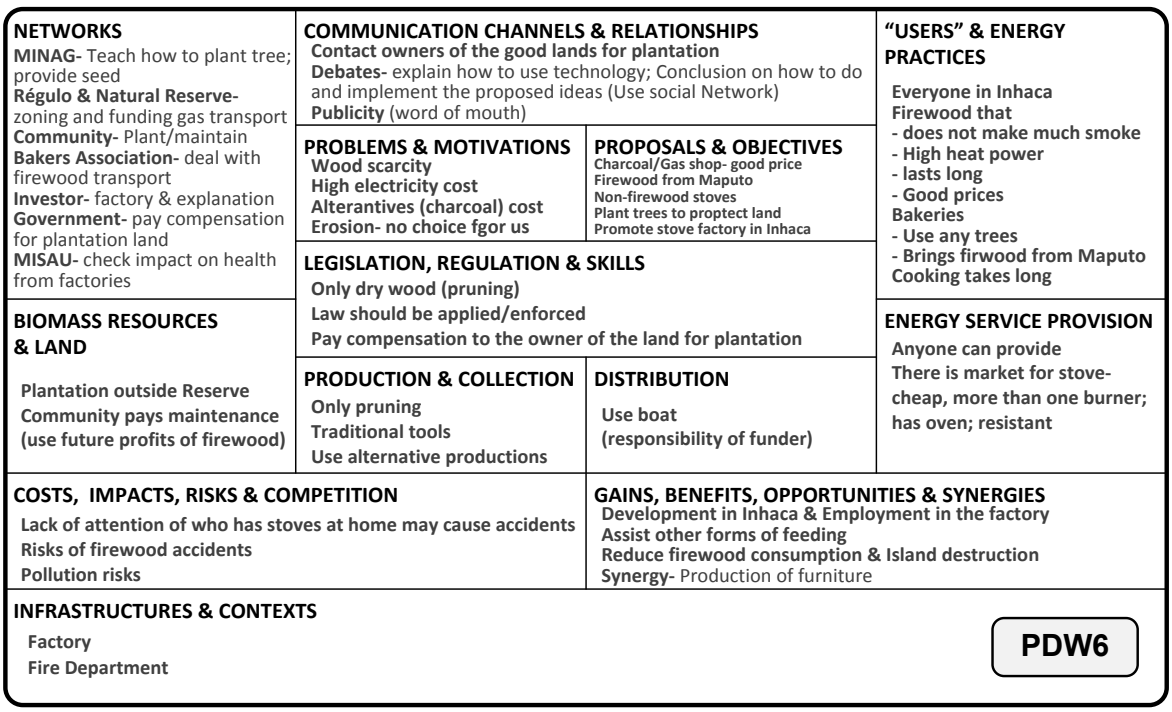


Figure 15.15| The WES conceptual design described using the 2MW in the PDW6 at Inhaca (MINAG- Ministry of Agriculture; MISAU- Ministry of Health) [Source: Inhaca Actors].

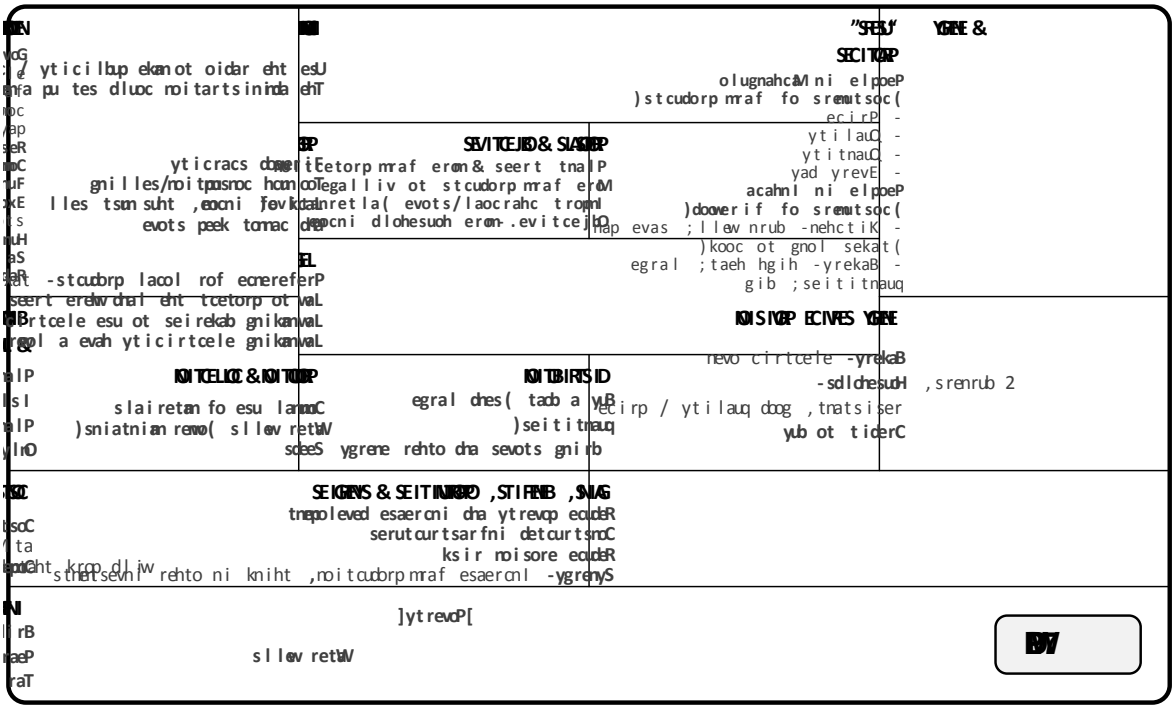


Figure 15.16| The WES conceptual design described using the 2MW in the PDW7 at Inhaca [Source: Inhaca Actors].

Note that the “standard” firewood WES description for Inhaca in fig. 15.13 is the most complete possible, that is, it integrates different, but essentially similar WES conceptualisations as portrayed by the Inhaca interviewees. For instance, while the firewood collection for self-consumption and/or selling to others, are presented together like two firewood WES “sub-stories, ” (in fact, most people are firewood collectors for self-consumption).Within the dilemma subjacent to this “standard storyline” for the WES, the three rural workshops defined for Inhaca were triggered by a relevant design challenge: “How to keep collecting firewood in Inhaca for the next 101 years”. From that simple line the fig. 15.14-16 were produced with a high degree of imagination and interesting stories.

Comparing the three WES designs proposed, it is interesting to realise that, while all propose a mix of planting trees and mode to new energy technologies and sources as a way to overcome the inherent island dilemma, the focus is quite different is all the designs. The WES design proposed by PDW5 is the most conservationist of all three and puts all the emphasis in forbidding firewood exploitation beyond the strict household needs while openly sustaining a stand against bakeries. This PDW was released in an area close to the Natural Reserve headquarters in the island, and it is also where the effects of erosion are more visible, which might explain this more conservationist approach. The PDW6 is clearly a business driven WES design, where the “creation of market” (to use an expression in that PDW) is believed to generate the drive to model other energy sources and technologies. There are some concerns with health and pollution, but the main focuses are on building factories and provide access to the technology. The presence of a participative outspoken entrepreneur/baker in this group might explain this result. Finally,

PDW7 focused on the socio-economic conditions and context to elaborate a WES that integrates firewood within a wider strategy to generate farming production and income. For the group in PDW7, the use of firewood was related with poverty and low income, and since farming is the main source of income for most islanders, improving farming production and sales would improve income and therefore facilitate access to other energy sources and technologies, reducing thus the pressure on the forest. Remarkably, all these three versions were not exposed or made explicit in the previous group interviews in Inhaca, but are present in the experts individual interviews and WES designs produced in PDW1 and PDW2 (expert workshops). Even more remarkable, is the degree of articulation and consistency provided by the three groups, which is presented through the 2MW in a comprehensive, intuitive and simple form, promptly accessible to others. Inhaca Workshops in comparison with Tinonganine, was show a higher degree of exploration of synergies, infrastructure and contextual aspects of design. From tourism to furniture and piers to factories, a number of ideas are presented and related with the WES. None of these aspects had ever been mentioned in the previous group interviews.

Like with the case of Tinonganine, using the 2MW it was possible to make a direct comparison between the firewood storyline in fig. 15.13 and the WES designs obtained in the workshops, fig. 15.14-16, and furthermore, visualise that comparison, fig. 15.17.

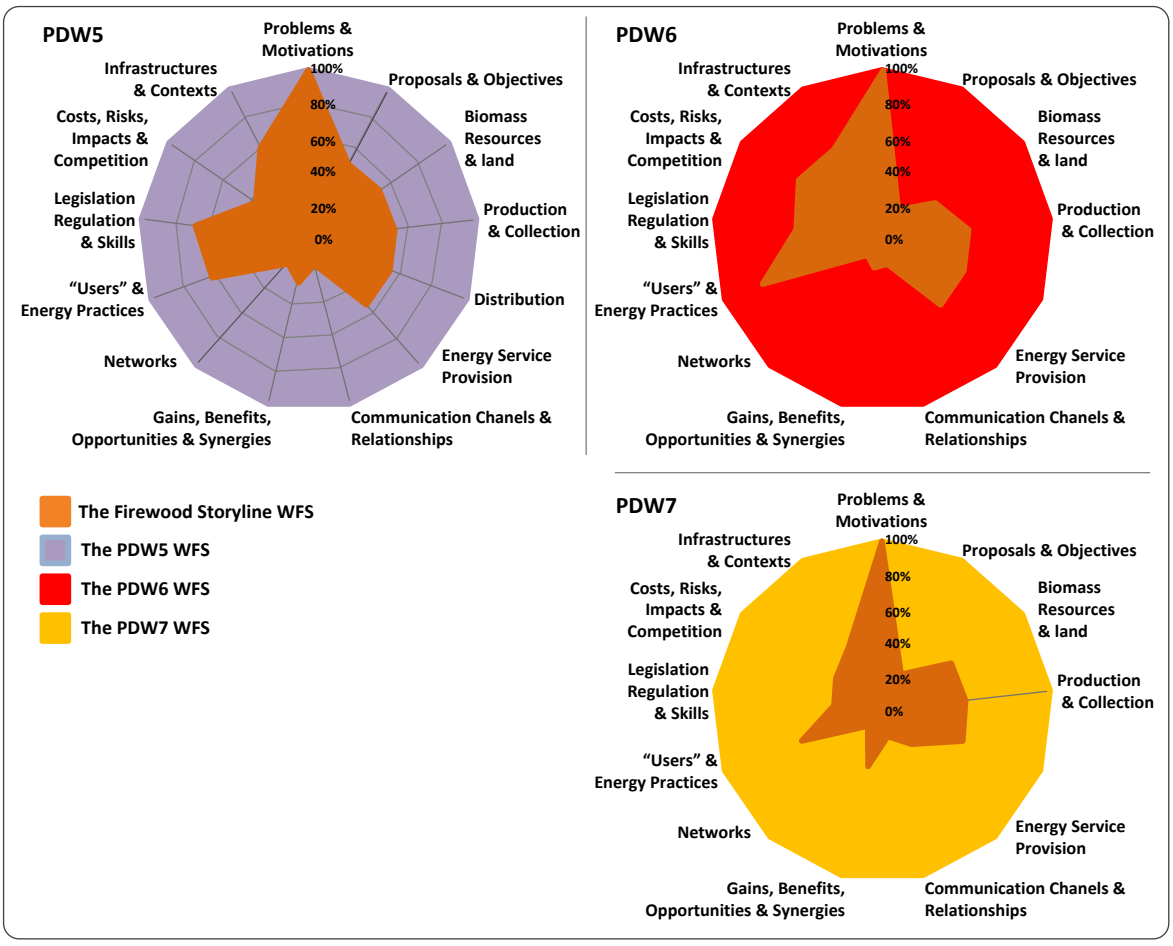


Figure 15.17| The relative position of the WES design obtained by translating the charcoal story line into the 2MW WES and the WES designs obtained in PDW3 and PDW4 [Source: the Author].

Remarkably, this comparison is only possible in theses terms since all the WES conceptual designs (fig. 14-13-16) are based and made explicit (represented) through the 2MW. Like with the case of Tinonganine, for Inhaca the WESs produced with the 2MW are more comprehensive, informed and detailed than the description encapsulated in the standard storyline. Considering the terms of the comparison, the standard firewood storyline produces a WES that occupies far less area than the WES design achieved by using the 2MW in the Inhaca PDWs (the entire area of each graphic in fig. 15.17). What is relevant in the Inhaca case is the fact that the standard firewood storyline uses all the design elements (even if some, like Distribution, are only mentioned implicitly or with less emphasis) and has a description of the Problem & Motivations that is exactly the same one identified by each of the three groups in the PDWs. The conclusions are twofold. On one hand, the 2MW does translate accurately the WES design exposed in the group interviews. These results also show how departing from a common description of the Problems & Motivations by using the 2MW in participatory design workshops, the WES conceptual design obtained is far more comprehensive, detailed, specified and integrated. Comparing the integrations or linkages between design elements identified (transparent red double arrowed lines) in the standard firewood story, fig. 15.13, and for the case of the WES design produced in the PDW7, fig. 15.18, the difference is quite visible. Not only there are more interactions in fig. 15.18, but there interactions are established between more design elements, which are more "richly" described and specified.

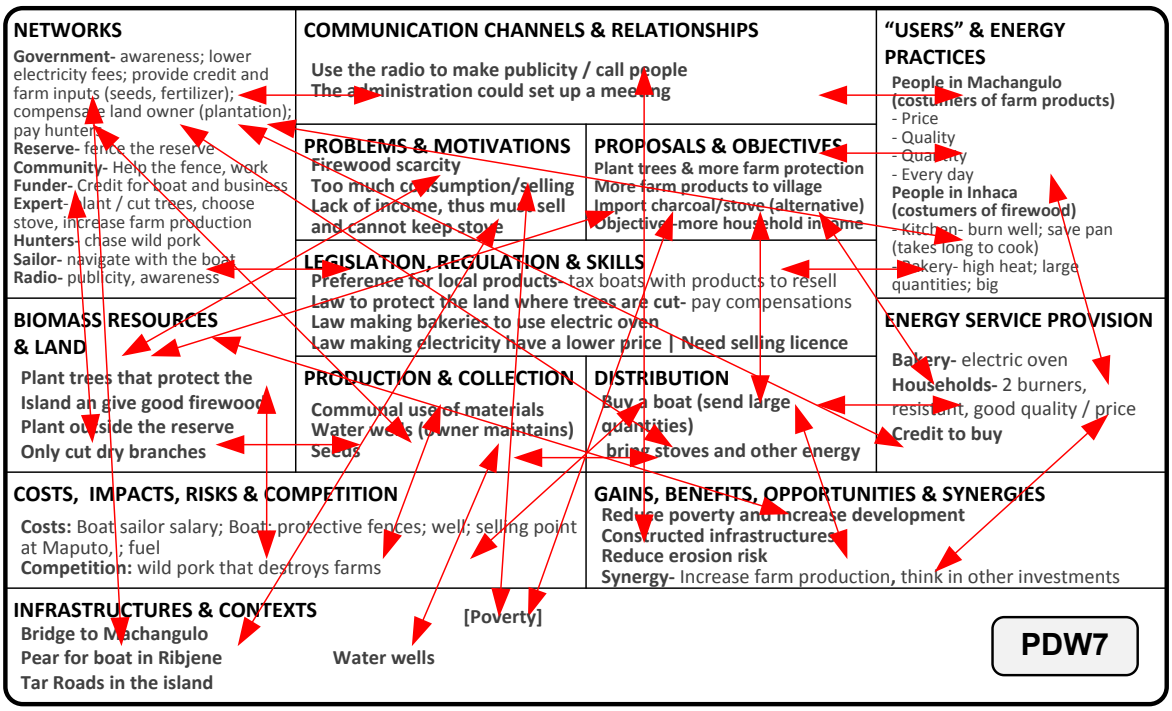


Figure 15.18| The WES from the PDW7 with the representation of interactions (transparent red double arrowed lines) between design elements (similar figures could be produced for the WES design from the PDW5 and PDW6) ([TEXT] a conclusion observed by the author) [Source: the Author].

This higher number of interactions also shows the capacity of the 2MW to generate interactive and iterative design. Like in Tinonganine, stimulated by the author, who was insistently repeating the suggestive question (i.e., reading) printed in 2MW, the participants in all workshops departed from an initial definition of the problems and proposal and then went to other design elements returning still for a couple of times to refine the proposal while refining also the other design elements.

In conclusion, the findings and rather positive results obtained in the Maputo and Tinonganine Participatory Design Workshops were also replicated in the 2MW testing in Inhaca. In all of the three WESs produced using the 2MW, there was a substantial increase in quality in comparison with the WES design obtained by translating the standard firewood storyline into the 2MW. This improvement was verified by a wider number of relevant design elements used, an increase amount of the design aspects considered in each design element and the increase in the number of interactions and number of design elements linked. These improvements were closely followed, motivating and being motivated by an active dialogue/debate between the participants stimulated mostly by the suggestive questions and the willingness to address them. Observation of the Workshop process also allowed the researcher to see how during 3:30h to 4:30h, each new design element inspired creativity, inquiring and learning by the participants. Motivated by a dilemma and context they know well, participants tried to articulate ideas on new technology and natural resources management to produce interesting and relevant WES design alternatives. The final thoughts shared by the participants with the author seem to confirm the value and interest of the 2MW as a design tool that stimulates debates, organises thinking and facilitates learning among participants. Even if tired, the participants were very appreciative of the work and exercise, and satisfied with the results.

15.5 A TESTING EPILOGUE

One of the original objectives of the 2MW testing was to join experts and rural interviewees in a Participatory Design Workshop. For reasons outside the authors control that was not possible, but a week after Workshops in Tinonganine a meeting between experts (a senior official in the Ministry of Agriculture and an ex-international project manager who was also in PDW1) and the representatives of each WES design produced in PDW3 and PDW4 could be arranged to assess the viability of the 2MW to promote design and dialogue around design across different knowledge backgrounds (experts and local). After a brief introduction to each WES designs developed in PDW3 and PDW4, it was very easy for the experts to make more quantitative and detailed questions beyond the conceptual design level, and it was possible for the Workshop teams to make a case for their WES design. Both experts and charcoal makers could go design element by design element in the 2MW (a piece of paper) and discuss in more detail and more quantitative terms (e.g. number of bags, seasonality in the Production design element) immediately

and quite intuitively. However, the most relevant outcome of this meeting arrived in the end, when the experts were rounding up the design exercise, explaining that they were just interested in this particular research, and the representative of the PDW3 asked: “But if we want to implement this project, to whom should we go?” A bit more than a week before the meeting this same participant could just articulate her reduced version of the standard charcoal storyline, and now she was able to articulate in context a major design element: “Networks”to the relevant actors who can help or prevent the achievement of the WES design purpose.

SECTION **E**

CONTRIBUTIONS, LIMITATIONS AND FUTURE WORK

> ***The only difference between the saint and the sinner is that every saint has a past, and every sinner has a future.***
>
> Oscar Wilde, in: *A Woman of No Importance* (1893)
>
> ***"The enemy of art is the absence of limitations."***
>
> Orson Welles (attributed)
>
> **… Where the limitations are undisclosed, future work envisioned, and main conclusions and results are discussed…**

16 RESEARCH CONTRIBUTION & ACHIEVEMENTS

The consumption/production of WF in DCs is a complex reality involving a number of equally complex issues and topics. In the context of this work, this conclusion was grounded on a critical, comprehensive, multi-disciplinary, quantitative and qualitative literature review on WF and associated issues (§5.1). This critical review was particularly intensive and extensive on Mozambique, integrating in the same document for the first time, according to the best knowledge of the Author, a comprehensive and up-dated socio-economic, political, cultural and ecological analysis of the WF reality in Mozambique (§5.2-3). Moreover, this critical review was also completed with an equally extensive appraisal, classification and classification of models and modelling approaches on WF that extended the review papers published on the subject since 2006 until 2014. Analysing the reviews, this research identified a modelling mismatch between complex, dynamic and uncertain nature of WF reality and the deterministic and *simplifying* nature of the models and modelling approaches applied. From a modelling perspective (§6.1) this work associated that mismatch with the normative, prescriptive and politically driven energy transition paradigm prevailing in almost all approaches to WF reality (§7-8). While the shortcomings of deterministic modelling to address complexity had already been discussed in the literature (§7), they are seldom referred in the context of WF and even less in terms of a prevalent energy transition paradigm. In fact, there are very few models actually devoted to WF in developing countries (§6.3).

Acknowledging the modelling mismatch and linkage with the energy transition paradigm, the research proceeded to tackle this complexity beyond such paradigm. This was achieved combining systems thinking and design thinking to reframe the WF reality complexity as a complex WES design problem (§9). While systems thinking and design thinking, are two approaches well known for their applicability to complex realities, the consideration of combination with the purpose to construct an alternative approach to WES design in quite novel. Accordingly, both systems and design thinking were laboriously and thoroughly reviewed in relation with complexity to produce three outcomes. First it was possible to theoretically ground the research objective as the conception, creation and testing of a design tool to support WES design. Secondly the set of design criteria (or specifications) to assist the design of this tool was also identified and included: be not-normative, non-prescriptive and focused on the interactions; support dialogue, knowledge sharing and leaning; assist participatory design; be constructed also through a participatory process; be modular; be fitted to the purpose, which in Mozambique means, be non-computer based and focused on conceptual. Thirdly, compared against these criteria, no available tool is able to support design of 2MW in the terms defined by this research (§9-11). In turn, three relevant and interweaved results emerged from this design objective and associated criteria. First, instead of looking for deterministic solutions a more suitable way to address the complex design is to consider

all users designers, and provide them with a tool that assists the *design process* and not *finding a solution* for WES design. A suitable way to support the design process in these terms is to identify what aspects to think about when thinking about the design of WES. The objective is, then, to identify the minimum set of necessary and sufficient ontological design elements that describe the logic of WES conceptual design. Secondly, this description is consistent with an ontological analysis, which was, thus, selected as the methodological approach (§13). Thirdly, the design tool should be a metamodel, that is, a model that generates models according to the user perspectives (§11).

With all the design and modelling well specified, a reflexive, exploratory and interactive design process was implemented (§13) a novel design tool, named 2MW, was effectively built and proved effective, relevant and useful to assist the participatory conceptual design of WES in Mozambique. As part of the 2MW design it was also produced a 7 element analytical framework (§14.1) for WES, that is, a set of DDs useful to analyse ESy in general and WES in particular. A methodical comparison with other similar literature and results from the interviews (§14.5, fig. 14.14) revealed that, the analytical framework created in this work is the only that integrates all others. Furthermore, there is a DD (Integrated Infrastructure and Networking) that is only mentioned in its full definition by this 7 element analytical framework (fig. 14.1). Note that while Mozambique was selected as the socio-ecological context to conduct research, due to the ontological nature of the design tool, there is no theoretical reason for the tool not to be applied in the design of WES elsewhere. Since the research *most important* achievement it will be addressed in more detail in the next paragraphs.

The WES metamodel, named 2MW, is a novel design tool that supports the participatory conceptual design of WES in a non-prescriptive, non-normative way. In physical terms, the 2MW does not require computer assistance since it can be represented as a set of 13 design elements drawn as boxes in a piece of paper or in the ground (fig.14.24), which makes the 2MW particularly useful in settings with low to no infrastructure and/or computer proficiency, that is, in most DCs.

The 2MW elements were co-defined through a participatory design process (§14) involving the Author, relevant literature and over 130 knowledgeable actors in the WES, among charcoal producers and firewood collectors in rural Mozambique, local authorities, forest rangers, bakers, government officials, NGO staff, international organisations staff, academics and experts (Mozambican and others). As already mentioned above, methodologically the 2MW was created trough an ontological analysis involving semi-structure interviews (individual, in group, face-to-face and over the Internet) to all actors and a critical literature review. During the interviews the interviewee was challenged with a design situation, in order to simulate the design process and thus unveil the individual design thinking at play. Trough a systematic process of coding and conceptual analysis, 16 design elements emerged as the first *prototype* of the 2MW. This prototype was tested in 2 urban participatory design workshops and 5 rural participatory design workshops, all

attended (with few exceptions) by selected previously interviewed actors. The selection of workshop participants was related with the equilibrium between range of knowledge, year of experience in WES, role in WES and quality of information provided in the individual (group) interview. In the workshops the groups would be faced with a design challenge similar to the one used in the individual interview. The participatory design workshops besides being used to test the 2MW quality as a design support tool also served as refinement to the tool, resulting in the preset 13 design elements configuration. In coherence with the combination of design/system thinking used to address complexity, this methodology also a combines Soft Systems Methodology and prototyping, which also constitutes a methodological novelty in the creation of a WES design support tool.

Subjacent to the ontological nature of the 2MW is the need to guarantee that the 13 design elements are necessary and sufficient to fully specify and describe the WES conceptual design. In this sense the major challenge for this research was to devise a simple, relevant, and intuitively understandable design tool, while not oversimplifying the complexities of WES conceptual design (after Osterwalder & Pigneur 2010). The results seem to confirm that the 2MW positively overcome such challenge in three different ways. First with the 2MW it was possible to convert all the verbal information provided in the individual (or group) interviews into the body of the 13 design elements, which means that the 13 design elements are sufficient. Secondly comparing the individual designs (as translated by the 2MW from the interviews) with the designs produced in the workshops, results show that the 2MW always provided more comprehensive, elaborated, integrated and original specifications for the WES conceptual design. Thirdly, from more than 60 workshop participants only one considered one design element irrelevant. In other words, the participants in individual interviews ignored some 2MW design elements not because these were known or considered irrelevant, but rather because they are new, relevant and necessary. Therefore, the 2MW built and tested in this research is ontologically robust and meaningful since all 13 design elements are necessary and sufficient.

In what might be the greatest achievement of the 2MW, in the 7 participatory design workshops where the 2MW was used as a design support tool 9 WES conceptual design specification were produced and, more importantly, all with no exception where more comprehensive and interconnected than any model produced in the individual interviews, including experts. Moreover, these participatory WES conceptual designs revealed to be more than the combination of individual conceptual designs (expressed in previous interviews). The test on coherence, innovation and interaction (§15.3.1) revealed that 2MW design tool generated synergies and creative thinking among the participants, resulting in more integrated, interactive and wider perspective on conceptual design of WES. These results are particularly relevant and visible in the case of the rural workshops. In the individual interviews the WES conceptual design produced in rural areas were basically the same simple and linear storyline from forest to household or side of the road. However, in the workshop, as mentioned, the result was a creative, integrated and

networked conceptual designs covering all WES (see fig. 6.2-3 and compare with Annex 5). In urban settings the design capability of the 2MW was also appreciated in terms of usefulness to facilitate more informed planning of WES, reaching an average rating of 82% (80% mode). This very high score seems to indicate that the experts appreciated the simple and visual format of the 2MW, which allows the prompt grasp of WES *big picture*, exposing simultaneously the interaction between the several design elements.

If the quality of WES conceptual design is measured in terms of comprehensiveness and richness of networking and interactions, and if an increased design quality is associated with learning mechanisms, the previous result could indicate that some degree of learning occurred in relation with the use of the 2MW. In the urban settings the participants rated with the average of 81.3% (mode was 100%) the capacity of the 2MW to support thinking Organisation, which could also be related with learning processes. This is an important aspect, because it was a major design specification/criteria defined in §9. However, in the absence of more direct and quantifiable measurements, the option was to rely on the comments and reactions of the participants in the workshops. Some workshop participants did mentioned that they had “learn more”, and during the workshops, particularly the rural ones, the presence of “new” design elements, that are the relevant, known but probably never considered before design elements, motivated participants to think outside their “professional” and “disciplinary” box in a more integrated, complete and creative way. In rural setting watching this game of reactions and stimulus was probably the most rewarding aspect of this research.

Another design criteria for the 2MW specified in §9 was the ability to promote dialogue. In urban workshops the easiness of communication reached the average value of 88.2% (mode 80%), which indicates that the 2MW indeed facilitated the communication of WES design ideas across different participants. This value was further confirmed with the high rate of 90.6% in average (mode of 100%) given by the participants to the 2MW capacity to stimulate the dialogue among participants on WES conceptual design. In rural areas high rating values were replaced by the enthusiastic and vivid open discussion between the participants. These results combined indicate that the research achieved one of its biggest objectives: stimulate design through dialogue.

An integrated analysis to these achievements seems to indicate that design, learning and dialogue are interrelated and mutually reinforcing elements supported by the 2MW. The 2MW facilitates the dialogue around the WES conceptual design, which stimulates knowledge share and learning on design. Likewise through conducting design on the 2MW the dialogue and learning evolves in a structured, explicit and comprehensive way. Central to these dynamics is the 2MW modular, ontological and visual nature. Presented as a set of design elements (boxes) the 2MW makes both the group and individual conceptual design logic “picturable”, i.e., “rationally visible, publicly discussible and debatable” (Ison 2008), a persistent and concrete object that can be revisited repeatedly. This explicitation of knowledge shifts the discourse from the abstract toward the concrete,

greatly improving the quality of debate (Osterwalder & Pigneur 2010). However, this "make explicit and visual" is not done from each participant cognitive island (fig. 9.4), but instead the users are stimulated to use a structured, coherent and comprehensive set of (necessary and sufficient) design elements in the 2MW. In this sense the 2MW provides a *common language*, a *common ground*, or a *collective reference point* between participants to translate and share tacit knowledge *from all participants* as explicit knowledge and to organise and formalise dialogue *outside particular perspectives or mind frames*. In this sense conceived as a set of simple design elements easy understood and intuitive in a visual format, the 2MW is truly a common visual language for WES conceptual design. On one hand informs the user which information to insert in the models and where (a visual grammar). On other hand, facilitates the capturing of the big picture with an easy and prompt identification of the essential design elements and possible interactions. Finally another related main advantage found in the 2MW is the fact that it does not imposes a method or solution to a problem, but rather provides a graphical representation of the design logic, supporting thus problem structuring, setting or exploration. The easiness, utility and intuitiveness of the 2MW layout was accordingly rated very high by the participants in the urban workshop, 85.9% of average (100% mode) which constitutes another evidence of the effectiveness of the 2MW as a design tool.

In resume all the purposes set for this research were met, in particular:

- Conducted a comprehensive, updated and integrated socio-economic, technological ecological and cultural analyses of the WES in Mozambique to level not available in the literature (§5.3).
- Integrated and updated the available reviews on WES models published between 2006 and 2014 (§6.3).
- Proposed, grounded and constructed a novel approach to the WES conceptual design integrating design thinking, systems thinking, meta-modelling and ontological analyses. Moreover, theoretically integrated systems thinking, design thinking in relation to complexity to derive the design purpose and specify the design criteria of that design, which constitutes a novel approach in the WES design (§9).
- Conceived, planned and implemented a novel methodology incorporating a truncated Soft Systems Methodology, ontological analysis and prototyping (§13);
- Developed a 7 DDs analytical framework that extends and integrates similar analytical frameworks available (§14.1).
- Conceived, designed and tested a design tool, the 2MW to support the participatory conceptual design of WES (§14)

Despite these achievements the research also has limitations and a future ahead, which are explored bellow.

17 RESEARCH LIMITATIONS

This chapter presents the limitations identified by the Author during the 2MW design process (§D), but also, considers limitations identified in other similar research to further inquire that same design process. Using this combination of self-criticism and self-inquire through other research the purpose is to increase both the comprehensiveness and objectivity of assessment of issues that can affect the accuracy and usefulness of the present research. Note that the possibility of bias, research shortcomings and validity threats was acknowledged in the research design and accordingly addressed explicitly in the research methodology (§13). Nevertheless, the nature of the research and the fact that it was conducted by people in social contexts, make bias and unexpected outcomes difficult to avoid. In this regard, methodological (§17.1), operational (§17.2) and theoretical (§17.3) limitations will be considered in the following

17.1 METHODOLOGICAL LIMITATIONS

The 2MW design elements were obtained from the integration of several design mind frames and perspectives hold by actors in the Mozambican WES through semi-structured interviews. As "knowledge extractors" processes interviews are always subject to interpretation and "interpretation of the interpretation", as total objectivity is probably impossible (Maxwell 2005). Moreover, as much as possible, bias derived from professional training, values and interests, have been avoided and replaced by a true and focused curiosity and respect for people's knowledge and experience, both on rural and urban areas. However, language might have been a barrier.

With some non-Mozambican experts, the interviews were conducted in English over the Internet, a language not native for the Author, or for some of the interviewees. Moreover, the internet connection in Mozambique was not always the best. Nevertheless the level of proficiency was never felt as a barrier, neither was the Internet quality, and the interviews run smooth and clear. The limitation with expert interviews over the internet was time. The standard interview was set up for 1hour, However, some experts did not have so much time, which made the interviews shorter or conducted in two, sometimes three different periods. This situation was further critical because during the research process (exploratory and reflexive as it was) new areas of inquiry were added to the interviews, and in order to have a common, equally inquired sample of data, it was necessary to re-visit some experts. For the experts in Maputo, representing the bulk or the expert sample interviewed and all fluent in Portuguese (the author native language), this was a relatively easy process and thus accomplished completely. For the experts interviewed over the internet two could not make the full set of inquiring. This had a minimal impact in the results, but highlights the limitations of reflexive and exploratory inquire processes, particularly, those involving the explicitation of tacit knowledge.

With rural interviews, both language and time were a limitation. the Author is not native or fluent in Mozambican Languages used in the research areas (Xi-Changana and Xi-Ronga). On the other hand, most interviewees did not speak, or felt able to fully express their ideas in, Portuguese. Therefore, the author had to rely on local translators, which implied a number of well document limitations (see Grenier 1998). Acknowledging those limitations, during the interviews no scientific or technical terms were used, most of the inquire was done on peoples' life in local terms and the interviews were recorded for reconfirmation of the data and re-evaluation of questions and replies with different translators. This recording revealed rather useful to increase the confidence in the translation, since local translators, with the exception of Inhaca, revealed not to be very proficient in Portuguese. This was a real limitation overcome through asking the same question in different forms and using a very basic Portuguese. Moreover, all the interviews were recorded, which allowed for time in the interviews in rural areas, which was a relative limitation in some areas. Population is normally scattered in wide areas, and have their daily activities to conduct, and thus time or place to interview them might be difficult to find. To overcome this, the interviews were schedule to the dry season (May-July) where farming is resting and charcoal production increases. Moreover, Inhaca is an (over) populated island and Goba a very small village which made meetings relatively easy. Therefore, in Inhaca and Goba, the researcher went with the translator to meet people and conduct in most cases individual interviews in their own houses. Moreover interviewees expressed an (unexpected) gratitude, a kind of social reward for participating in the interviews (something most acknowledged by the author)[1].

However, in Tinonganine, by official protocol the meeting was called by local authorities, the *Regulo* Santaca, (kindly responding to the Author request). Therefore, in the course of 5-6 hours, more than 30 persons had to be interviewed properly. In order to respond to all attending while keep the quality of the inquire, the interviews were made in groups of 2-3 people. Initially the semi-structured interviews were not set to be group interviews, However, the flexibility of the semi-structured proved useful in this case. Moreover, since the groups were made on the spot, there is some randomness added to the data. While done in group, an effort was also made to keep the replies as individual as possible and, for quantitative data analysis, they were entered as individual data. In the case of Tinonganine village, since the large majority were outspoken charcoal makers (mostly women) this was rather easy, while in the case of Djabula (a community 18km from Tinonganine village) this was not the case. Group interviews, as in any social communication act (Foucault 1972; Habermas 1971) involves power issues, which in the present case were expressed by one or several member of the group following the opinion of a socially more preeminent element in the group interviewed. This was

1 With a strong sense of humbleness, the Author cannot express in words the gratitude toward the people that after more than an hour responding to questions, would say "Thank you for considering me", or "You make me feel part of the society".

notorious in Djabula (where people were also called by the local chieftain) in a group composed by farmers and a well-off family member of the chieftain, where it was difficult to perceive if the people were expressing their opinion or simply avoiding confrontation or felt uncomfortable to freely express their opinion. In Djabula another methodological aspect related with research in rural areas of Maputo was felt. By congregating people on a venue for the purposes of interviewing with few (if any) valuable benefit (except for the researcher) might reduce drastically the interest in participation, or worst, result in co-opted participation. Contrasting sharply with Tinonganine, the people in Djabula were never much communicative. For all these reasons, in order to keep the robustness of data, the interviews from Djabula were not considered in this work.

Finally, two other limitations to consider are the number of cases used and the type of actors considered. The research visited only three research sites which might be an insufficient number to draw conclusions in a much larger areas such as Maputo. However, it is not certain that expanding the research to more geographical areas would provide more findings and reveal different perspectives. The literature and experts with large experience in other areas of Mozambique seem to converge remarkably around the same aspects (all included in the 2MW). Moreover, time, logistics and resources available prevented the research to achieve such scale. The risk for an inverted project bias might also be pointed. Instead of selecting a "showpiece: the nicely groomed pet project or model village, specially staffed and supported" (Chambers 1984a), it seems that all sites had a bad project experience. This was not the case, since the areas were selected by rigorous criteria (tab. 13.1) and regarding the "project failure bias" that is only the result of the simple fact that all WF related projects in Maputo Province failed. Considering the WF commodity chain in Mozambique (fig. 6.2) or the WES (fig. 6.4) and evaluating the type of actors considered (tab. 13.2) it is possible to conclude that the research was strongly biased towards the producers and experts. The reason for this was the limited amount of resources and the fact that consumers are well covered in the literature in terms of costumer choices (e.g. Kowsari & Zerriffi 2011; Howells 2010). As for the transporters, another actor in the WES, it is rather complicated to arrange meetings, particularly during the dry season when the charcoal production increases. Nevertheless, is important to know in firsthand the perspectives of all elements of the WES, which leaves the door open to future work.

17.2 Operational Limitations

During the use and testing of the 2MW three operational limitations were identified: the tool still requires some degree of literacy, which might be impeditive in some areas of Mozambique; the 2MW is intellectually intensive and extensive; and the conceptual design produced through the 2MW is influenced by the facilitator and group composition.

One of the design criteria (§9-10) set up for the 2MW was the need for a visual format, non-computer based, making, thus, the 2MW accessible to everyone everywhere.

However, that is not exactly the case since the tool requires some reading and writing skills, at least from one person in the group. In a country with a high level of illiteracy this might be a serious drawback. In practical terms, while representing a considerable advance towards a "democratization of design" when compared with the computational design tools, there is little to be done when the designs need to be formalised in some sort of linguistic format.

The time taken by the several groups to complete the design challenge proposed using the 2MW was always over 3 hours, sometimes went even over 4 hours. While from the author experience this is not a long time for similar workshops, the participants mentioned it several times. To an extent this is a relative limitation, since it might be related with the motivations and schedule of each participant. As far as the Author could understand, design workshops where some actual design activity is conducted are not very common in among the experts invited, and a complete novelty in rural areas. Therefore, the amount of dedicated effort expected might have been lower than the effort actually required. Nevertheless, despite relatively high motivation throughout the process, particularly in rural areas, in general the attendants revealed fatigue by the end[2]. For under-motivated or tight schedule participants, this might be a serious limitation.

The last operational limitation observed, is clearly in line with the already mentioned power issues in group dynamics or dialogue events (§14.1). The 2MW was built from a design perspective (§9.3) that perceives the facilitator as a "co-designer" or "knowledge broker", that is, his/her role is not to "conduct" the participatory conceptual design, but rather to spike it, raising attention to linkages that should be considered, design elements that have to be in agreement with the other, or motivating everyone to participate equally. The final purpose is to avoid normative and prescriptive pre-defined ideas from the facilitator to guide the participatory design process. An easy solution for the facilitator influence would be to eliminate the facilitator from the process. However, as the previous limitation exposed, in situations where no one can write and read there is always the need of a facilitator. This makes the possible effect of a facilitator in the design process particularly noticeable in rural areas. This effect might be further increased by a perceived power dynamics between rural and urban people, expert and lay people (Cline-Cole 2006). Therefore, the absence of a facilitator in a group where all know how to read and write does not solve the problem either, as that power dynamic logic might also be in place within the group. This research tried to avoid these issues carefully constructing the design groups, avoiding having friends in the same group, and distributing expertise and years of experience in the field homogenously within and between groups. Moreover, it was stipulated that each design element (box) should be "completed" by all members, exactly to avoid the distributions of expertise by design element resulting thus in a "addition of experiences", rather than a true integrated design. However, and probably,

2 One participant in Tinonganine actually commented that he needs to rest for being "to tired of the head".

inevitably, power dynamics will always exist beyond group formation or rule making. In fact, in one "non-facilitator" design workshop held in Maputo, one of the members basically dictated opinions, two other chip-in and a fourth was only concentrated in writing.

17.3 THEORETICAL LIMITATIONS

The main theoretical limitation found on this research is also a fundamental critic made to the energy transition approach commonly followed in the WES design: the normative and prescriptive nature of design. The 2MW was conceived (§C) as an alternative to the deterministic, normative and prescriptive energy planning and modelling prevailing in most approaches to WES, all of which are funded in the ETP (§6-8). Indeed, the 2MW do not hold any normative judgement regarding technology, practices or knowledge around the WES. Likewise, the 2MW do not prescribe a certain supply chain, production sequence or specific WES or promote "sustainable", "efficient", "green" or other *adjectivated* form of production, consumption and conceptualisation of WF. As long as the 2MW design elements are completed and their relations are meaningful and explicit, the conceptual designs produced with the 2MW are comprehensive and valuable options. However, since the 2MW makes explicit a design logic, it is completely possible to use the 2MW in a normative mode. In fact, that was partially the case in the participatory design workshops, since the design challenge proposed "how to guarantee that Maputo would have charcoal in the next X years", implicitly holds the normative design target that charcoal production *must* be guaranteed. Therefore, the 2MW is not "normative-free" which might not be a limitation for those wanting a participatory conceptual design support tool to construct, e.g., a sustainable WES based on coconut shells. However, for those that what to use the 2MW to create innovative designs without "adjectives" (e.g. sustainable) the 2MW is still a valuable option.

On a more basic level, it can also be argued that by *identifying* and *labelling* and "*what*" composes the design logic, the 2MW also prescribes "*how*" the design should be made. This is actually the basic principle of the ontological analysis used to build the 2MW. In this regard, the 2MW was built not from the Authors perspective alone, but as a participatory effort of many different knowledge and perspectives. The design elements are not in the 2MW because the Author *thinks* they are useful to make a WES conceptual design, but rather that design element is there because one or several people doing conceptual design actually had *to think about* or actually *implemented* that design element. Nevertheless, it would be interesting to set up an experiment to check how much different design(s) would be produced if the labels (names) of the design elements were different.

Finally, as repeated throughout the thesis, the Author holds nothing against the "normative" and/or "prescriptive" models and design tools. They are useful in their own right and could inclusively be integrated with the 2MW. The critic goes to the inexistence

of tools that could question the overwhelming and unquestioned normative and prescriptive design of WES. In resume, this limitation could actually be seen yet another evidence of the flexibility of the 2MW as a design tool, mostly because it was constructed with a critical, non-normative and non-prescriptive perspective.

18 FUTURE WORK: EXPLORING THE 2MW POTENTIAL

As this chapter intends to show, the 2MW is not restricted to WF actors, conceptual design and, possibly WES. A great advantage of the 2MW is its comprehensive, modular, visual and flexible simplicity. In just 13 design elements, (boxes) exposed in a simple visual format easily accessible the entire WES is represented well beyond the usual biomass supply chain or ESy (§6.2-3) allowing for each user or group of users to experiment, design, analyse, compare, catalogue and refine existent designs, designs-to-be, partial designs our from scratch designs of WES. However, the 2MW is not rigid or closed and, if necessary, other design elements could be added or subtracted and even renamed to adapt or adopt, to new situations. Moreover, the 2MW encapsulates (inboxes) a design logic on WES, a kind of ESy, and, in that sense, the 2MW might be also useful to assist the participatory conceptual design of other ESy. In the following a tested, potentialities and future work with the 2MW will be exposed.

18.1 SUPPORT KNOWLEDGE SHARE & COMMUNICATION

The 2MW could, in many ways, be compared with a knowledge management tool (§9.3.3) since it can improve the understanding and knowledge shared among the participants in the design process by creating a common and explicit understanding of the design at hands. In this regard, future research could investigate its applicability of as a platform for visual thinking, i.e., as a visual aid to think, construct and discuss meaning (e.g. Ware 2010). In the participatory workshops carried in the course of this work the 2MW had this role as knowledge management tool, but only considered written input and, eventually some mapping (e.g. Annex 5E) or diagramming (e.g. Annex 5A), in future research sketching, drawing and even painting could be included. This approach should be very useful to overcome the low level of literacy (a limitation identified in §17.2), since it would allow participants to draw their perspectives and storylines directly on the 2MW instead of relying on the interpretation of the interviewer like in the case here. These exercises would test the capacity of the 2MW to represent a shared visual language able to: produce a structured rich big picture of how people see WES problem/situation; identify previously unknown or overseen interactions; create a reference map of bottlenecks and/or areas for improvement;; increase understanding on WES design.

Another idea for future work involving knowledge management is to test the capability of the 2MW to represent (*translate*) available models, approaches and/or perspectives into the 13 design elements format. This was already done in this research for assessment purposes (§15) when the 2MW group design was compared with each individual 2MW design created by the Author from the respective individual interview. Expanding this translation to other work would be possible to create portfolios libraries of WES designs, and conduct comparative analysis both among designs and through time.

18.2 SUPPORT ANALYSIS: COMPARE, COMBINE, EVALUATE & EXPLORE

A major advantage of the simple visual format of the 2MW is the possibility of rapidly grasp the essential design ideas and relations, facilitating thus the analysis on the WES designs. This is quite a visual task, for instance when some design element is empty or when an idea or specification in one design element is not reflected in other design element. While interesting, this analysis focused only on the design coherency and was limited to individual WES designs. Future research would expand this analysis to include more aspects of the design and promote comparative analysis between different WES conceptual designs and across time frames. All these analyses are possible and straightforward due to the modular nature of the 2MW. The 13 design elements allow contained analysis (analysis on the contents of that design element) and comparison between the same design elements in different WES designs and across time frames (fig. 18.1). Remarkably a wider analysis can be achieved integrating different analytical tools, approaches and/or methods into the 2MW modular ontological structure like, for instance, a SWOT analysis (Strengths, Weaknesses, Opportunities and Threats, fig. 18.1A) or LCA (Life Cycle Analysis fig. 18.1B), fig. 18.1.

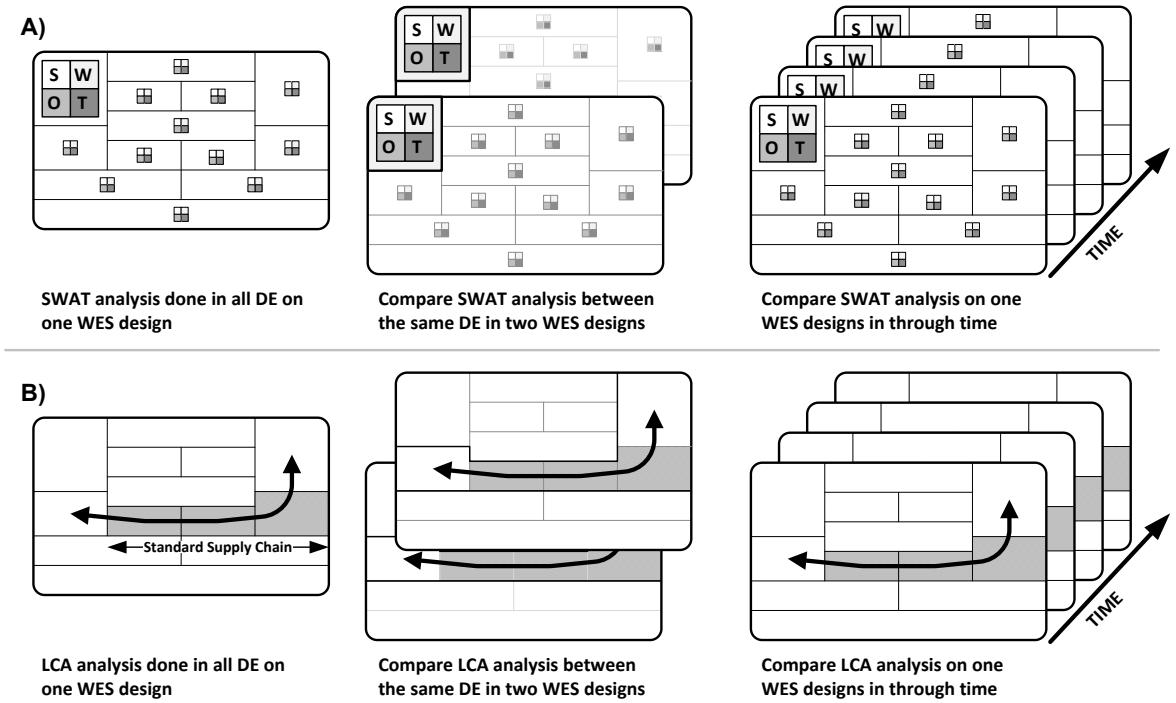


Figure 18.1| SWOT (A) and LCA (B) performed in one WES designs and comparative analyses between two different WES designs and across different time frames [Source: the Author]

While not depicted in fig. 18.1, the comparative time analysis can also be done between two different WES designs. Also note that, as seen in fig. 18.2B, the 2MW allows a full LCA unlike standard chain models (§6.2-3) and, moreover, allows a LCA analyses integrated in the wider WES, unlike standard LCA which only considers the production cycle. The possibility to consider an extended supply chain embedded in a wider set of design elements in the 2MW is also an interesting feature to be explored in future research. In

particular, the modularity of 2MW could be used to define wider MCDA and participatory modelling schemes in relation with WES identifying both the actors to set the criteria and associated weights (fig. 16.2A), and/or facilitating the definition of indicators and criteria (fig. 18.2B). Naturally a combination of these two approaches could also be used, e.g., identify actors to define weights on directly identified criteria and/or indicators.

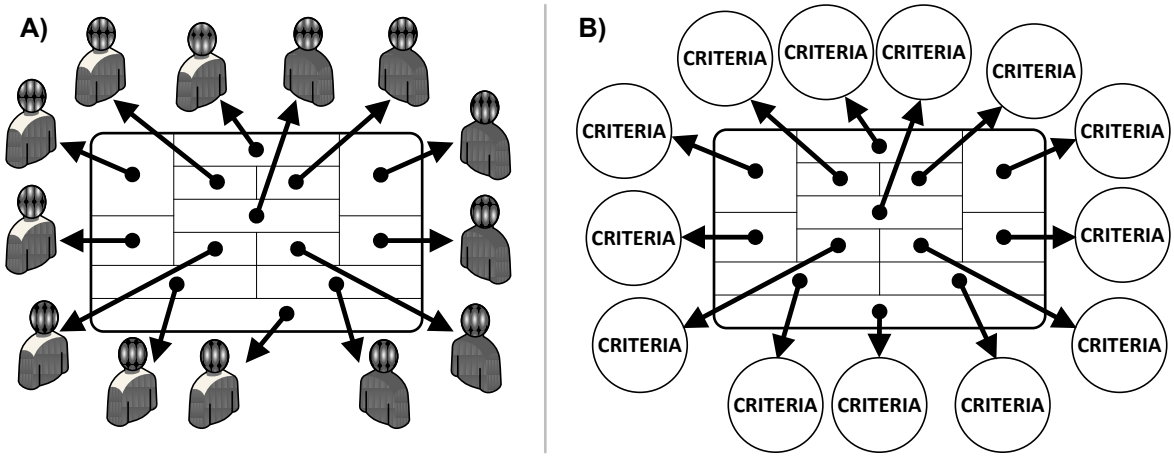


Figure 18.2| Possible integration of the 2MW and MCDA identifying actors to define criteria/indicators and respective weights (A), and direct identification of criteria an d weights (B) [Source: the Author].

By making possible to identify actors, and directly or indirectly make explicit and visible criteria and interactions, the 2MW opens a real possibility of structured integration of analytical and simulations tools. For instance, taking advantage of the relations between MCDA and Systems Dynamics (e.g. Santos *et al.* 2014; Robinson *et al.* 2014) 2MW could be integrated with MCDA and Systems Dynamics, to produce, e.g., an exploratory decision support tool for WES, fig. 18.3.

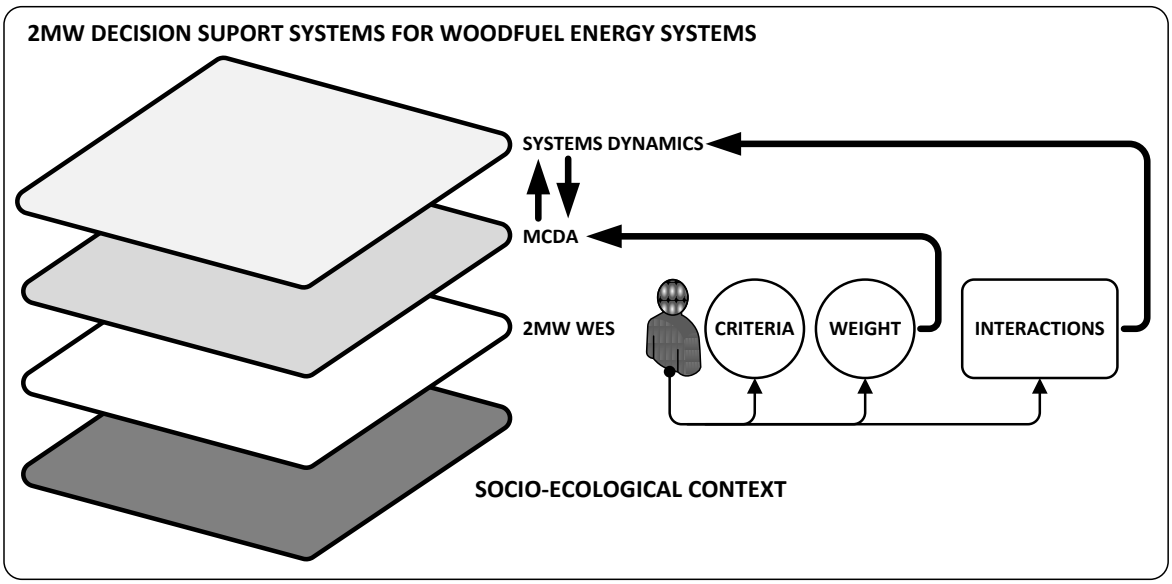


Figure 18.3| Possible integration of 2MW with MCDA and Systems Dynamics in a Decision Support Tool for WES [Source: the Author].

What is potentially different in this approach is the fact that all criteria, weight and interactions are identified in a participatory learning process based on 2MW. In other words, future research would have to build, integrate and test the possibility to build a decision support tool that combines participatory design and participatory modelling, and where actors are indeed the designers of the criteria, weigh and interactions. This is a clear depart from the present decision making in WES (§6.3, 7) where the relations are always a task conducted by experts. Additionally, future research could consider other possible integrations, e.g., the use of GIS in combination with LCA and 2MW (fig. 18.1B), or other type of analysis, like "what if" scenario analysis.

Another interesting research to explore the 2MW analytical possibilities would be a ramification of the possibility of using 2MW to identify relevant actors in the WES, fig. 18.2. Instead to identify actors to work with them, another possibility to be considered would be to analyse those actors. Indeed, making explicit the otherwise implicit or tacit knowledge, the 2MW can also be used to analyse the design strategies that different users of the 2MW follow to do design, analysing what is *written* in the design elements and mapping the sequence of design elements as done by the user. In fig. 16.4, six possible strategies are presented. Since these strategies are also an expression of certain "mental framework" this analyses of "design strategies" could also be useful to identify points of possible collaboration or conflict between actors in order to, e.g., set up and/or manage design teams.

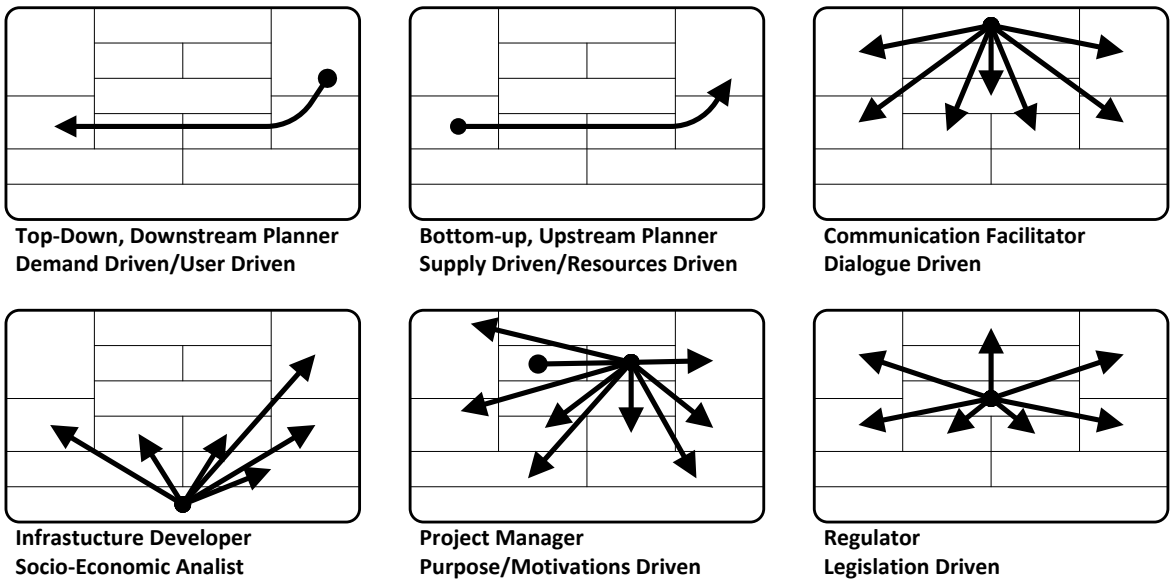


Figure 18.4| Six design strategies and associated mental framework identifiable while using the 2MW [Source: the Author].

Regardless of the possible integration of tools, approaches and/or methods, future research involving 2MW would have to investigate new ways to conduct participatory design and modelling to compare, combine, evaluate and explore WES conceptual design.

18.3 SUPPORT INNOVATIVE DESIGN: PROBE & REFINE

The future research on 2MW mentioned in the previous §16.2 was mostly focused on using 2MW as a conceptual framework to co-evaluate, co-compare and co-explore, which is very much the realm of participatory planning, management and decision making. Here another branch of future research with the 2MW is proposed: innovative design. The present research already made use of the 2MW to produce results that are innovative in the sense that the WES conceptual design produced in participatory design using the 2MW was wider in scope and solutions beyond the mere sum of the individual contribution of the participants (§15.3.2, §15.4). However, in fact, that was designed only as the first step in a most extensive process of refinement of designs. The objective was to expose the first WES conceptual design produced to other teams to mutual critical analysis and with that process increase leaning. However, due to time constraints (a limitation pointed in §15.2) that refinement step was not taken, remaining this as future work to be accomplished. Besides this mutual-critic process, other processes could be tested to produce refinements to initial designs. This include, for instance (fig. 18.5): the combination of different design elements from different WES designs (on 2MW); the integration of different design aspects within the same design element (on 2MW) from different WES designs (on 2MW); or a combination of the two processes.

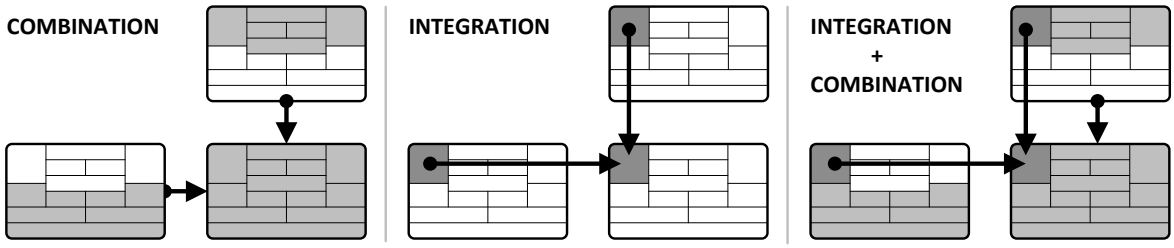


Figure 18.5| Possible processes to create innovative WES conceptual design using the 2MW [Source: the Author].

Regardless of the process used, refinement is above all a continuous dialogue between probing and reflection (§9.3.2), where some designs are rejected, other accepted for further refinement, others only partially used until a satisfying design is reached, fig. 18.6.

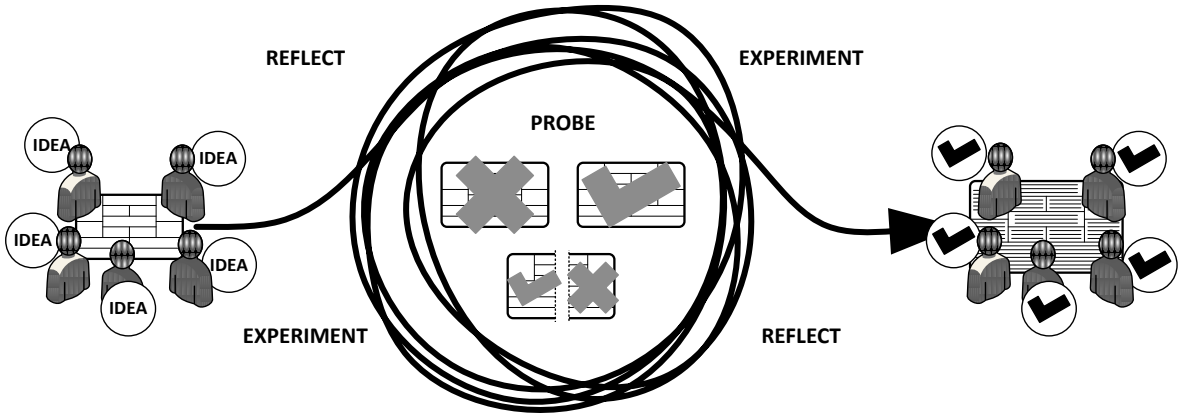


Figure 18.6| The refining design process [the Author after Osterwalder & Pigneur 2010].

In resume, an interesting line of future work would be the extension of the present research into the probing & refine cycle depicted in fig. 16.6, investigating (probing) the usability, efficiency and effectiveness of 2MW as an innovative participatory conceptual design tool departing without any kind of design challenge (like it was the case in the participatory design workshops in this work (§15) in practical situations. In practical terms this could also imply the investigation of the 2MW platform as a physical object (i.e. an a piece of a paper with boxes in it) that can be simultaneously a simple and visual support to communicate WES conceptual designs, as well as, a design artefact itself able to be manipulated in continuous circles of dialogue and refinement among the participants till reaching a reasonable degree of agreement or, alternatively, the identification of the design elements, design aspects or reasons behind persistent discordances. This is a research that would be somewhere in the border between management sciences and semiotics.

18.4 INTEGRATE AND EXPAND

So far the 2MW has only been used in the context of WF and Mozambique socio-ecological context using the 13 design elements format. Future research could include the test and possible adaption of the 2MW to other countries and ESy. In a first stage other DCs (the neighbouring Tanzania) and WES (e.g. biofuels) would be considered, but further into the future, it would be interesting to test other non-DCs as well as other non-biomass ESy. This research should also test the possibility of increase or reduce the actual number of design elements and/or change their names and definitions.

SECTION **F**

ANNEXES

> ***There are three kinds of mathematicians, those that know how to count and those that don't.***
>
> Citation in Rechtin (2002)

…Where the Annexes that supported the main work are presented…

ANNEX 1: ON COMPLEXITY AND COMPLEX SYSTEMS

While complexity is an ongoing subject on philosophy (e.g. *Morin 2008*) for the purpose of this research probably the best starting point is the "paradigm of complexity proposed by "Edgar Morin in opposition of the "paradigm of simplicity" hegemonic in European society (*Morin 1977, 1990, 2008*). The "paradigm of simplicity" is characterised by disjunction and closed specialization which assumes that reality can be objectively separated in smaller parts for specific analysis inside closed sciences; reductionism, i.e., the use of mechanicist, determinist and positivist logic to reduce complexity to a set of quantifiable properties; and abstraction, the assumption that the *whole* can be unified through an intellectual synthesis process). These processes extract reality from its context destroying or ignoring, thus, diversity and systemic interactions. On the other hand, "[What is] complex cannot be summarised in the word complexity, brought to a law of complexity, reduced to the idea of complexity [and cannot] be defined in a simple way and would replace simplicity. Complexity is a word-problem and not a word-solution" (*Morin 1990: 10*, free translation provided by *Alhadeff-Jones 2008*). Nevertheless, the paradigm of complexity can be characterised by a set of properties (*Alhadeff-Jones 2008*):

- Complication- complexity is composed by multiple elements, some of them unknown, of similar nature;
- Interactive and complementary disorder and order- association with chaos, randomly unpredictable behaviour and teleological behaviour, self-Organisation;
- Emergent- new/different properties emerge from the interaction of smaller parts or different levels of Organisation;
- Retroaction- a consequence can have an effect over its generating conditions;
- Hologramatic properties- a basic element of a set contains almost all information about the set (like a system);
- Interaction- outcomes depends on who interacts and how one interacts with it;
- Uncertainty, ambiguity, incompleteness- partial ignorance regarding the composition and interaction nature among the composing elements.

Cilliers (1998: 3-4) establishing the link with systems thinking identified ten basic characteristics in complex systems:

1| Complex systems consist of a large number of elements. For a sufficiently large number of elements, conventional means (e.g. a system of differential equations) not only become impractical, they also cease to assist in any understanding of the system.

2| In complex systems the composing elements interact continuously and dynamically physically or through the transference of information.

3| The degree of interdependency is high but the behaviour of the system is not determined by the exact amount of interactions associated with specific elements.

A number of sparsely connected elements can perform the same function as that of one richly connected element.

4| The interactions are nonlinear which also guarantees that small causes can have large results, and vice versa.

5| The interactions usually have a fairly short range, i.e. information is exchange locally, and long-range interaction can usually be covered in small local steps which can change, enhance or suppress the initial behaviour in a number of ways.

6| Complex systems are recurrent, as there are loops in the interactions and the effect of any activity can feedback onto itself positively (amplifying, stimulating) or negatively (dumping, inhibiting) directly or after a number of intervening stages.

7| Complex systems are usually open systems, i.e., they interact with their environment. Instead of being a characteristic of the system itself, the border and scope of the system is usually determined by the purpose of the observer in what is called framing.

8| Complex systems are dissipative and operate under conditions far from equilibrium with a constant flow of energy to maintain the system.

9| Complex systems have a history and path dependence, whereby current and future states/behaviours depend on the path of previous states/behaviours, and this ignoring time results in incomplete analysis, or in a synchronic snapshot of a diachronic process.

10| Each element in the system is ignorant of the behaviour of the system as a whole, it responds only to information that is available to it locally since it is physically impossible for one single element to entail all complexity. The focus is then on the complex structure of the system which emerges as a result of the patters of interaction between the elements.

Besides the characteristics identified by Cilliers (*1998*), and partially derived from them, additional characteristics have been identified as common in complex system, including (*Montagna 2006; Nicolis & Prigogine 1977; Ramos-Martín 2002; Rotmans & Loorbach 2009*):

- Hierarchy- Besides being nested within systems and being made up of systems, like all systems, complex systems encompass various organisational levels and operates on multiple spatiotemporal scales.
- Dissipative Structure- While being open and far from equilibrium, complex systems maintain themselves in a stable state. This is only possible with a continuous flux of energy, matter and information from the surrounding environment.
- Multiple possible steady states- steady states might exist given the complex system a long enough time of evolving, however, due to the its non-linear dynamics and dissipative nature, the location of these steady states in complex systems is uncertain, unpredictable and very sensitive to small changes in the environment and history.

Recognising the complex nature of reality or socio-technical systems Rittel & Webber (*1973*) coined the term *wicked problems* to describe most problems emerging or perceived in real life situations of managers, engineers and designs. Directly derivable from complexity theory and complex systems descriptions wicked problems (*Courtney 2001*):

- Have no definitive formulation since formulating the problem is the problem;
- Have no stopping rule, i.e., a mechanism for deciding whether to continue or stop a process on the basis of the present position and past events, and which will almost always lead to a decision to stop at some time, the “solving” process ends not because “the” answer was found, but because there is no more time, money, patience, or because the answer is "good enough";
- Have no True/False solutions, but Good/Bad, Better/Worse since values are inherently a large part of the problem and the values vary among the stakeholders;
- Have no ultimate test of a solution because wicked problems are inextricably bound to their environment and generate waves of unpredictable consequences over an extended period of time;
- Have solutions that are one shot operations, because there is no opportunity to learn by trial and error and, consequentially, solutions and outcomes cannot be undone;
- Have no enumerable (exhaustively describable) solutions, set of potential solutions, nor is there a well-described set of permissible operations to be incorporated into the plan;
- Are essentially unique problems;
- Can be considered a symptom of another problem and "solving" a wicked problem may exacerbate other problems;
- Have a number of different stakeholders interested in how it is solved, which determines the representation of the wicked problem, the choice of explanation and the nature of the resolution.

All this knowledge have been summarized by Harrison (*2006*) in the tab. A1:

Table A1.1- Simple and complex systems compared *[Continues in next page].*

SIMPLE SYSTEMS	COMPLEX SYSTEMS
Few agents	Many agents
Few interactions	Many interactions
Centralized decision-making	Decentralised decision-making
Decomposable	Irreducible
Closed system	Open system
Static	Dynamic
Tend to equilibrium	Dissipative
Few feedback loops	Many feedback loops
Predictable outcomes	Surprising outcomes

Table A1.1- *[From Previous page]* Simple and complex systems.

SIMPLE SYSTEMS	COMPLEX SYSTEMS
Examples:	Examples:
Pendulum	Immune systems
Bicycle	Genes
Engine	Molecules in air
Boyle's law	Ecosystems
Gravitational system	Markets

Finally a special case of complex systems relevant for this research are the Complex Adaptive Systems. Complex Adaptive Systems have the capacity to change and learn from experience which provide them with unique features such as (e.g. *Bammer 2005; Holland 1995; Perez & Batten 2006; Rotmans & Loorbach 2009*):

- Coevolution. Different systems interact influencing each others', leading to irreversible patterns of change within each of the systems through feedback loops which results in the final evolution of those systems and larger systems . In this sense, the units of evolution are no longer individual components, but rather networks capable of self-organising configurations.
- Emergence. Novel and coherent structures, patterns, and properties arise in higher level systems resulting from interaction between lower level components. As collections of interacting elements, complex systems show characteristics that are properties of the collective behaviour of these elements.
- Self-Organisation and Adaptation. Internal Organisation process defining the spontaneous and co-evolving of individual systems without any guidance or management from an outside source. These systems develop new system structure recursively in response to environmental changes. In this sense, self-Organisation is a form of emergence and, in cognitive beings implies learning.
- Non-state Equilibrium. The systems display ever-changing dynamic equilibrium, driving back and forth the system between chaotic to ordered states.

ANNEX 2: SYSTEMS & SOFT SYSTEMS METHODOLGY: A BRIEF

A system has at least nine characteristics (Gibson *et al.* 2007; Manderson 2006; Rammel *et al.* 2007):

1| Components or subsystems as the fundamental internal units of a system. While typically referred to as system components, they often represent subsystems with their own functions and resource flows.

2| Resources and resource flow. System resources can be simplified down to energy, matter, and information (Clayton & Radcliffe 1996). Resource flow is described as the input, throughput, and output of resources. Outcomes are intangible outputs or emergent properties.

3| Relations as system internal intra-relations and external inter-relations. Relations represent resource flow pathways. Relations and resource flows imply that systems undergo transformation.

4| Control and regulation mechanisms that add order and coherence to a system. These can be subsystems unto themselves, becoming more distinguishable and important with increasing system complexity. Also known as communication and feedback-loops as a part of system cybernetics (Dale 2001), and sometimes as 'management' or 'government' within anthropocentrically controlled systems.

5| System boundaries that encompass components and internal relations. Boundaries can be difficult to distinguish in reality because external relations often have the effect of blurring where one system stops and another starts.

6| System hierarchy representing levels of relative system complexity. Lowest tiers represent basic system components that interact to build successively higher and more complex tiers. Here "hierarchy", rather than a top-down sequence of control and power, indicates a series of semiautonomous levels that are created by interactions among variables that share similar spatial and temporal attributes.

7| Emergent properties representing 'something extra', as they cannot be explained solely through examining the sum of a system's parts. Ideas of holism and synergy are often used to explain emergent properties.

8| Inherent Complexity. Because of the large number and variety of its elements, the LSS is often difficult to describe analytically or to model precisely via dynamic computer simulation.

9| Policy Component. In addition to the physical infrastructure, or the so-called "engineering component, " a large-scale system often contains a social or "policy component whose effectiveness must be evaluated by its accord with general social, governmental, or other high-order judgments, rather than by simple economic efficiency.

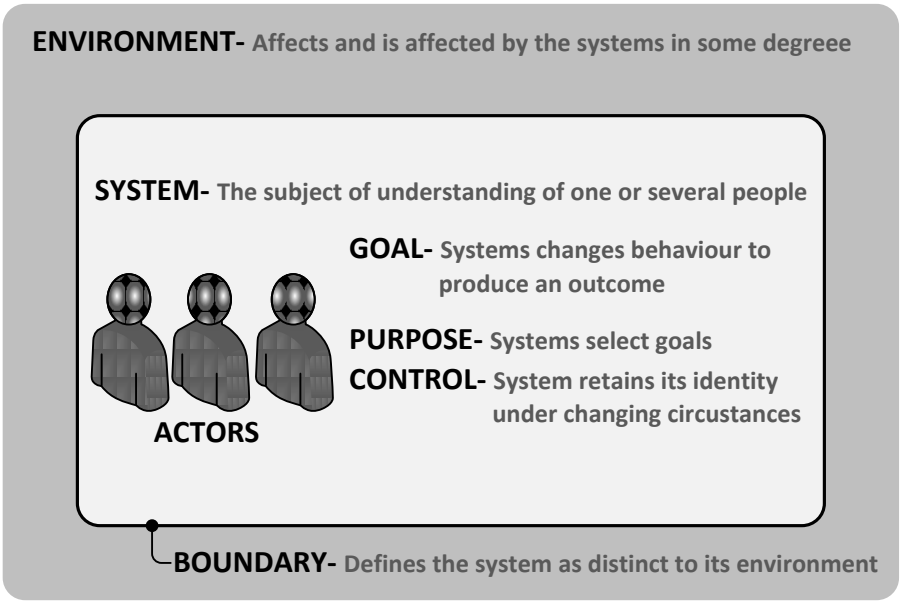


Figure A2.1| Defining features of a systems view of a particular context [Source: adapted from Bell and Morce, 1999, p. 87].

Soft Systems Methodology (SSM) is a systems thinking approach with an underlying interpretive philosophy (Rose 2000) and set of principles organized around a flexible process which can be both adopted and adapted for use in real situations characterised by complexity, multitude of actors and divergent perceptions and/or interests about the problem definition (Checkland 1981; Naughton 1984; Mingers & White 2010). SSM was developed as a response to what Checkland perceived as the major failures of hard systems traditional engineering approaches, particularly when applied to management problems, that is (Checkland 2000; Mingers & White 2010): the difficulty to deal with complexity; the inability to include social phenomena; and the prevalence of abstraction over real world problems. Hard systems assume a positivist stance, focusing on the modelling (e.g. mathematically) of technological aspects of design, assuming that the all problem is known (e.g. Röling 1997; Mingers & White 2010). Conversely, soft systems are guided by reasons rather than driven by cause and do not have an assumed goal, but instead creates "a process of enquiry as a system, with discussion structured using models based on a range of worldviews in order to query perceptions of the situation" (Mackrell 2006: 73).

SSM is problem driven and assumes social construction of reality (Ison *et al.* 1997) to addresses messy problems, meaning problems that are socially constructed on the basis of different perspectives and as part of an interrelated network of problems with emergent properties which will not yield to a reductionist research approach (Ison *et al.* 1997). This perspective is exactly the same followed in the constructivist stand taken for this research (§3.2.3). One of the major objectives to build the design tool is to provide a common platform for stakeholders to formulate the problem system, i.e. the design of rural biomass energy systems/services, as a composite of all versions of the problem, combining expert and indigenous knowledge. From this participatory framework emerges

a “problem-determined system” (Ison & Ampt 1992; Smith 1994; Ison 1993), “problem-solving” (Clark 1999) or “issue-driven” research (Robinson 2008), exactly the methodological perspective taken in this research.

SSM is also both a methodology and a learning system (Rosenhead & Mingers 2001). SSM is a methodology used to support and to structure thinking about, as well as intervening in, complex organisational problems (Checkland & Winter 2006), i.e., SSM can be used both for general problem solving and in the management of change (Mingers & White 2010) by taking actors through a process of shared problem appreciation, learning about the problem and taking collective action to improve it (Checkland 1981). Both perspective are present in the ontological approach taken which intends to explicit the knowledge system associated with design of rural energy to make perspectives explicit, and through debate and leaning by using the tool facilitate the definition of the design specification of rural biomass energy systems/services. Moreover, in line with systems thinking the present research intends to involve the participants in the problem definition making it possible for them to influence the design (after Langefors 1995) and “discover” for themselves the benefit of new practices (after King 2000).

To illustrate the appropriateness of SSM for this research, it is worth mention that it has been applied in relevant fields such as: natural resources management (e.g. Bosch *et al.* 2007; Ison *et al.* 1997; Mingers & White 2010); farming systems research (Bebbington *et al.* 1994; Jiggins 1995); systems agriculture (Bawden 1991); participatory learning (Hamilton 1995; Scoones & Thompson 1994); participative ecodesign (Ison 1993) and ecological knowledge systems (Roling & Jiggins 1996).

Despite revisions to the methodology (e.g. Checkland & Poulter 2009), it is the classical view of the methodology which is most widely used in practice (Mingers & White 2010), and thus was the one considered in this study, fig. A2.2.

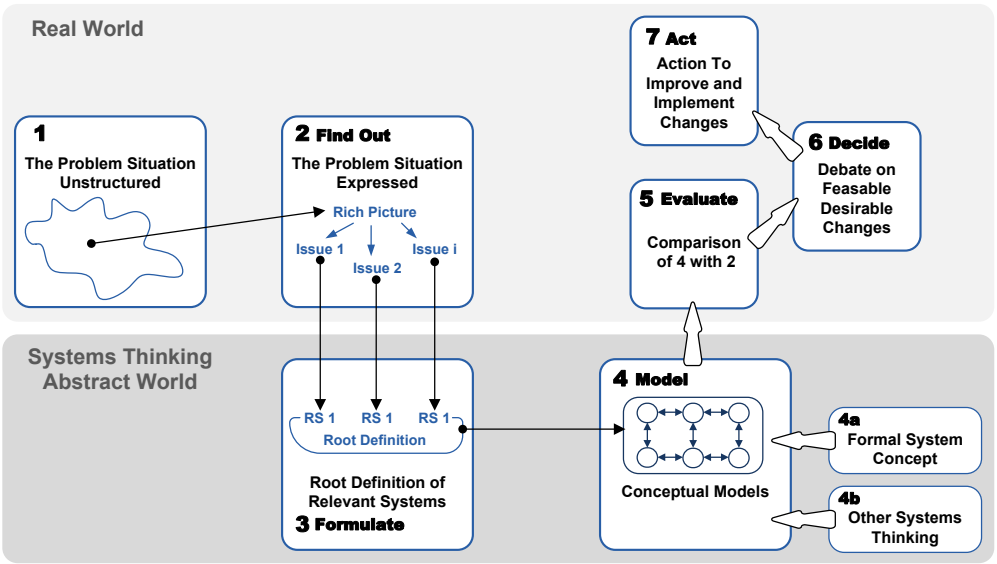


Figure A2.2|- The “classic” Soft Systems Methodology (after Bell & Morse 1999: 85).

While SSM provided the theoretical support and practical structure to generate models able to express the design logic behind WES in Mozambique, the research methodology is consistent with stages 1-5, but time constraints prevent the execution of stages 6 and 7. Nevertheless, it is an explicit research objective for the design tool to support stakeholder through those two last stages. Moreover, in most reviews of SSM, it is the possibility of change in practice, the focus on act0ors and their views, and the process as learning that are crucial to SSM (Jackson 2001; Pala *et al.* 2003).

ANNEX 3: PARTICIPATORY DESIGN WORKSHOP INVITATION

The two participatory design workshops held at Maputo with experts on WESs have been preceded by an invitation sent to all the experts previously interviewed individually. Here the invitation for the first PDW is presented as an example which only differs from the second invitation on the venue and date

WORKSHOP

CONCEPTUAL DESIGN of FUELWOOD ENERGY SYSTEMS in MAPUTO

Maputo, 29 of July 2013

Organized by: Ricardo Martins

CONTEXT

If energy is the motor of Humanity, the daily life of the large majority of Mozambican is moved on fuelwood (charcoal and firewood). In the shadows of the gigantic dams, power lines and biofuel mega-projects, the fuelwood business expands. An old, profitable, essentially informal involving thousands of small (and not so small) operators based on simple technology and free access to forest resources. In the last decades, fuelwood has been associated with: deforestation; poverty; urbanization; absence of suitable policies and strategies; insufficient access to cleaner and modern technology; cultural habits; land and forest resources access and property regimes; and to socio-economic and historical Mozambican. This diversity of perspectives clearly points to the complex nature of design of fuelwood energy systems. Moreover, such diversity can also be a reason why so much interesting work produced on the subject over the years from different perspectives remains, fundamentally, dispersed and unconnected.

Within this general picture **this Workshop intends to test a tool developed to facilitate the dialogue, knowledge exchange and learning among relevant actors (experts or not) in the conceptual design of fuelwood in Maputo (Mozambique)**. This design tool intends to be the major outcome of a PhD and was conceived as a co-design project involving the author, rural communities in Maputo Province and several experts working or somehow related with fuelwood energy systems in Mozambique and other developing countries.

OBJECTIVES

The Workshop intends (but is not limited to) the following objectives:

1. To present and test a prototype of a tool to support the participatory conceptual design of fuelwood energy systems for Maputo Province (but potentially useful for all Mozambique);
2. To introduce changes in such design tool by the Workshop participants, i.e., to promote the participatory design of the conceptual design tool;
3. To promote the experiences and knowledge share among the participants on fuelwood energy using the Design tool as a dialogue and debate catalyst;
4. To serve as a *Think Tank* (or at least the beginning of one) on the subject of fuelwood energy systems in Mozambique.

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PROGRAM

08:00 |	Arrival and registry of participants
08:10 |	Individual presentations of the participants and formation of teams
08:30 |	Presentation of the conceptual design tool and briefing on its usage
08:45 |	Group work on the first design challenge for Maputo
09:30 |	Presentation of each team conceptual design for the first design challenge
10:00 |	Debate among the groups regarding their conceptual designs
10:30 |	Coffee/Tea break
10:45 |	Group work on the second design challenge for Maputo
10:30 |	Presentation of each team conceptual design for the second design challenge
11:00 |	Debate among the groups regarding their conceptual designs
11:30 |	Conclusion and suggestions from the participants
12:15 |	Workshop closing

VENUE

The Workshop will take place at SNV central office in Maputo

Av. Julius Nyerere nr. 1339 (in front of Polana Hotel)

THANK YOU

The workshop organization deeply appreciates and acknowledges SNV support, particularly, Mr. Vignati for offering the SNV facilities and logistics for this workshop.

NOTE

While taking place at SNV the Workshop and its objectives are not, in any way, related with SNV work and/or policies or with any other political, institutional or organizational entity in Mozambique or abroad.

The Workshop and the conceptual design tool presented are part of na ongoing PhD work with purely academic objectives.

All results will be shared among the participants.

CONTACTS

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ANNEX 4: QUESTIONNAIRES USED IN FIELDWORK

4.A| EMAIL INTERVIEW QUESTIONNAIRE TO WES EXPERTS

Before You Start…

This questionnaire aims to make explicit how you think and conceptualise charcoal/firewood (or biomass) issues and forest energy resources in rural areas of developing countries. The questionnaire has been conceived as a "design exercise", with several questions emphasising description and illustration to generate "rich pictures" of "how you think", and "what you think of" regarding charcoal/firewood (or biomass) and forest issues. Thus, as long as clearly definable and understandable, graphics and drawings are also acceptable complements to the written answers. Also note that while the focus is on Mozambique, experiences and/or information on other developing countries are also appreciated. Likewise, while the focus is on charcoal/firewood information on any other form of biomass or biomass technology is appreciated.

Please note that this questionnaire is intended to serve many different perspectives, therefore, please, skip the questions you feel that are outside your expertises or experience. Finally, the content of the questionnaire is to be used exclusively for my PhD research in Imperial College of London and any specific information will be appropriately and clearly referred in the thesis.

Thank You Very Much For Your Patience And Collaboration!!!

QUESTIONS

1| Within the biomass context how do you justify the relatively low interest from funders and policy makers in charcoal/firewood issues when compared with other fuels (e.g.biofuels)?

2| How would you define a typical supply chain for charcoal/firewood? What actors, stages and connections would you consider? Why?

3| What are for you the most important aspects to be considered when addressing the charcoal/firewood subject?

4| What would you change in the way charcoal/firewood subject is addressed in Mozambique? (by "addressed" you could understand planned, designed, implemented, assessed, managed, financed)

5| Imagine that you are named, with full might powers, to address the topic of charcoal/firewood in Mozambique:

a. What would be the main goal(s) of the taskforce?

b. Who would you invite to take part in a charcoal/firewood task force? (please remember you can invite whoever you like and they would come)

produced by group one. The third group would consist of EDM, UEM, engineering, commerce,

c. Which topics would you like to be discussed by each of these working group members and which would be transversal to all of them?

6| Considering the present context in Mozambique, what would be the main barriers to implement the task force and its initiatives?

7| What would you do, considering again having full might powers, to overcome those barriers and achieve the desired goal(s) of the task force, within the present context?

8| Please, present additional comments on the subjects discussed or on questionnaire improvement.

4.B| EVALUATION QUESTIONNAIRE FOR MAPUTO'S PDWS

QUESTIONNAIRE ON CANVAS

1

NOTE: **Here energy system refers to fuelwood energy systems; Design Elements are the "boxes" in the Model; 2MW stands for wood fuel energy systems metamodel, a tool to help with participaotry conceptual design**

1. **Which version Model you prefer? 2MW-1** ☐ **2MW-2** ☐

Why? _____

_____

_____

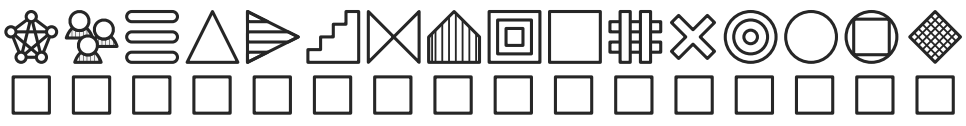
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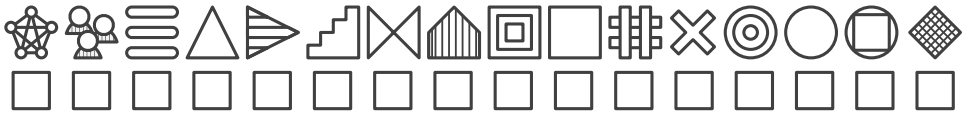
2. **In your opinion this conceptual design tool (the 2MW) is useful for:**
(rating from 5= Very Much to 1= Nothing)

a.	**Facilitate the participatory design of energy systems (ES)**	5	4	3	2	1
b.	**Assist the dialogue among professionals of different areas**	5	4	3	2	1
c.	**Communicate better design ideas to others**	5	4	3	2	1
d.	**Understand better the ES's conceptual design of others**	5	4	3	2	1
e.	**Organise better the thinking on ES's conceptual design**	5	4	3	2	1
f.	**Think *outside the box* and be creative designing ESs**	5	4	3	2	1
g.	**Do more informed strategic designs of ES**	5	4	3	2	1
h.	**Analyse and see better the *big picture* & interactions in ESs**	5	4	3	2	1
i.	**Do the participatory design of ESs with rural communities**	5	4	3	2	1

3. **Is there any new Design Elements for you? Which?** (If there are not go to 4)



4. **Is there any Irrelevant Design Elements? Which?** (If there are not go to 4)

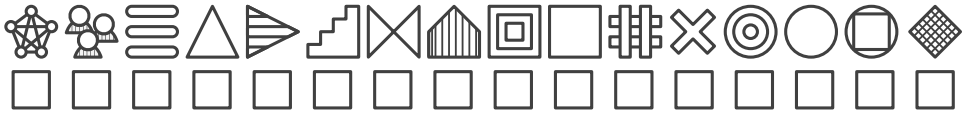


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QUESTIONNAIRE ON CANVAS

2

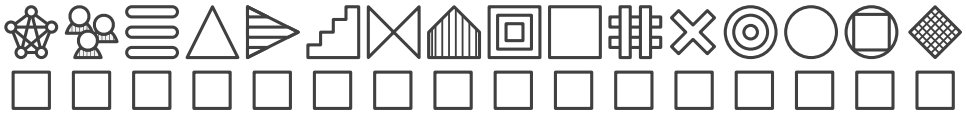
5. Is there any *hard to get* Design Elements? Which? (If there are not go to 6)



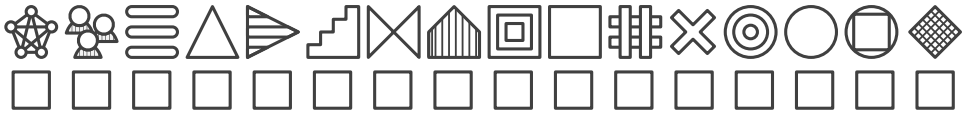
6. How was the navigation through the Design Elements?

☐ Random ☐ Iterative ☐ Sequential ☐ Mix of these/Other

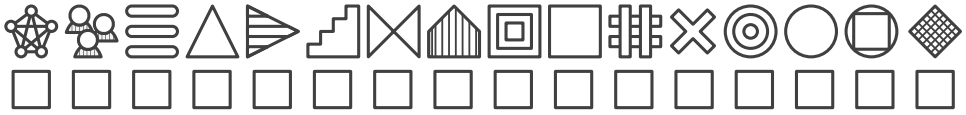
7. If it was sequential, or mostly sequential, please indicate the order
(1for the first, 2 for the second...)



8. Order from the most important
(1 for the most important and use the same number for Elements of equal importance)



9. In which Design Elements did you spent more time?
(1 for the most important and use the same number for Elements of equal importance)



10. Is there any Design Elements missing? Which? Why?

_____

_____

_____

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QUESTIONNAIRE ON CANVAS

3

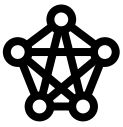
11. **Would you like to add any suggestive question to the Design Elements in the canvas?**
(Please, indicate the design element name for each question.)

12. **General Comments** _____

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DESIGN ELEMENTS SYMBOLIC ID

4



ACTOR NETWORK & RELATIONS



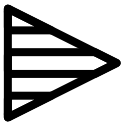
USERS



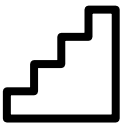
LAND & BIOMASS RESOURCES



PRODUCTION



DISTRIBUTION



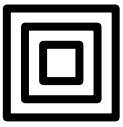
CONSUME & SELLING



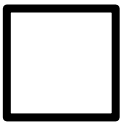
COMMUNICATION CHANNELS & RELATIONSHIPS



LEGISLATION & REGULATIONS



COSTS, RISKS & IMPACTS



PROFIT, BENEFIT, OPPORTUNITIES



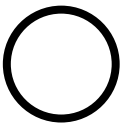
INFRASTRUCTURES



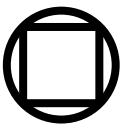
COMPETITION & SYNERGIES



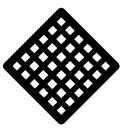
OBJECTIVE(S)



PROBLEM(S)



PROPOSAL(S)

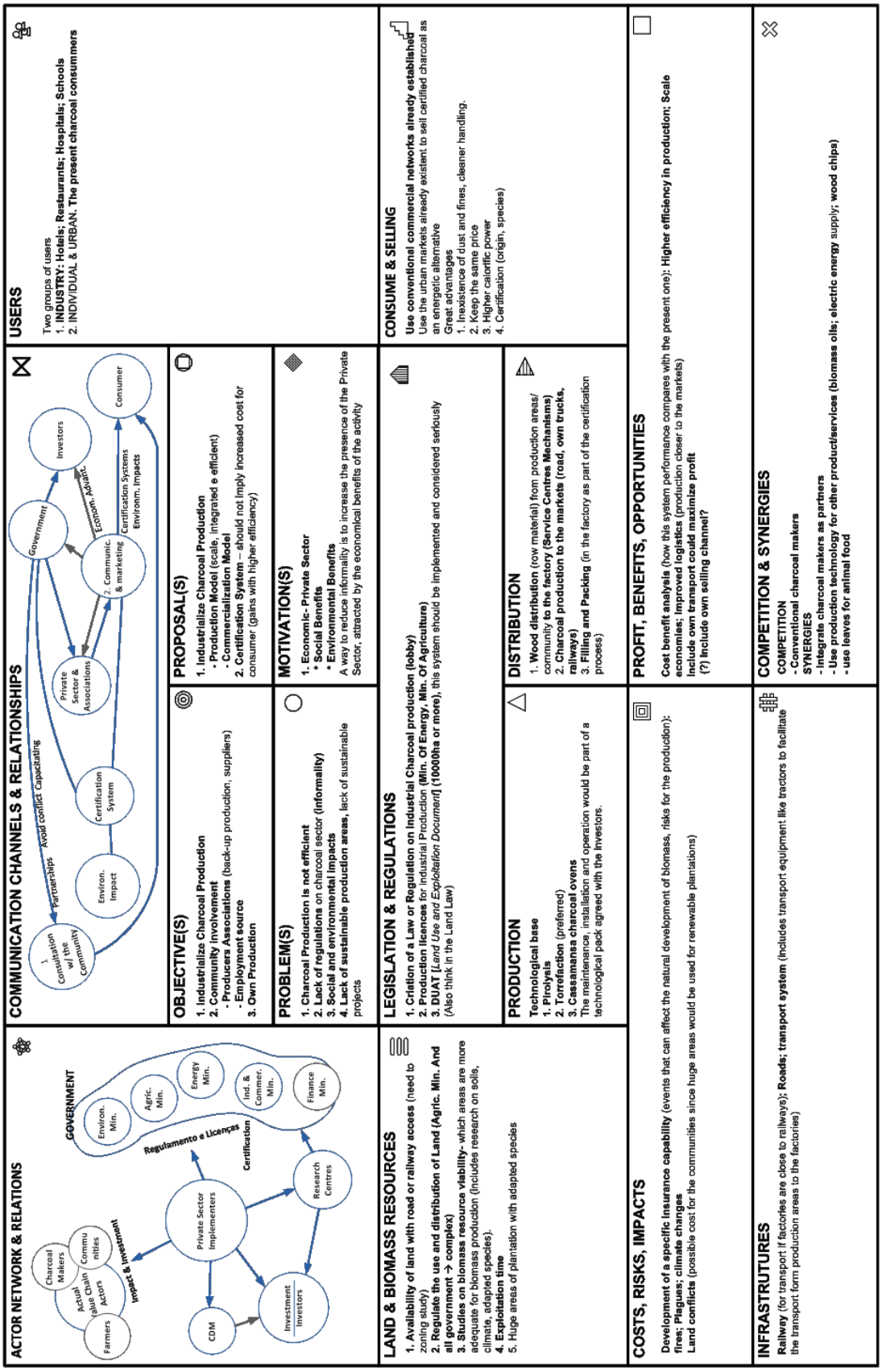


MOTICATION(S)

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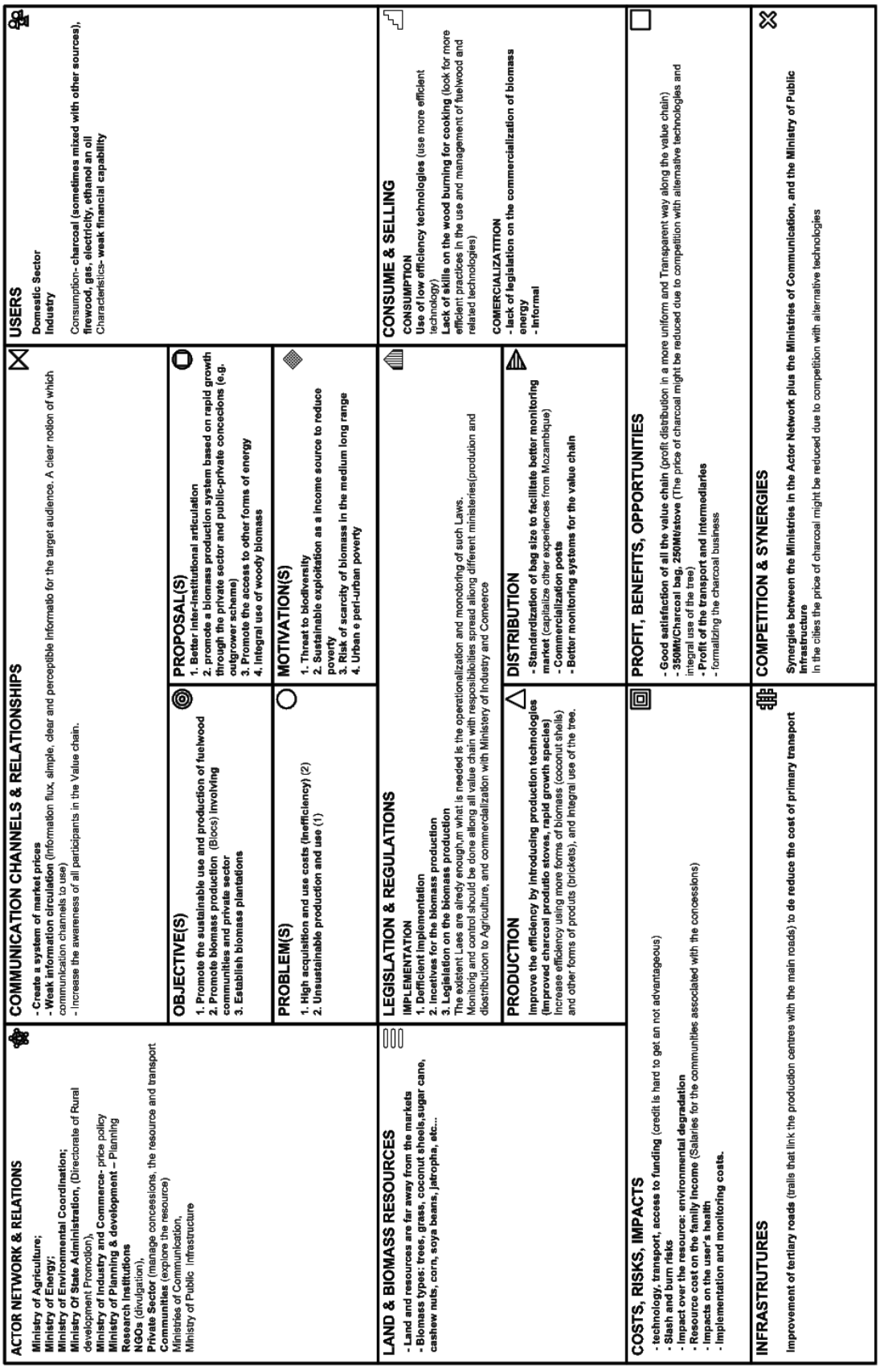
ANNEX 5: 2MW RESULTS OBTAINED IN WORKSHOPS

5.A| GREEN TEAM 2MW (URBAN PDW I, MAPUTO 29/07/2013)



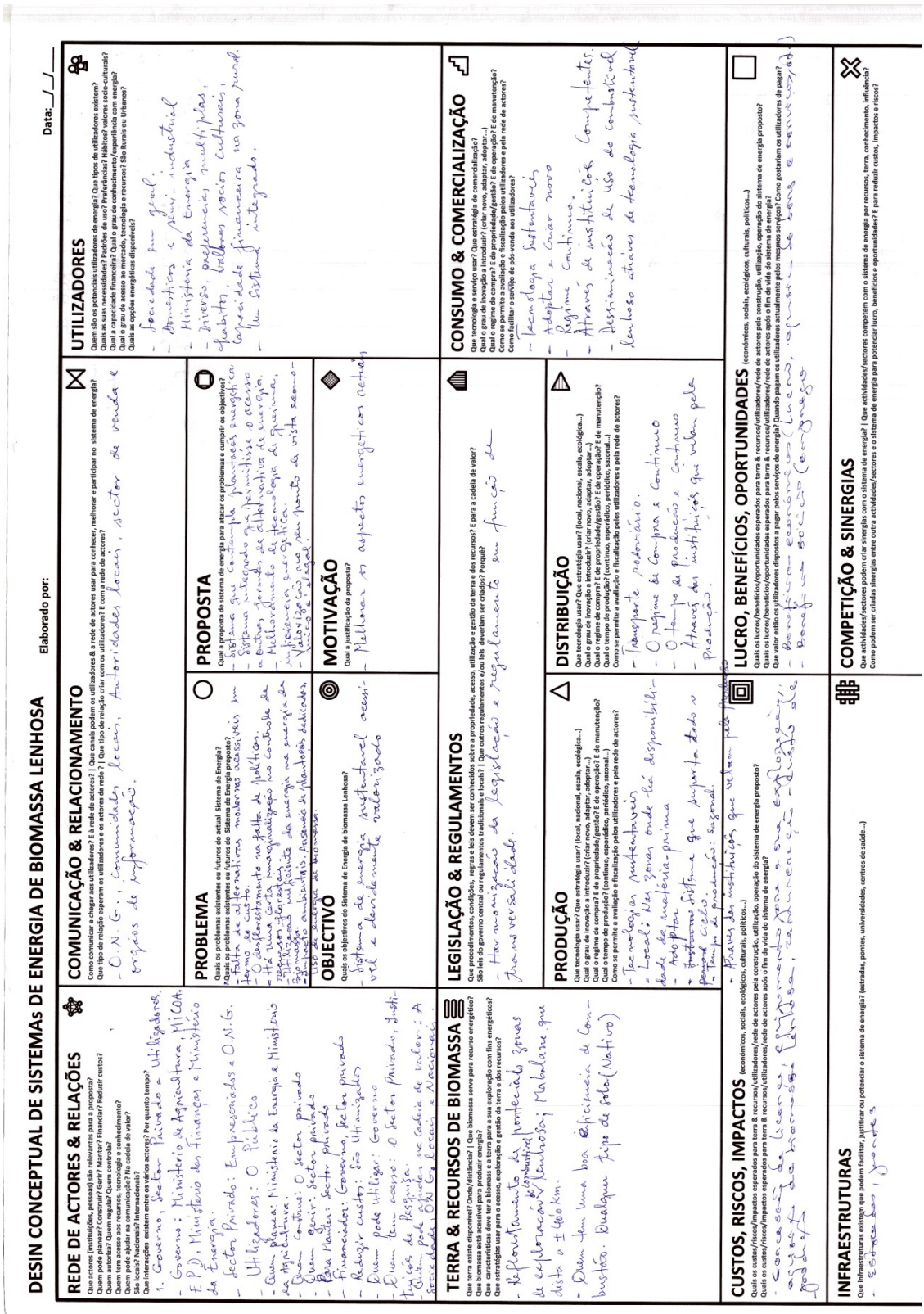
NOTE: This 2MW layout has been produced by the Author using the loose A5 paper sheets filled by the group for each Design Element and data from the group presentation doen after the design exercise.

5.B| RED TEAM 2MW (URBAN PDW I, MAPUTO 29/07/2013)

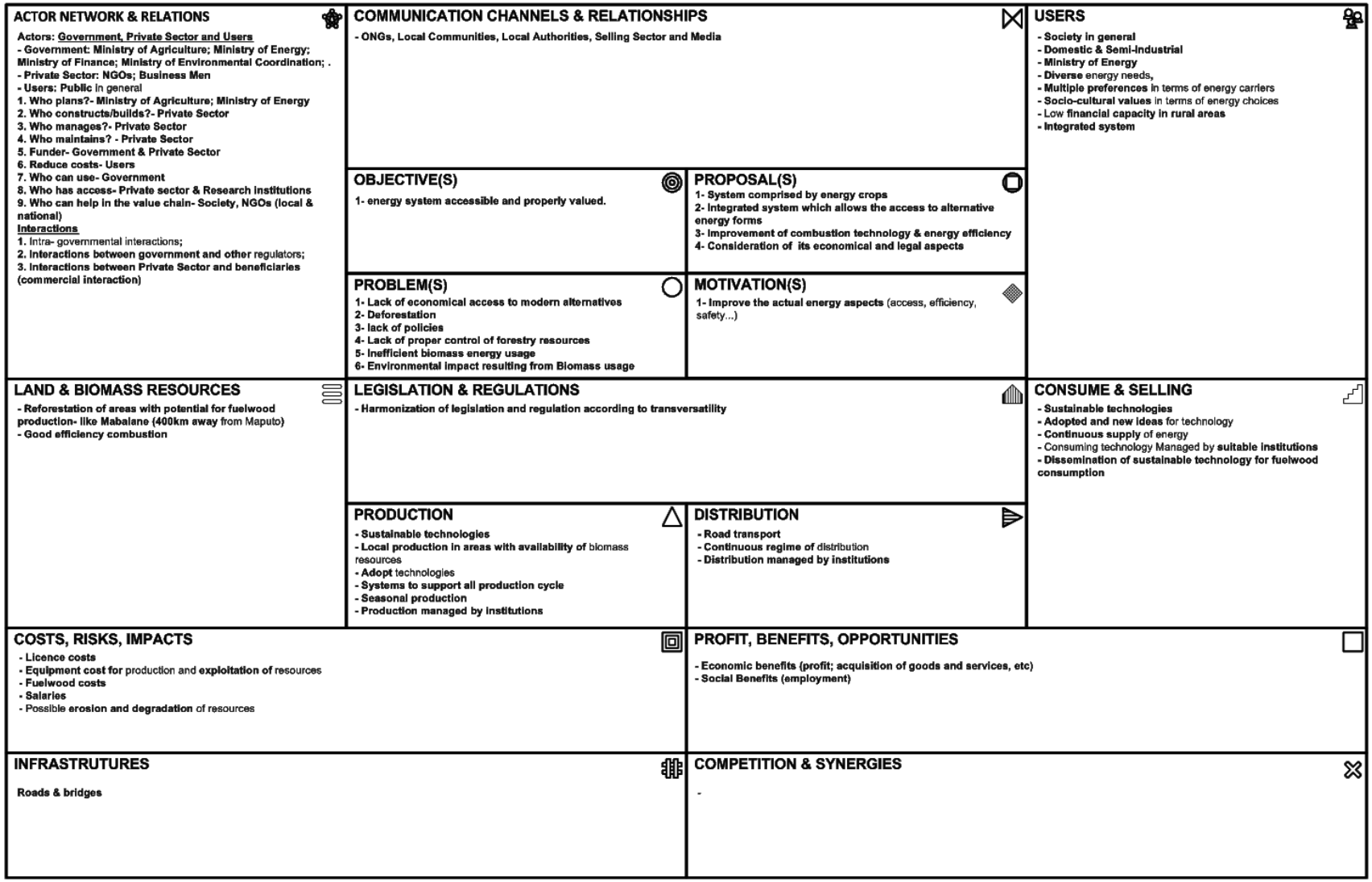


NOTE: This 2MW layout has been produced by the Author using the loose A5 paper sheets filled by the group for each Design Element and data from the group presentation doen after the design exercise.

5.C| BLACK TEAM 2MW (URBAN PDW II, MAPUTO 22/08/2013)

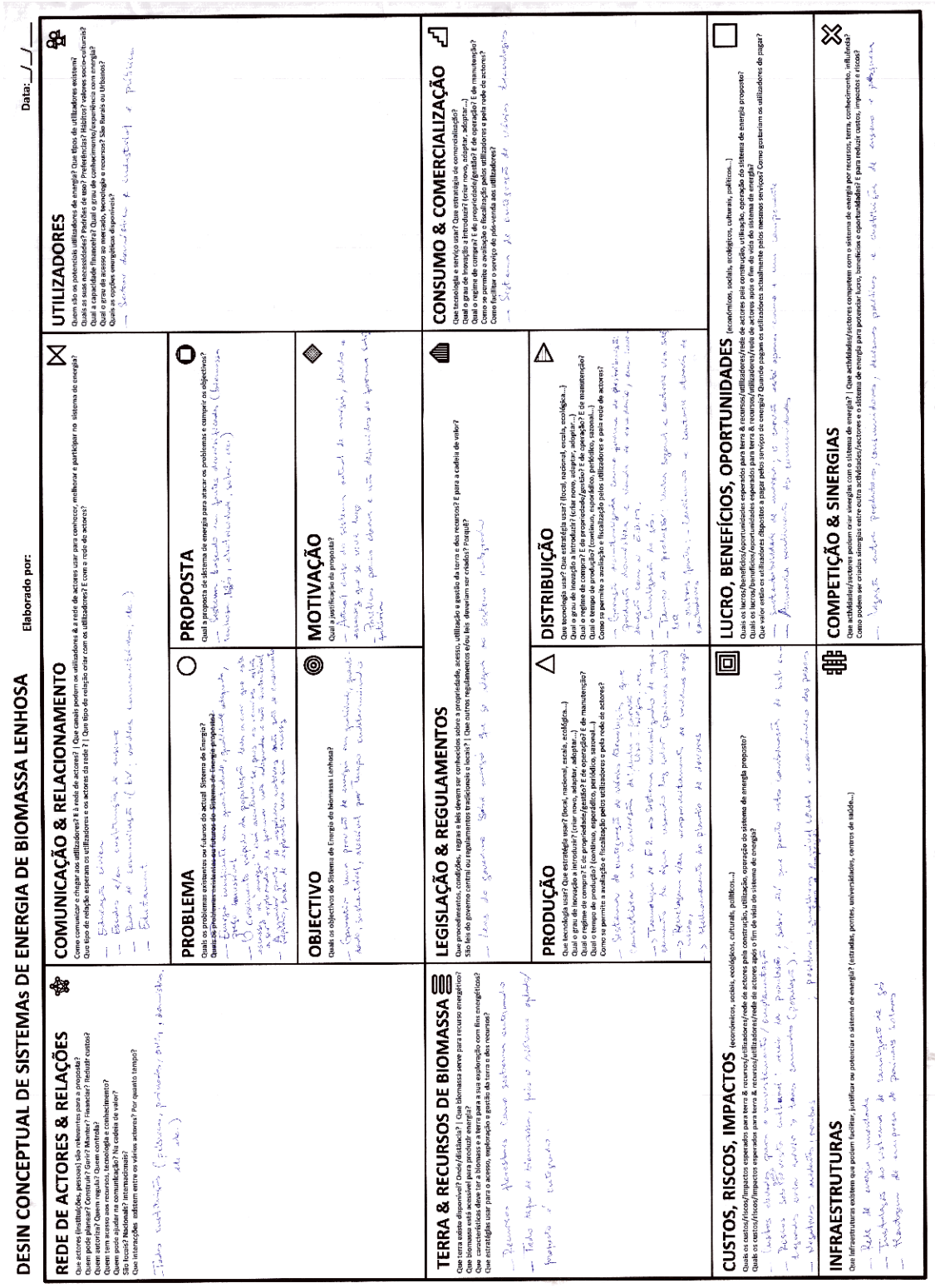


NOTE: This is the original 2MW produced by the Black Team on the spot [in Portuguese].

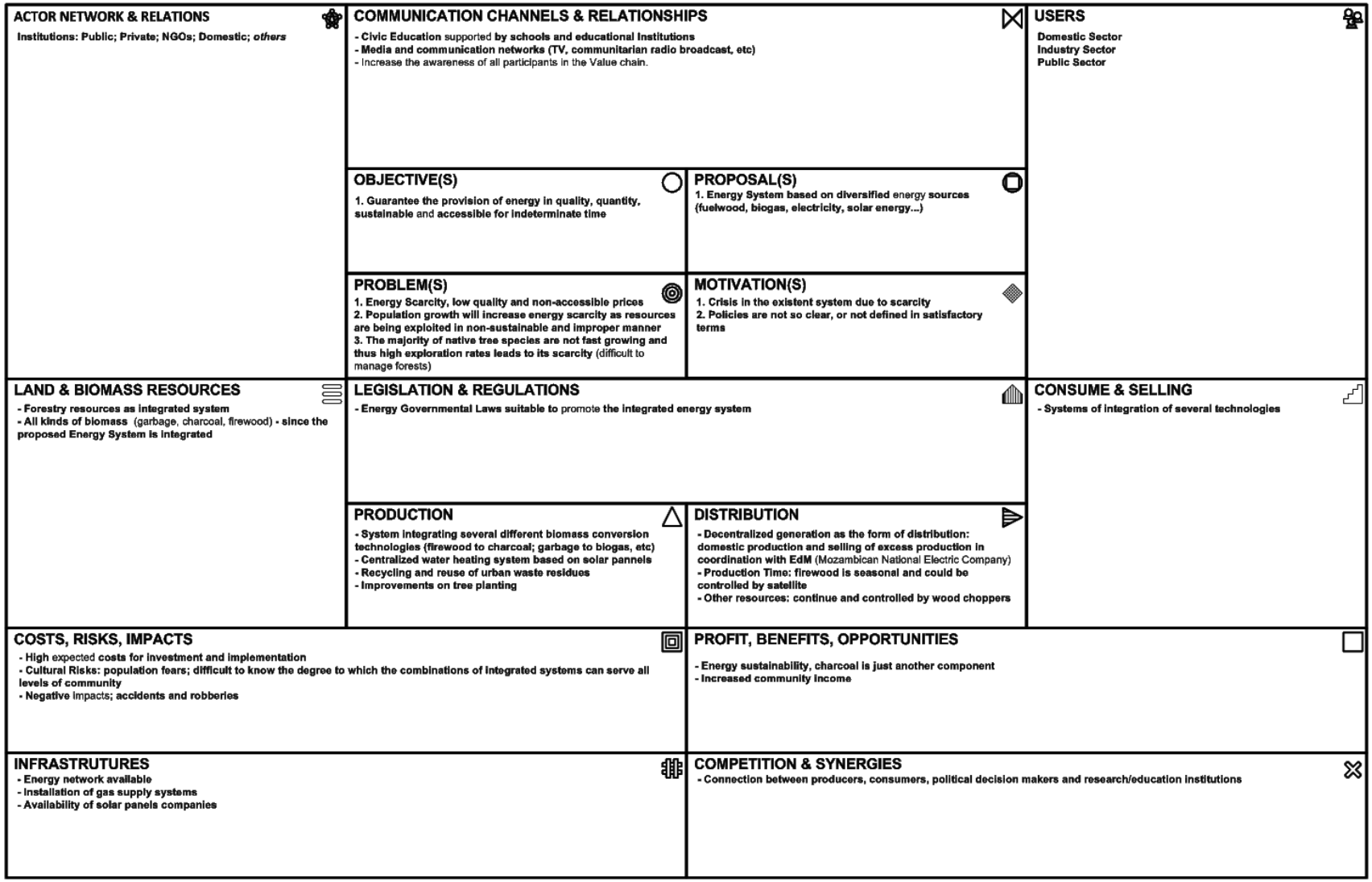


NOTE: This is the 2MW the Author after translating the 2MW presented in the previous page.

5.D| YELLOW TEAM 2MW (URBAN PDW II, MAPUTO 22/08/2013)

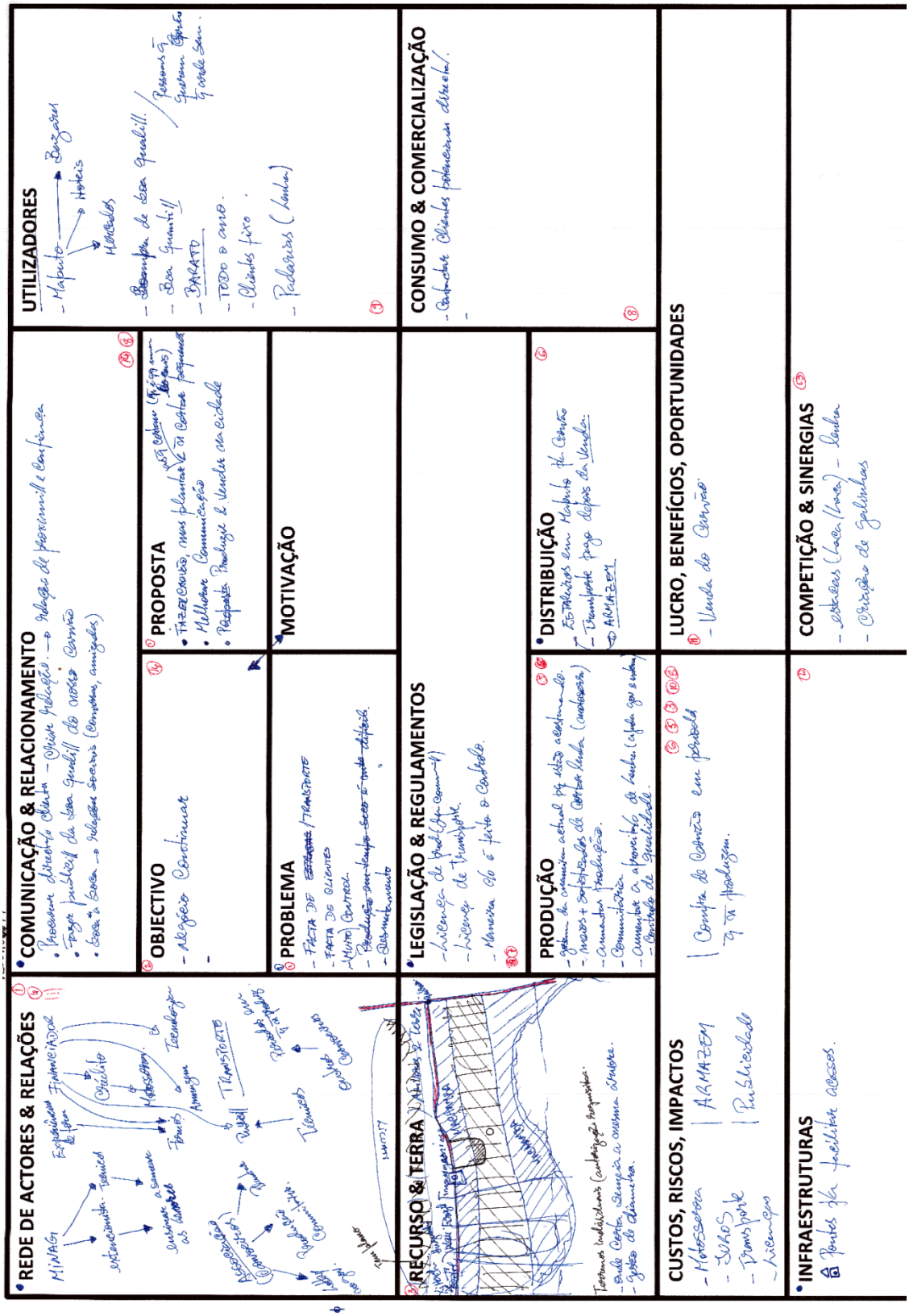


NOTE: This is the original 2MW produced by the Yellow Team on the spot [in Portuguese].

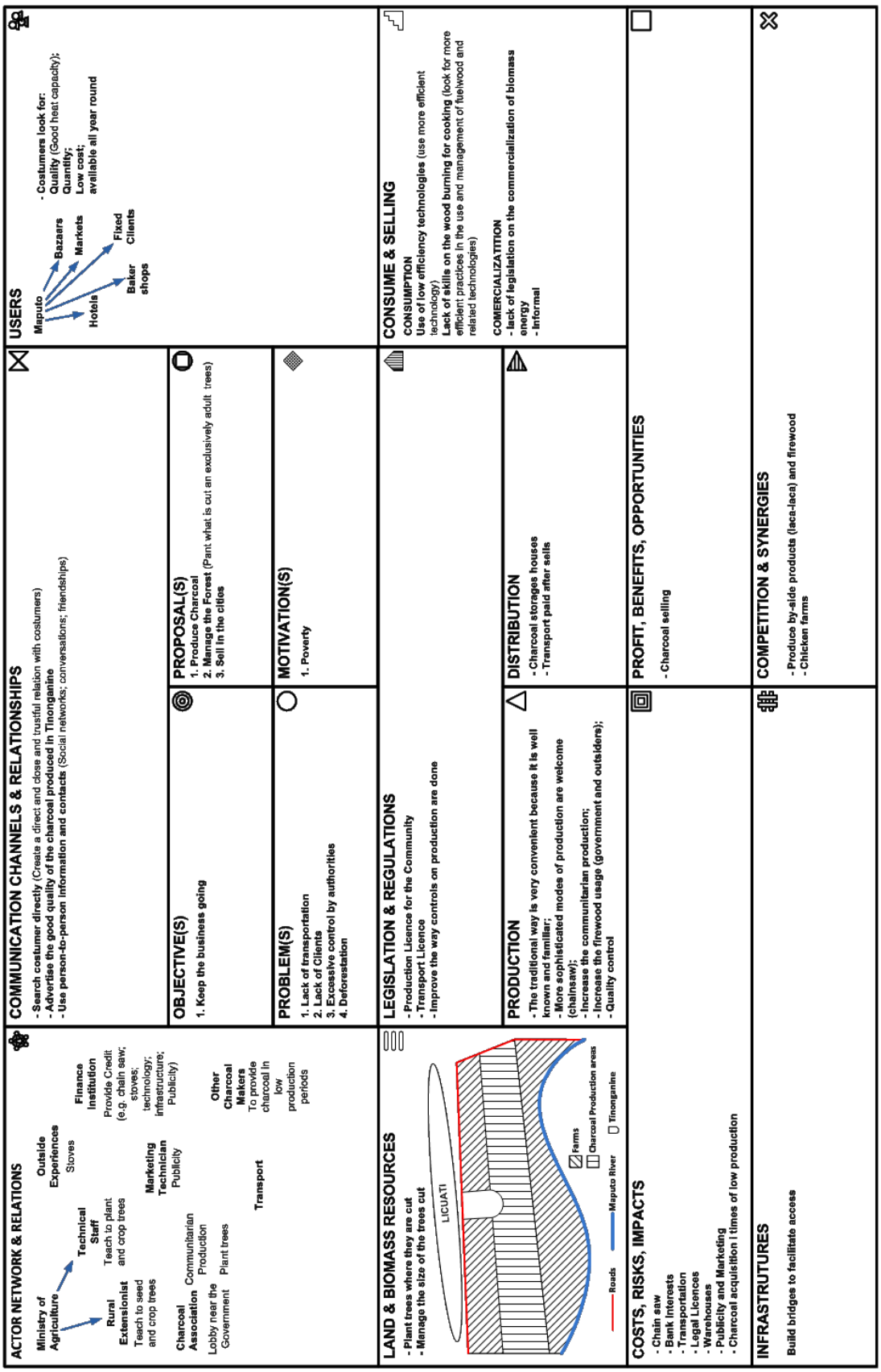


NOTE: This is the 2MW the Author after translating the 2MW presented in the previous page.

5.E| TINONGANINE TEAM 1 2MW (RURAL PDW, SANTAKA 11/08/2013)

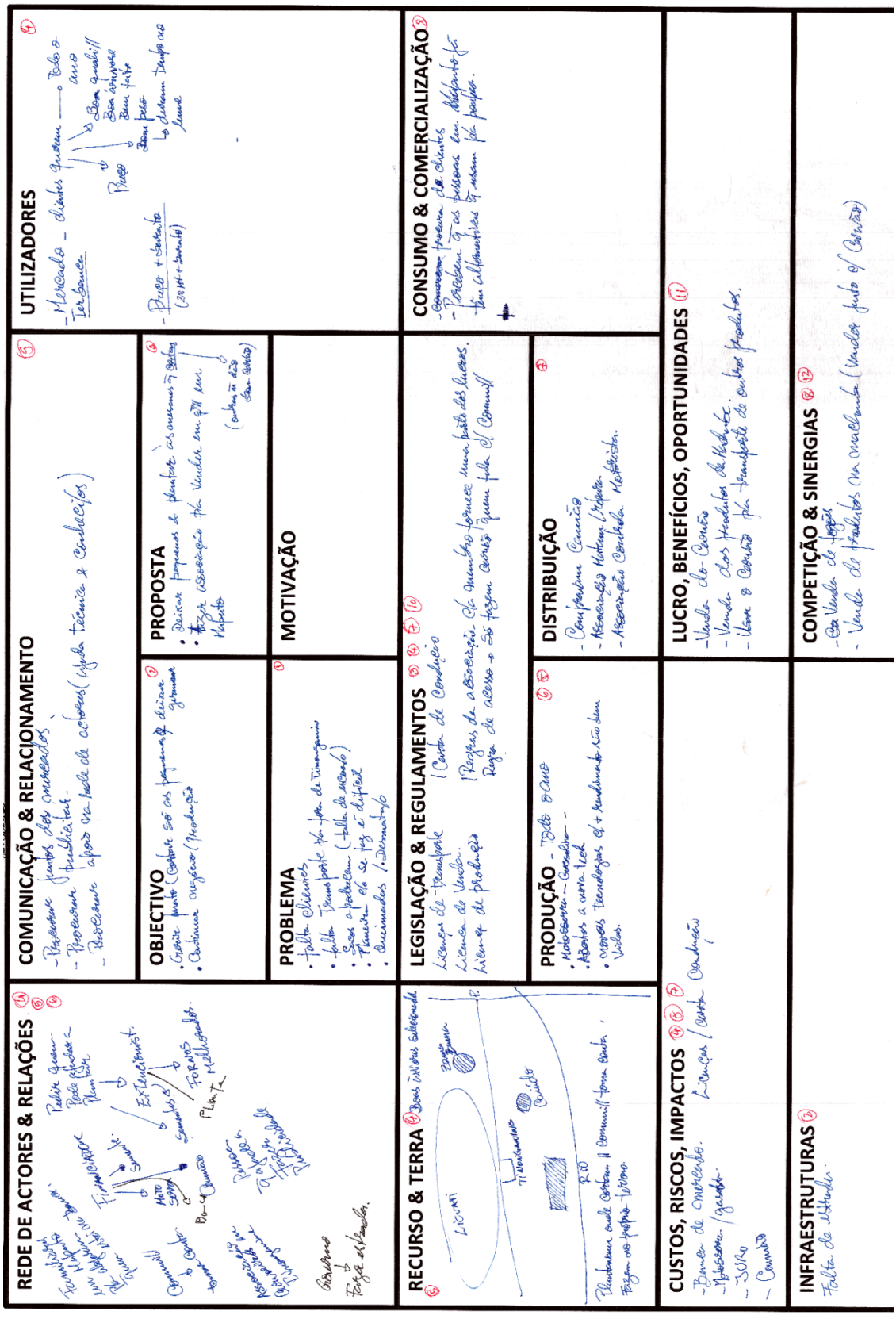


NOTE: This is the original 2MW produced by the Team 1 at Tinonganinen [in Portuguese].



NOTE: This is the 2MW the Author after translating the 2MW presented in the previous page.

5.F| TINONGANINE TEAM 2 2MW (RURAL PDW, SANTAKA 12/08/2013)



NOTE: This is the original 2MW produced by the Team 2 at Tinonganinen [in Portuguese].

ACTOR NETWORK & RELATIONS

- **Family members in Maputo-** shelter worker in Maputo Market
- **Community-** Take care of plantations and other communal initiatives
- **Funder/Bank-** Seeds, chainsaw, truck
- **Charcoal Makers Association (to be created)**
- **Someone with experience in (e.g. extencionist):** planning techniques, supply seeds and plants, improved stoves
- **Someone with experience in marketing and publicity**
- **Government-** Build a road to Tinonganine

COMMUNICATION CHANNELS & RELATIONSHIPS

- **Look for costumers and conditions near the markets**
- **Try to make publicity on Tinonganine's Charcoal**
- **Try to get the support from Actor Network (technical support and knowledge)**

USERS

- **Clients in Maputo Markets want:**
  - **+ Product all year round**
  - **+ Quality** (good tree, well done, good weight, durability)
  - **+ Cheap (charcoal could be cheaper 25Mt e.g.)**

OBJECTIVE(S)

1. **Manage the woods (do not cut the small ones; allow germination)**
2. **Continue the charcoal business**

PROPOSAL(S)

1. **Leave small trees**
2. **Plant the same trees cut to produce charcoal**
3. **Create a Charcoal Association to sell in quantity at Maputo's Markets**

PROBLEM(S)

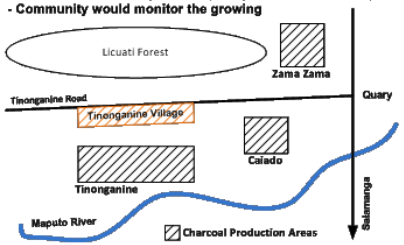
- **Lack of costumers**
- **Lack of transport to get charcoal out of Tininganine** (charcoal rotten in the side of the road)
- **Difficult hard process of production**
- **Deforestation and wildfires**

MOTIVATION(S)

- **Reduce poverty and provide better living condition for families**

LAND & BIOMASS RESOURCES

- **Select good trees to plant**
- **Plant trees where they are cut (family slots in the woods)**
- **Community would monitor the growing**



LEGISLATION & REGULATIONS

- **Licences: transportation, selling, production**
- **Drivers licence**
- **Charcoal association regulations: each member provides a share of the profit; only locals can produce charcoal**

CONSUME & SELLING

- **Search for clients**
- ***People in Maputo have other energy alternatives, so there is a competitive market**

PRODUCTION

- **All year round production**
- **Use of better technology (chainsaw)**
- **Open to new production technology with higher productivity**

DISTRIBUTION

- **Buy a truck for the Charcoal Association**
- **Truck managed by the Charcoal Association**
- **The driver is hired and controlled by the Charcoal Association**

COSTS, RISKS, IMPACTS

- **Market post in Maputo**
- **Chainsaw & gasoline**
- **Bank interest**
- **Purchasing of truck**
- **Licences**

PROFIT, BENEFITS, OPPORTUNITIES

- **Charcoal selling**
- **Farming products selling**
- **Truck can be used for other profitable purposes (e.g. transport of other products for other people)**

INFRASTRUTURES

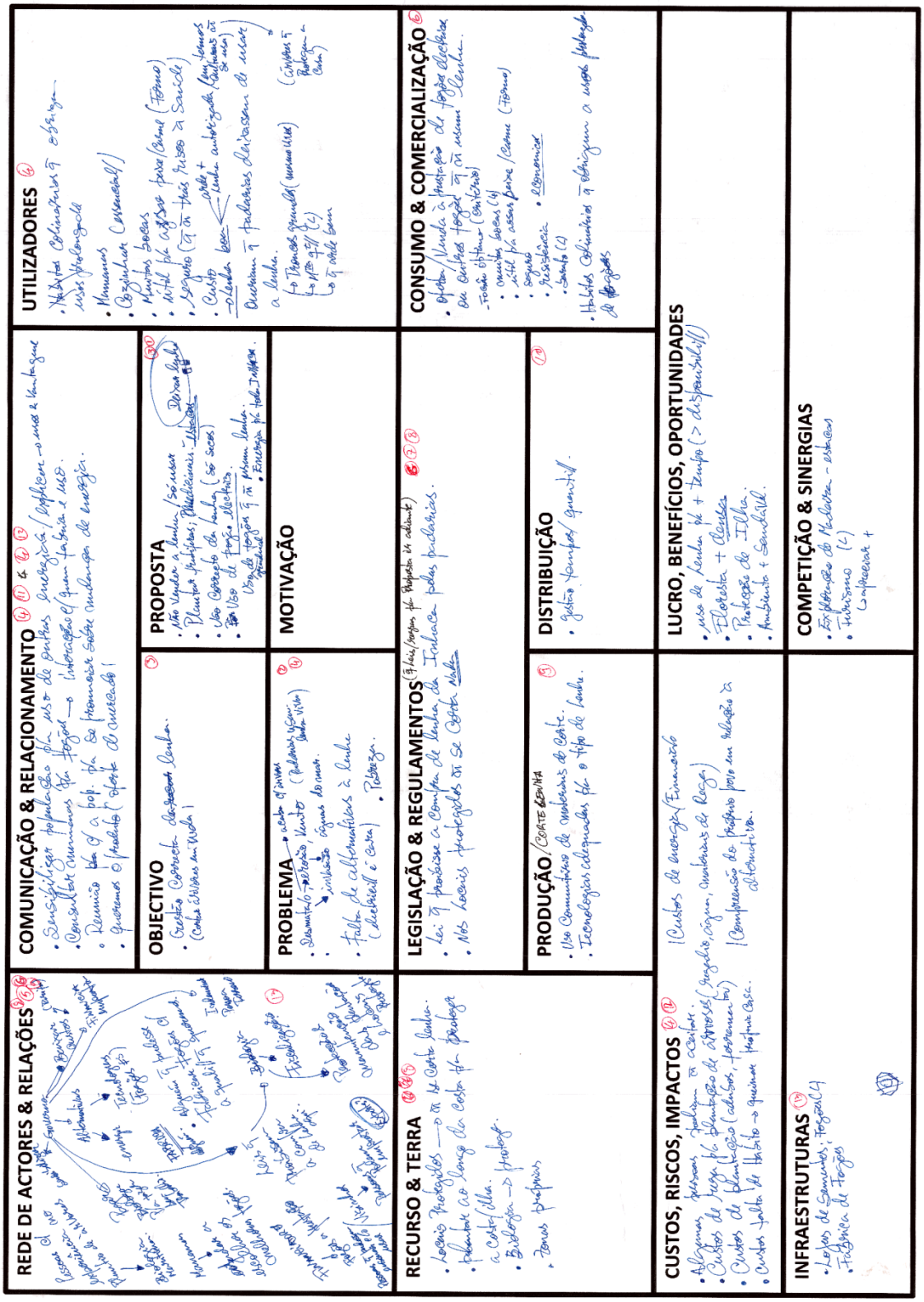
- **Lack of roads**

COMPETITION & SYNERGIES

- **Sell stoves next to charcoal**
- **Sell farming products next to charcoal**

NOTE: This is the 2MW the Author after translating the 2MW presented in the previous page.

5.G| NHANKENE TEAM 2MW (RURAL PDW, INHACA ISLAND 14/08/2013)



NOTE: This is the original 2MW produced by the participaotry design Nhankene Community Team [in Portuguese].

ACTOR NETWORK & RELATIONS

Government:
- Community awareness;
- Financial support (reduce costs, credit; indemnizations);
- Provide alternatives (energy and technology)
- Legislation (forbid firewood selling in Inhaca)

Maritime Biology Station:
- Law enforcement
- Protection and maintenance of protected areas

People with experience in planting trees: e.g. Maritime Biology Station
Elder women: help to choose stoves
Finance Sponsors: Credit to buy stoves
Technical staff:
- Teach how to use the stoves
- Implement a factory producing good low cost stoves

Neighbours and knowledgeable people

COMMUNICATION CHANNELS & RELATIONSHIPS

- **Community awareness to use other energies** (explain the uses and advantages)
- **Consulting with elders in stove design** (promote interaction between those who produce and those who use)
- **Public meetings with the community** (community could express their feelings regarding the change of energy)
- **Communicate the availability of market in Inhaca** (attract investors)

OBJECTIVE(S)

1. **Sound management of firewood** (cutting trees still in live)

PROPOSAL(S)

1. **Don't sell firewood, only use**
2. **Plant fruit trees, medicinal trees and wood for construction**
3. **Correct use of firewood (only dry wood)~**
4. **Change gradually to stoves that work without firewood**
5. **Energy for all island**

PROBLEM(S)

1. **Deforestation** (erosion; wind; sea; bakeries)
2. **Lack of suitable alternatives to firewood**
3. **Poverty**

MOTIVATION(S)

USERS

Users want quality Firewood:
- Burns more
- Culturally acceptable by the community
- Good quantity

- Criteria for quality stoves:
- Useful for long cooking times;
- Many burners (>4) and stove for grill;
- Safe (it is not risky for health)
- Low cost
- Resistant

People with experience in planting trees: e.g. Maritime Biology Station
Elder women: help to choose stoves
Finance Sponsors: Credit to buy stoves
Technical staff:
- Teach how to use the stoves
- Implement a factory producing good low cost stoves

Neighbours and knowledgeable people

LAND & BIOMASS RESOURCES

- **Establish protected areas where it is impossible to cut trees**
- **Plant along the seashore to protect the island**
- **Assign suitable areas for tree plantation**

LEGISLATION & REGULATIONS

- **Forbid the use/buying of firewood by bakeries** (Bakeries use large quantities of good wood from big living trees)
- **In the protected areas the cut should be completely forbidden**

CONSUME & SELLING

- **Provide/sell electric stoves or other stoves that don't use firewood**

PRODUCTION

- **Communitarian use of materials**
- **Technologies appropriated to the kind of wood**

DISTRIBUTION

- **Managing times and quantities**

COSTS, RISKS, IMPACTS

- **Some people could not accept this plan/design**
- **Costs associated with the tree plantation** (e.g. watering materials, seeds, substrate, tools)
- **Risks associated with the use of unfamiliar technology** (e.g. houses could burn)
- **Costs associated with energy use**
- **Costs associated with the understanding by the community of new technologies**

PROFIT, BENEFITS, OPPORTUNITIES

- **Availability of wood for longer extended periods**
- **Forest becomes more dense**
- **Protect the Island**
- **Healthier environment**

INFRASTRUTURES

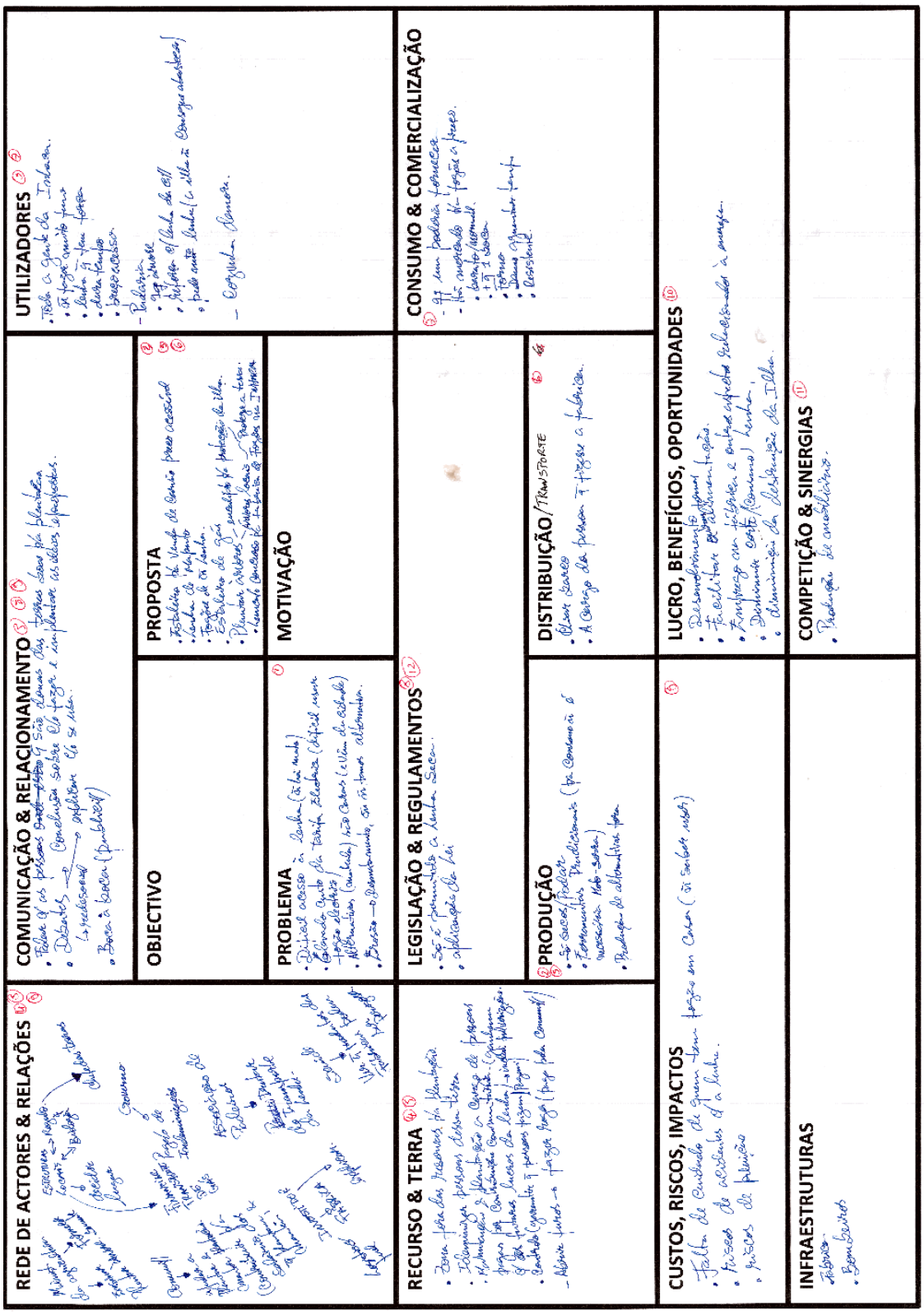
- **Seed Shops, stove shops**
- **Stove factory**

COMPETITION & SYNERGIES

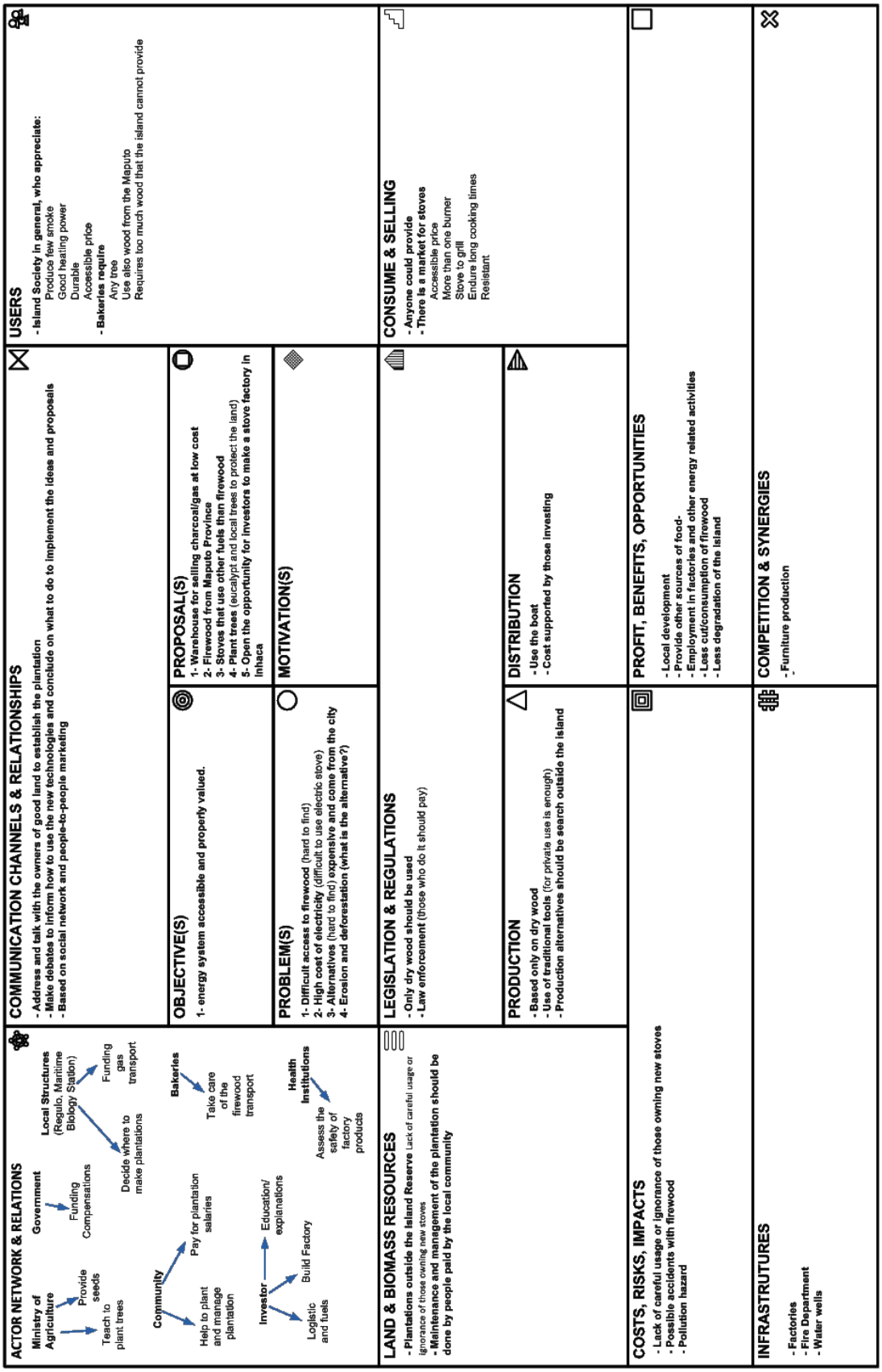
- **Export wood for construction**
- **Tourism** (people would come)

NOTE: This is the 2MW the Author after translating the 2MW presented in the previous page.

5.H| RIBJENE TEAM 2MW (RURAL PDW, INHACA ISLAND 15/08/2013)

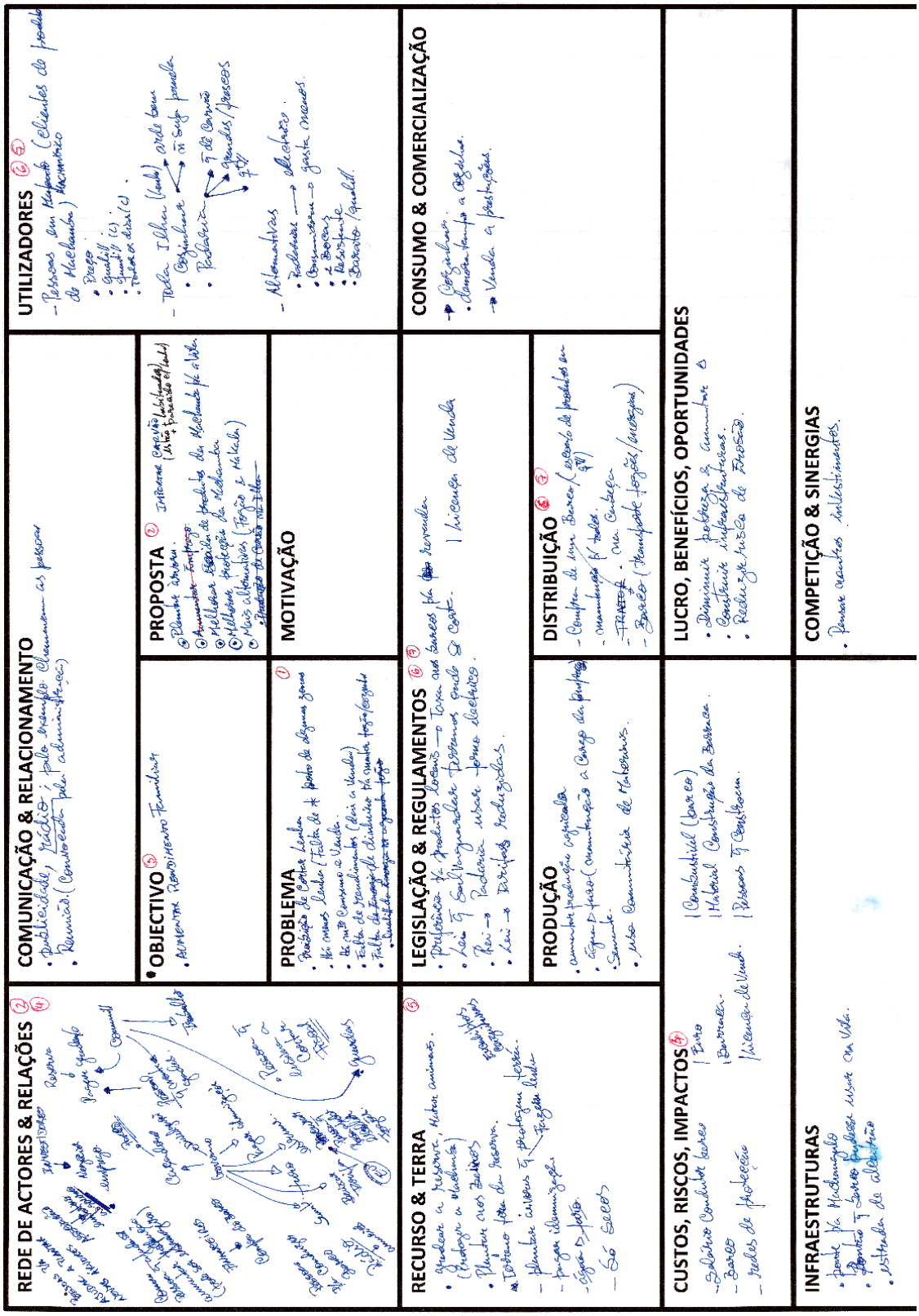


NOTE: This is the original 2MW produced by the participaotry design Ribjene Community Team [in Portuguese].



NOTE: This is the 2MW the Author after translating the 2MW presented in the previous page.

5.I| INGWANE TEAM 2MW (RURAL PDW, INHACA ISLAND 16/08/2013)



NOTE: This is the original 2MW produced by the participaotry design Ingwane Community Team [in Portuguese].

ACTOR NETWORK & RELATIONS

- **Government**:
  - Community awareness;
  - Financial support (reduce energy costs, compensations);
  - Provide support with hunters (chance wild boars that destroy farms); tree seeds; substrate; wells
- **Maritime Biology Station:**
  - Help selecting, plant and crop trees
  - Pay for the fences and provide people to install it
- **Experts (could be foreigners)**
  - Chose appropriate stoves
  - Increase production
- **Community**
  - Provide workers for the plantations and fence works
  - Guards
- **Funding entities:**
  - Buy boat
  - Open business and generate jobs
- **Radio** (for marketing)

COMMUNICATION CHANNELS & RELATIONSHIPS

- **Publicity, Radio**
- **Acting by example** (local authorities)
- **Meeting proposed by local authorities**

USERS

- **People in Maputo, the costumers for the farming products:**
  - Affordable prices
  - Good quality products
  - Good quantity
  - Every day (reliable)
- **All Island:**
  - Good quality firewood (provide good heat);
  - Don't make the pans dirty and black;
  - Use stoves with 2 burners, resistant and low cost
- **Bakeries:** use electrical stoves or charcoal, since they use all kind of wood (even not dry) and consume high quantities

OBJECTIVE(S)

1. **Increase Family income**

PROPOSAL(S)

1. **Plant trees**
2. **Import charcoal** (more like firewood, more familiar use)
3. **Better flow of agriculture products to the village**
4. **Better crop protection**
5. **More energy alternatives to fuels and technologies**

PROBLEM(S)

1. **Prohibition to cut wood**
2. **Lack of wood in some areas**
3. **Increased firewood consumption and selling**
3. **Poverty, lack of income** (hence the selling and the inability to sustain other energies)

MOTIVATION(S)

LAND & BIOMASS RESOURCES

- **Protect the reserve and farming fields**
- **Plant trees in areas outside the reserve**
- **Plant trees that could protect the land and provide firewood** (e.g. Casuarinas Sands, Eucalypts)
- **Cut only dry wood**
- **Pay compensation to those offering the land for plantations**

LEGISLATION & REGULATIONS

- **Protect and favour local products:** create tax on boats from the city
- **Laws to protect the fields where wood is cut**
- **Make bakeries to use electric stove**
- **Low fees for new technologies**

CONSUME & SELLING

- **Facilitate the purchase of energy technolgy using payment by instalments**

PRODUCTION

- **Increase agricultural production**
- **Water well (maintenance by the water company)**
- **Seeds**
- **Communitarian use of tools**

DISTRIBUTION

- **Acquire boat to transport agricultural goods for the markets**
- **Maintenance all farmers**
- **Use the same boat to transport energy fuels and technology**

COSTS, RISKS, IMPACTS

- **Salary for the sailor**
- **Cost of boat and its maintenance (fuel)**
- **Protection fences for the fields**
- **Wells**
- **Warehouses**
- **Legal licences**

PROFIT, BENEFITS, OPPORTUNITIES

- **Reduce poverty and increase development**
- **Built infrastructures**
- **Reduce risk of erosion**

INFRASTRUTURES

- **Bridge to Machangulo**
- **Pear to be used by sailing boat**
- **Tar roads in the island**

COMPETITION & SYNERGIES

- **Think in other investments**

NOTE: This is the 2MW the Author after translating the 2MW presented in the previous page.

SECTION **G**

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> ***Knowledge is the only treasure you can give entirely without running short of it."***
>
> African proverb

…WHERE THE REFERECES REST…

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