
CONCEIVING A SYSTEMIC APPROACH TO IMPLEMENT
SOLAR ENERGY TECHNOLOGY: THE CASE OF ISRAEL

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A thesis submitted for the degree of
Doctor of Philosophy

Supervised by Dr. Judith A. Cherni

To my beloved family

Declaration

I am hereby declare that this thesis is my own work and that it has not been previously submitted, either in the same form or different form, to this or any other University for a degree.

The research undertaken between May 2010 and May 2014 at the Centre of Environmental Policy, Imperial College London. Except where acknowledged in the customary manner, the material presented in this thesis is, to the best of my knowledge.

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Avi Luvchik

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Abstract

Population growth, lifestyle and income changes as well as urbanisation are powerful driving forces behind increasing demand for energy. Since 1900, world population has more than quadrupled, real income has grown by a factor of 25, and primary energy consumption has risen by a factor of 22.5. The joint phenomenon of urban and economic growth is particularly relevant in Israel where 76% of the population lives in cities and Israel economic growth rate stood at 5.4% in 2010, a relatively high value compared to most of the OECD countries. As a consequence, total green House Gas (GHG) emissions originated from the use fossil fuels in Israel are expected to rise sharply in 2030. The promotion of renewable energy, particularly solar is a way to deal with predicted rising emissions as well as addressing energy security and increase of oil price that afflict the Middle East region. Worldwide, solar cell electricity generation market has grown dramatically, both in terms of electricity generation and market size. A paradox that this study addresses is that while Israel has developed and exported advanced solar technology, it is among the last countries that actual use this type of technology for self consumption.

For most of its history, Israel has been an energy-poor state, relying almost completely on imported fossil fuels to meet its energy needs. However, the Israeli energetic independence has been changed dramatically in 2009 when two large fields (nearly 3.1 Trillion Cubic Feet) of natural gas were discovered in the Mediterranean Sea 60 km off the Israeli coast line. These discoveries have changed the energy market in Is-

rael, bringing the decision makers to rethink about electricity production by renewable energy sources.

The approaches developed in this thesis aims to achieve two main goals. To find electricity capacity can be generated by solar technologies based on atmospheric parameters and to find the optimal government incentive for renewable energy to encourage private investors to invest in PV solar systems and thus to meet the government goals of greenhouse gas reduction.

To tackle these two main goals of the research, two mathematical approaches and decision-making models were developed. One model -Technical Environmental and Atmospheric (TEA Model) and optimises the application and selection of solar energy technologies in Israel. TEA model taking into accounts mainly atmospheric, demand and environmental parameters. The model provides quantitative and qualitative formulations to energy production capacity, costs, environmental impact and future electricity demand. The second model (policy model) designed to optimise the level of Feed in Tariff (FIT) by using a linear program and a Monte- Carlo Simulation. The innovation of the study is that the decision-making model takes into account factors that had not been considered together before but could have a decisive influence on the uptake of the right solar energy technology.

This research found that the annual average energy output by PV system in Israel is $1735kWh/kW_p$ (+/- 10%) and the annual average of performance ratio is 82.3%. In regards to atmospheric pollution, it was found that the increasing of air pollution causes to decrease of electricity generation by more than 10% a year. In respects to the policy analysis it was found the optimal FIT should be 0.15 \$/kWh compared to 0.165 \$/kWh which was paid in 2015.

Acronyms and Abbreviations

AC	Alternating Current
AOT	Aerosol Optical Thickness
BCM	Billion Cubic Meters
BOS	Balance Of System
BIPV	Building-Integrated Photovoltaic
CBS	Central Bureau of Statistics
CCN	Cloud Condensation Nuclei
CCS	Carbon Capture & Storage
CDM	Clean Development Mechanism
CPV	Concentrating Photovoltaic
CSM	The Chief Scientist Ministry
DC	Direct Current
DFID	Department for International Development
DNA	Designated National Area
EIA	Energy Information Administration
EM	Econometric Model
EPC	Engineering Planning & Consulting
FAO	Food and Agricultural Organization
FIT	Feed In Tariffs
IEC	Israel Electric Corporation
IES	Inbar Solar Energy Company

IMFA	Israel Ministry of Foreign Affairs
IMI	Israeli Ministry of Interior
IMS	Israeli Meteorological Service
IPCC	Intergovernmental Panel on Climate Change
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographical Information System
LCA	Life–Cycle Assessments
LCOE	Levelised Cost of Energy
LP	Linear Program
MBE	Mean Bias Error
MENA	Middle East and North Africa
MEP	Ministry of Environment Protection
MJ	Multi Junction
MITL	Ministry of Industry Trade & Labor
MNI	Ministry of National Infrastructures
MOA	Ministry of Agriculture
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NOCT	Normal Operating Cell Temperature
OECD	Organisation for Economic Co-operation and Development
PC	Polycrystalline
PGR	Population Growth Rate
PSH	Peak Solar Hour
PUA	Public Utility Authority
PV	Photovoltaic
RE	Renewable Energy
RET	Renewable Energy Technology
RF	Radiative Forcing
RMSE	Root Mean Square Error
RS	Residential Sector
SDE	Stochastic Differential Equation

SI	Standards International
SL	Sustainable Livelihoods
STC	Standard Test Conditions
SWH	Solar Water Heaters
TEC	Total Electricity Consumption
TF	Thin Film
TMY	Typical Meteorological Year
VLS-PV	Very Large Scale-PV
UHI	Urban Heat Island
UNEP	United Nations Environment Program
WMO	World Meteorological Organisation
<i>aSi</i>	Amorphous Silicon
<i>cSi</i>	Crystalline Silicon
<i>CdTe</i>	Cadmium Telluride
<i>CIS</i>	Copper Indium Diselenide
<i>CIGS</i>	Cooper Indium Gallium Diselenide
<i>eV</i>	Electron Volt
<i>f</i>	Fine Mode Fractions
<i>j</i>	Joule
<i>kW</i>	Kilowatt
<i>kWh</i>	Kilowatt Hour
<i>kWp</i>	Kilowatt Peak

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1

Introduction

1.1 Introduction

Israel has experienced considerable economic and population growth in the past two decades from 4.66 M inhabitants in 1990 to 7.62 M at 2010. This 40% growth rate

entails an average growth of 2% a year (Shaffer, 2011). At the same time, Israel's Gross Domestic Product (GDP) grew at a rate of 4.5 percent per year (CBS, 2009a). The ability of the energy-supply system to meet the ever-growing demands of Israel's booming economy, particularly with respect to electricity is one of the main priorities of the government (Israel-Government-Decision-4450, 2009).

In recent years reservoirs of natural gas of significant volume have been found in the Mediterranean Sea off the coast of Israel (Shaffer, 2011). However, the Israeli energy market is still dependent upon external sources of energy as Israel's total primary energy production is still lower than its primary energy demand and remains so to this day. Thus, Israel must rely heavily on fuel imports to meet its growing energy needs (EIA, 2013). The electricity demand requires extensive use of fossil fuel that in turn pollutes the atmosphere with large quantities of greenhouse gas. This phenomenon occurs not only in Israel, but throughout the world.

As the global economy continues to grow, worldwide energy consumption has grown by 2.5%, a figure which roughly corresponds with average global economic growth over the last decade (BP, 2011). During the same period global emissions of carbon dioxide (CO_2) the main cause of global warming increased by 3% in 2011, reaching an all-time high of 34 billion tonnes (Olivier et al., 2012).

With regard to CO_2 emission, Israel is ranked 56th in the world, out of 191 countries, pumping 79.8 million tons of CO_2 into the atmosphere annually. This accounts for 0.21% of global CO_2 emissions (BP, 2011). Yet, Israel is 28th in the world in terms of per capita emissions, with each Israeli emitting on average 11.5 tonnes of CO_2 . Israel's per capita emissions are about the same as those of other small developed nations like Austria, Greece, and South Korea (Sterman, 2009). More troubling, Israeli emissions of CO_2 continue to grow. In 2006 Israel emitted almost 74 million tonnes of greenhouse gas, a 17% increase over 1996 emissions. Research commissioned by the Israeli government and conducted by the "McKinsey" Consulting Firm projects that under this "business as usual" scenario GHG emissions in 2025 will be 63% higher than the 2000 levels (McKinsey and Company, 2009).

GHG emission and the projected scarcity of fossil fuel have strengthened the need to promote Renewable Energy (RE). Deployment of solar photovoltaic (PV) electricity could play a crucial role in helping Israel meet its energy commitments while at the same time ensuring security of supply and reducing dependency upon energy imports.

There are also economic and technical reasons motivating a transition towards a low carbon economy such as: (a) Energy independence; as of 2009, Israel relied on external imports for meeting most of its energy needs (the majority of electricity production is generated using imported coal). Israel spends more than 5% of its GDP per year on imported energy products (Shaffer, 2011). (b)Economic development: Israel has the potential to be a global leader in the market for solar energy technology with a climate promising hours of sun on an almost daily basis and a relatively small country that can be used as a research laboratory for new technologies. Developing a local market for these goods, increasing the number of employees in the RE sector, and exporting this technology could have an important effect upon the Israeli economy. (c) Climate change is a high priority on the global agenda. In September 2010 Israel joined the Organization for Economic Co-operation and Development (OECD). As a member of this partnership, Israel must align itself with other member states in achieving a 10% reduction in greenhouse gas emission by 2020. In addition, GHG emission also has an economic aspect. GHG reduction reduces the number of respiratory diseases (Haines et al., 2010), thereby increasing the number of working days and decreasing the number of hospitalisations.

1.2 Israel Energy Policy

Israel has historically led in the use of solar energy for domestic purposes. Israel's interest in solar water heaters began even before 1948 when the nation gained its independence. Today more than 85% of the houses in Israel employ solar water heating

systems (Stermann, 2009; Kreith and Goswami, 2007). However, since its pioneering efforts to develop rooftop solar water heating, Israel has done little to develop a renewable energy industry that can both substantially reduce its GHG emissions as well as increase the amount of energy available.

In 2009, the government of Israel set 2020 as the target date for generating at least 10% of its total electricity demand from renewable energy sources (Israel-Government-Decision-4450, 2009). The decision requires the construction of power plants that generate not less than 250 MW each year by 2010. Although many programmers have been written, little has been done in practice to implement the policy. At present only about 0.1% of the country's electricity supply comes from renewable energy sources (Yaniv, 2010).

With regard to RE policy in Israel, in 2008 the first regulative FIT framework was introduced for small scale PV systems setting a quota of 50 MW for residential consumers (for systems up to $15kW_p$, there is a quota of $15MW$) and for commercial consumers (systems up to $50kW_p$, there is a quota of $35MW$). In December 2009 the quota for small-scale commercial consumers was exhausted and in August 2010 a new quota of 120 MW was introduced along with an unlimited quota for residential consumers. A new 2011 governmental decision has set a quota of 110 MW for 2012-2014 (Israel-Government-Decision-250, 2009).

Israel has been considered a world leader in research and development of solar energy technology, a place where much innovative research and companies specialising in RE are located. Moreover, environmental conditions such as high solar radiation and the number of daylight hours that allow increased production of energy using photovoltaic systems obtain, but for some reason Israel has failed to produce PV generated electricity on a large-scale as has been done in Italy, Germany, and China (BP, 2011).

The United Nations Environment Program (UNEP) European Regional Director Christopher Bouvier called it the Israeli Paradox; "*While Israel was the foremost exporter of solar technology in the world and an incubator for solar technologies, it was last in*

actual production of electricity from solar energy”, said Mr. Bouvier (Zion, 2009). Contrary to the global trend, which has instituted rapid investment, development, and deployment of renewable energy over the past decade, Israeli efforts to promote domestic use of renewable energy have been minimal and most Israeli engineering has been in the sphere of technological innovation, rather than in evaluation and implementation.

The global photovoltaic technology market

Over the past five years, global annual installation of photovoltaic (PV) systems has grown at a rate of 60% per year (EPIA, 2011). In 2012, the 100 GW mark was reached and by 2013, almost 138.9 GW of PV had been installed globally an amount capable of producing at least 160 terawatt hours (TWh) of electricity every year. With regard to the European market, Europe with 81.5 GW as of 2013 remains the world’s leading region in terms of cumulative installed capacity (EPIA, 2014). This rapid worldwide growth has been driven by declining prices of PV systems, state and federal incentives, and other forms of policy support (Candelise et al., 2012). In addition, improvements in technology and economies of scale have spurred steady cost reduction. This trend should continue into the near future as the PV industry approaches competitiveness with conventional energy production (Couture and Gagnon, 2010; Candelise et al., 2012). This impetus includes Israel as well where the installation of PV systems has jumped by more than 600% to 190 MW in 2011 as compared to only 3 MW in 2008 (Siderer, 2012). This growth is due to government subsidies, such as Feed-In- Tariff (FIT) and green certificates. These policies were established to stimulate growth of the PV market and bring it to maturity. The spur in price reduction was necessary to make PV generated electricity cost competitive without the subsidies that are still required throughout most of the world. Under the right policy conditions PV generated electricity can continue to advance toward competitiveness in key electricity markets and become a mainstream energy source. However, determination of the correct subsidy is not simple due to the conflict of interest between investors and the general public. Investors wanting to maximise their profits through sales of electricity produced by PV systems, while the general public underwrites the subsidy through

indirect taxes such as increases in conventional electricity rates. This conflict needs to be settled by government policy encouraging renewable energy electricity production and the government should be the sole party determining the level of subsidy. This thesis addresses just those policy issues.

1.3 Aim and Objectives

Aim

Achieving solutions for today's environmental problems requires long-term planning for sustainable development. Renewable energy appears to be the one of the most efficient and effective solutions for the Israeli market. This research aims to define the potential capacity for deployment of solar energy in Israel in order to reduce energy dependence, overcome increasing GHG emissions, and promote a low-carbon economy. The objectives of the research are both to devise an approach and to design models to maximise renewable energy output, contribute to a national electricity supply, and provide guidelines based upon financial policy scenarios that promote low-carbon energy technology in Israel.

Objectives

The main objectives of this research are:

1. To define environmental conditions and technical factors that affect solar energy generation in small-to-medium sized cities in Israel
2. To estimate the electricity generation capacity of PV solar systems including calculation of losses due to atmospheric and meteorology conditions in PV systems in Israel.

3. To define appropriate policy in terms of financial incentives and subsidies so as to expand the solar energy market in Israel.

To meet the goals of this research, two mathematical models were developed. The first one, called the TEA Model is based upon atmospheric and meteorological parameters and defines available electricity capacity and electricity losses. The second model is a financial policy model which minimises government subsidies and maximises return for investors. The results obtained in the TEA model are the input data for the total energy generation capacity in Israel. The objectives of the mathematical models are to (1) identify present barriers to development of Renewable Energy Technology (RET) in Israel, especially with regard to the regulatory environment. (2) To optimise the capacity and transmission of intermittent solar energy technology and storage technology to achieve the least cost production for the maximum expansion capacity. (3) To illustrate how the technology can be implemented, which technology can be used, and what the environmental impact will be. (4) To find the optimal FIT for electricity generation from solar energy systems that will balance public interest with investor profits.

1.4 Research Contribution

The literature while containing many publications that focus on the electricity generation potential of solar panels. (Häberlin et al., 1998; Kimber et al., 2006; Kymakis et al., 2009; Thevenard et al., 2010) it is more limited with respect to solar energy generation in Israel. Nevertheless, thorough studies were undertaken in the last decade most of them focusing on the general potential of electricity production (Faiman et al., 2000, 2004) or on the available area of electricity production by PV systems such as Vardimon (2011). However, none of these studies takes into account anthropogenic contribution to air pollution or economical parameters as this research does. These factors are necessary for estimating both the amount of energy that can be generated in Israel and its cost to investors and the government in its subsidy for that kind of

energy production. Moreover, the methodological approaches of Linear Program (LP) modeling, Monte-Carlo Simulation, and Linear regression that have been implemented in this research are unique. They have never been used before as an applied model for decision-makers or policy-makers. These models neutralise external factors influencing decision-makers and maximise the profitability of renewable energy electricity production both to investors and the government through a set of mathematical tools.

Therefore, the first contribution of this research is its methodological approach for the assessment of potential PV electricity deployment in Israel. The value of this research to the scientific community is:

(a) The specific analytical focus on PV technology in Israel and the effect of specific atmospheric parameters upon electricity generation (b) Its exploration of the issue of PV loss due to dust and aerosols using a mathematical model (c) Its use of an integrated environmental and financial approach to PV technology deployment.

Another contribution is the policy analysis. The use of linear programming and Monte Carlo simulation to determine the optimal FIT in Israel is unique to this study. Most of the current literature examines payback periods based on just a few assumptions concerning costs and revenue. This research takes into account many more parameters, such as uncertainties in the PV market, changes in electricity prices, changes in loan size, interest rates, etc. All of these parameters are input into a mathematical model that optimises the FIT. Given that PV systems have been on the market for 20 years or more, and a large number of factors affect the economic viability of this kind of product, this model is able to determine the current optimal FIT that will cover any future scenario containing different types of uncertainties.

The last contribution is the environmental analysis which calculates GHG reduction as a result of use of photovoltaic systems employing mathematical models that compare use of fossil fuel emissions and PV system emissions in order to determine the environmental contribution and GHG reduction accruing from use of PV systems in Israel, a potentially useful by-product of the research.

In summary, the innovative aspect of this study is that the decision-making models take into account factors that had not been considered together before, but that could have a decisive influence on the uptake of the right solar energy technology. The models examine the impact of atmospheric data and the way that environmental and economic indicators affect electricity generation capacity. In addition, the research details electricity consumption based on different policy incentives scenarios.

1.5 Structure of the Thesis

This research focuses on the potential role of PV technology within the Israeli electricity grid and analyses the conditions for its successful deployment, both in terms of technology and governmental action. Implementation of mathematical models to evaluate generation electricity capacity as well as determining a solution for the economic problem of the appropriate level of subsidy are the basis of this research.

The thesis is structured as follows:

- **Chapter 1- Introduction:** discusses the background research, describing the photovoltaic market both worldwide and in Israel in particular. It also describes the role of environmental policy in Israel and the problem of deployment of RE policy. The last section of the chapter defines the goals and the objectives of this research and the contribution it makes toward the understanding of the issue.
- **Chapter 2- Methods:** describes the research methodology which includes a literature review, technical assessment of PV, and the models that have been designed and implemented in this study. Measurement and data collection are described as well. The data used in this research were drawn mainly from ground-based stations of the Israeli Meteorology Services (IMS), the Ministry of Environmental Protection (MEP), and atmospheric data from NASA.

- **Chapter 3- Literature review:** The section first introduces the problem of rising energy demand, especially in urban environments. It then presents additional literature on global electricity consumption and global and local GHG emission. The section also reviews technological solutions for GHG emissions and focuses in particular on photovoltaic systems, justifying the use of solar energy in Israel. It describes the technical features of renewable energy, the factors affecting solar radiation and the manner in which electricity is produced in PV systems. The third section of the literature review analyses computer tools and models for PV systems. The computer models optimise the capacity and dispatch of solar energy technology and neutralise external factors influencing decision-makers when determining the level of FIT. This section reviews the existing models and the research that has been done using other models.

- **Chapter 4- Renewable energy and Environmental Policy in Israel:**

This chapter is divided into three sections; (a) resources (b) supply and demand and (c) renewable energy policy.

The first part of the chapter presents the resources of the electrical energy market. It also includes a special review of the Natural Gas (NG) market in Israel and the anticipated effects of the recent discovery of NG. In the last five years an Israeli company (Delek Energy) in cooperation with an American company (Noble Energy) has found large gas reservoirs along the Mediterranean coast (see 20). These discoveries are dramatically changing the energy balance and future electricity costs in Israel. Since these discoveries directly affect energy production and the RE market in Israel, these matters are reviewed here.

The second part of the chapter deals with supply and demand of the energy market including electricity consumption in the past and the present with projections for the future. The last part of the chapter reviews renewable energy and climate change policy in Israel. This includes international treaties that Israel has signed from the Kyoto Protocol of 1997 to the Copenhagen Conference in 2009. In addition, it also reviews Israeli governments goals with respect to implementation of RE and steps undertaken to achieve it.

- **Chapter 5- TEA Model:** The aim of this chapter is to build a mathematical

model (TEA Model) that can assess electricity generation by a PV system based on atmospheric parameters. At the beginning of the chapter the background and different techniques for assessing performance of PV systems are presented. Then, the TEA model is presented including its methodology, equations, and assumptions. The model uses primary data collected from eight local stations of $50kW_p$ that were installed in Israel between 2010-2012. Finally, the model's results with regard to capacity for electricity generation and the conclusions are presented.

- **Chapter 6- Policy chapter:** The chapter concentrates on Israeli governmental policy regarding FITs which effectively started in 2008. The first part of the chapter introduces the Israeli FIT policy framework and the cost reduction of PV systems. It presents the imbalance tariffs for electricity produced by PV systems between 2010-2012 in relation to the cost of PV systems. Then the chapter presents an innovative way to find the optimal FIT using a numerical model. The model is based on number of economic parameters such as: Net Present Value (NPV), Internal Rate of Return (IRR), interest rate, loan rate, and historic data on the price of 412 PV systems installed in Israel during 2010-2015. The model uses linear programming to find the optimal FIT using historical data on system costs. In addition, the model runs multiple scenarios of future technology prices, using Monte-Carlo simulation to reduce uncertainties inherent in the photovoltaic market. The last part of the chapter discusses results and conclusions drawn from the model for future optimal FIT.
- **Chapter 7- Discussion & Conclusion:** This chapter analyses the research results. Starting with the results obtained by the TEA model regarding the capacity for PV electricity generation in Israel and the corresponding reduction in GHG due to the use of PV system. It then finds the optimal FIT based on the Linear Program (LP) model including the imbalance tariffs from 2010-2015. In addition, it presents the uncertainties in the market of photovoltaic energy capacity and discusses the way in which this study deals with it. The chapter also includes research limitations and further work with respect to PV system analysis and policy analysis.

2

Methods

2.1 Introduction

This study touches upon a variety of issues ranging from PV technology to atmospheric conditions, electricity generation, and public policy as well as the specific conditions obtaining in Israel for PV deployment.

The variety of factors and a multidisciplinary approach seems to be the most appropriate way to provide a comprehensive picture of the factors affecting electricity generation and PV deployment in Israel.

The methods entailed in this study include: 1. A literature review, 2. Technology assessments, 3. Analysis of technical data, and 4. Policy analysis for FIT. This section does not describe the methodology, which is detailed in Sections 5.5 and 6.4)

2.2 Literature Review

The literature review assesses available research and highlights relevant gaps in those studies. It provides of a clear view of the state-of-the art in PV system efficiency, Greenhouse Gas (GHG) emission, and computer tools for solar systems. The literature review includes secondary sources and non research sources such as governmental decisions and technical reports.

2.3 Technology analysis

The technology assessments of photovoltaic identify electricity generation capacity, system losses, and GHGs reduction. The technology analysis constitutes a new approach to the problem combining three different methods: (1) Collection of primary information on five atmospheric measures, (2) Design of a multi-linear regression that elucidates the correlation between the atmospheric parameters and electricity production, and (3) statistical analyses of reduction in GHG following use of a PV system.

2.3.1 Sources for PV performance, meteorological and atmospheric data

The methodology draws upon information relating to atmospheric, technical, and environmental factors affecting the quality and quantity of electricity that can be generated by PV systems (Chapter 5 details the modeling methods developed).

Primary data on PV performance across Israel was obtained from eight registered $50kW_p$ PV stations controlled by Inbar PV Systems, Ltd. "Inbar" builds, maintains, and operates more than 100 PV solar systems in Israel. All information was provided voluntarily for purposes of research only.

The data was obtained over the course of three years (Jan. 2010 Dec. 2012) from sunrise to sunset. Measurement is based on average hourly data.

2.3.2 Measurement of Atmospheric Parameters

In addition, seven atmospheric parameters Particulate Matter (PM), Nitrogen Dioxide (NO_2), and Aerosol Optical Thickness (AOT), as well as meteorological parameters such as wind speed, solar radiation, and temperature were measured over the same period. The meteorological and atmospheric information was donated by the Israeli Meteorological Services (IMS), the Israeli Ministry of Environmental Protection (MEP), and NASA.

2.3.3 Multi-Linear Regression (MLR)

Multi-Linear Regression (MLR) is a statistical technique using several explanatory variables to predict the outcome of a response variable. The goal of MLR is to model the relationship between explanatory and response variables.

In this research the MLR technique is used to determine the impact of each one of the atmospheric and meteorological factors upon electricity generation capacity by PV systems in stations in Israel.

The MLR was conducted by the software program, *Eureqa* that implements multi-regression using genetic programming and the analytically functions of a training data-

set (Schmidt and Lipson, 2009). The linear regression allows us to determine the impact of each one of the atmospheric and meteorological factors that impinge upon the electricity generation capacity of a PV system.

2.3.4 Statistical calculations

An additional calculation forecasting the environmental contribution and impact of use of PV systems upon total GHG emission in Israel was made . To obtain these figures, a comparison between electricity production by fossil fuels (conventional electricity production) and that produced by PV systems was undertaken. Figures on GHG emission resulting from the use of fossil fuel electricity production are based upon statistical data obtained from the IEC (Israel Electric Corporation) and the Israeli Central Bureau of Statistics (CBS). Data on GHG emission as a result of the use of PV systems are based on the literature (Sherwani et al., 2010), which details average emissions over the life cycle of a PV system.

2.4 Policy analysis

The intention of the approach to policy analysis was to uncover long-term actions for sustainable development. Implementation of these actions should lead to widespread use of solar energy technology, prevent market failures in the energy sector, and maximise profits for private investors. However, use of this approach should take into consideration country specific conditions.

The specific economic conditions in Israel that affect the use of PV systems consist of such variables as Net Present Value, internal return rate, annual yield, and return on investment. The technical variables consist of system performance, electricity capacity, and PV loss. In addition, the method of payment for electricity generation by PV systems in Israel must also be considered.

In order to implement this multi-factor approach, a numerical model which calculates all the variables and takes into account a large number of possible scenarios was employed (see 6).

This model determines the level of payment for renewable energy based electricity production. The results are posited upon future scenarios of the cost of technology, changes in the electricity market, construction costs, interest rate changes, and the percentage of the loan undertaken by entrepreneurs.

2.4.1 Policy Analysis Scenarios

Factors affecting PV system profitability vary not only between end user, technology type, and location but can also change due to policy corrections and technological developments (Candelise, 2009). Scenarios are therefore developed to reflect this multiplicity of possible outcomes. In particular, the model simulates scenarios of the following parameters: PV systems prices (technology price), electricity prices, Engineering Planning & Consulting (EPC) prices and FIT prices. In addition, the model uses different types of loans and different interest rates.

2.5 Summary

Table 2.1 describes where the data was collected at all stages of research so as to elucidate differences in source, type, and nature of the data. The Figure shows the path of data transfer and how results obtained in a previous section allow the next level of research to proceed.

Finally, Figure 2.1 shows the methods and approaches applied in each chapter. This Figure shows the path of data transfer between the chapters and how any result ob-

tained in a previous section allows the progress the next level of the research.

Table 2.1: Type, description and the sources of data

Type of Data	Indicators	Source of Data
Met. & Atmos ^a Data	Solar Radiation	MOA ^b , Met-Office
	AOT	NASA ^c
	Wind Speed	Met-Office
	Temperature	Met-Office
Economic Data	O & M	Literature
	Land costs	Literature
	Feed in Tariff	Literature
	PV system costs	Literature
Technical Data	Electricity production using PV systems	IES ^d
	PV efficiency	Literature
Electricity Data	Past electricity demand	MNI ^e , CBS ^f
	Current electricity consumption	PUA, MNI
Environmental Data	GHG's emissions	Literature
	GHG's emissions costs	Literature

^a Meteorological & Atmospheric

^b MOA-Ministry of Agriculture

^c NASA-National Aeronautics and Space

^d IES-Inbar Solar Company Ltd

^e MNI- Ministry of National Infrastructures

^f CSB- Central Bureau of Statistics

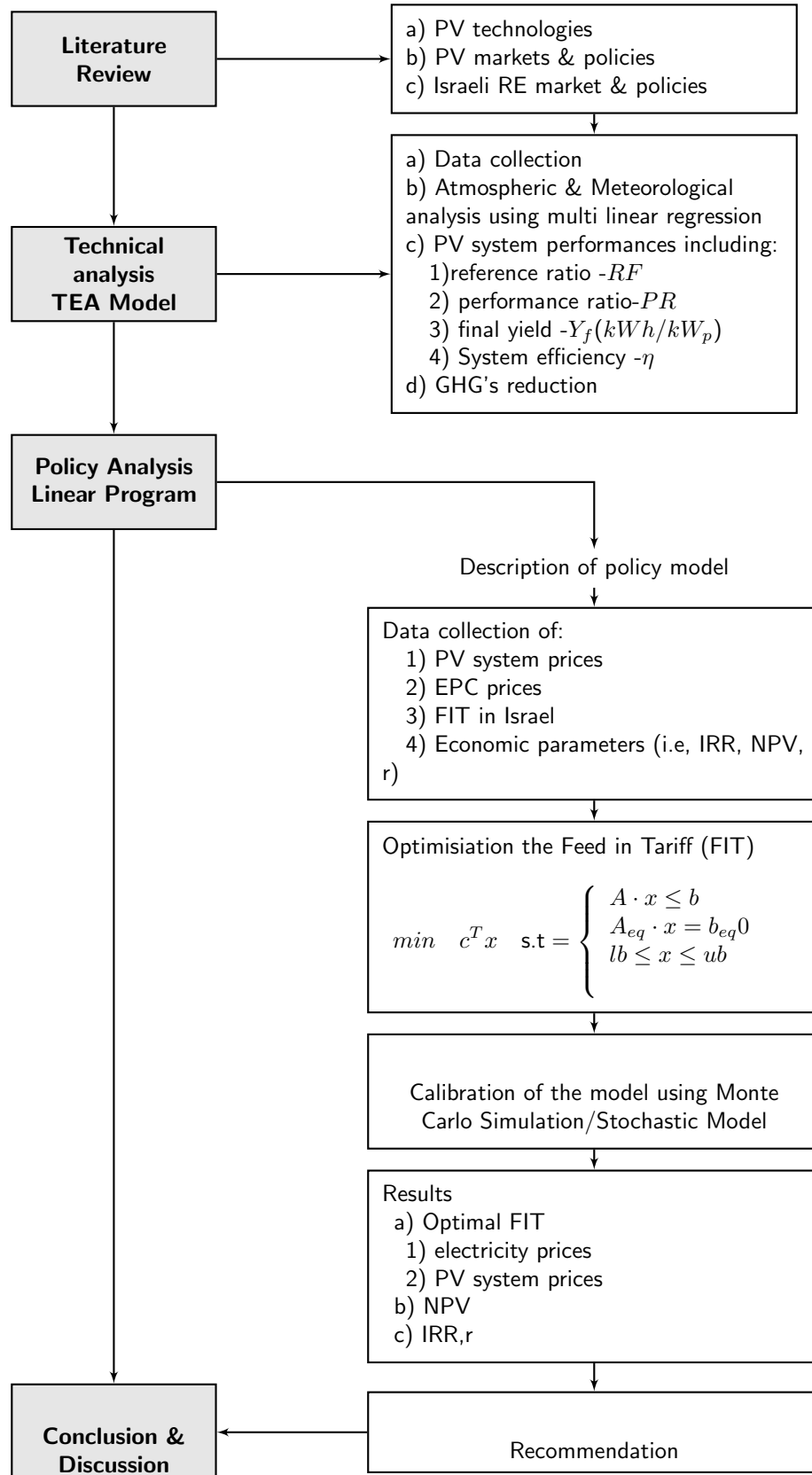


Figure 2.1: Flowchart and the transfer of information between the various chapters throughout the research

3

Literature Review

3.1 Introduction

In both developing and emerging countries fossil fuel is the main energy source for meeting the ever increasing demand for electricity from the industrial, domestic and transportation sectors. Based on figures from the Energy Information Administration (EIA, 2010a) current use of large quantities of fossil fuel together with forecasts for increased growth in global demand for energy raise two important concerns: First, the

availability of oil and coal to cover the increasing demand and second, the damaging effect of pollution from fossil fuel combustion upon the global atmosphere and regional environments. These concerns are particularly relevant for Israel, a country that relies on imports of raw material for power generation to provide for its ever increasing energy demand.

Renewable energy technology, an alternative to fossil fuel combustion has been increasingly considered as an option for overcoming shortages in fossil fuel, improving energy access, and reducing GHG emissions and air pollution. However, due to reliance upon variable local natural resources such as sun and wind, renewable energy technologies are not without their problems. Hence production capacity using these technologies can vary according to daily, seasonal, and annual conditions. Moreover, solar and wind energy technology have only been implemented on small or very large scales and less is known about how renewable energy technologies work on a medium-to-small scale. Scale is important because many cities in the Middle East, and in Israel in particular, are classified as small- to medium-size and it is just these sized cities whose energy requirements are expected to increase (CBS, 2009b). Nevertheless, switching to renewable energy is not simple because many factors such as atmospheric conditions, price, current and future demand come into play. The choice of an appropriate energy system for urban areas is important because any decision affecting energy supply impacts not only the public, but also future characteristics of the region's potential economic growth as well as the quantity of CO_2 emission.

This chapter discusses current and expected global energy consumption and demand, examining the most dominant environmental consequences of burning fossil fuel over the past decades. It also analyses how global energy demand has impacted the Middle East and Israel in particular, indicating whether available information is sufficient to estimate Israel's potential for implementing renewable solar energy technology.

The chapter also discusses energy and electricity provision for urban areas in both developed and developing countries and stresses CO_2 emissions originating in cities. The chapter's third section analyses the experience of alternatives to fossil fuel for

electricity generation in cities, highlighting gaps in information and experience with renewable energy in small- to medium-size cities. Finally, the chapter reviews the appropriate tools for decision-making, considering the advantages and disadvantages of each tool in order to determine what is lacking

3.2 Global and Regional Energy Consumption and CO_2 emission

In 2010 primary global energy consumption grew by 5.6%, the largest percentage increase since 1973. While consumption in OECD countries grew by 3.5%, the strongest growth rate since 1984, the level of OECD consumption remains in line with that of 10 years ago. However, Non-OECD consumption grew by 7.5%, which is 63% above the 2000 level (BP, 2010).

Population increase and income growth are the two most powerful forces driving the global demand for energy. Since 1900 world population has more than quadrupled, while real income has grown by a factor of 25. In line with this income and population push, primary energy consumption has increased by a factor of 22.5. In 2010, worldwide consumption of fossil fuel for primary energy amounted to approximately 11×10^9 million tons of oil equivalent (BP, 2010). Accompanying this marked increase in global energy consumption, CO_2 emissions resulting from fossil fuel-sourced energy use have grown at their fastest rate since 1969.

Worldwide energy consumption is projected to increase by 53% between 2008 - 2035 with much of the increase being driven by strong economic growth in China and India (EIA, 2010b). As a result of the continued rise in population in the developing world, the next 20 years are likely to see rapid growth of low and medium-size economies. Per capita energy consumption from the present until 2030 is likely to increase at about the same 1970-1990 rate (i.e., 0.7% p.a.), (EIA, 2010a). forcing nations to find alternatives to fossil fuel so as to meet this energy demand.

Energy consumption between 2010-2015

Energy consumption in the developing world *

Energy consumption in the developing world will be 68% higher by 2030 compared to 2010. This level account of averaging 2.6% p.a. growth and accounts for 93% of global energy growth. However, OECD energy consumption in 2030 is just 6% higher than today, with growth averaging 0.3% p.a. to 2030 (see Figure 3.1) (BP, 2011).

Israel & Regional context

Based on the Energy Information Administration (EIA), electricity generation in the Middle East region is projected to grow by 2.5 percent per year, from 0.7 trillion kWh in 2008 to 1.4 trillion kWh in 2035 (EIA, 2010b). The region's young and rapidly growing population, along with a projected strong increase in national income is expected to produce even greater demand for electric power. The Middle-East depends upon natural gas and liquid petroleum to generate most of its electricity and that pattern is projected to continue through 2035. In 2008, natural gas supplied 59% of the electricity generation in the Middle-East, while liquid fuel supplied 35%. By 2035, the share of natural gas is projected to be 75% while the share of liquid fuel is projected to be only 14%. In the Middle-East other energy sources have made only minor contributions to electricity supply. Israel is the only country in the region that uses significant amounts of coal to generate electric power (EIA, 2010a).

With the continuing increase in demand for energy, most countries, both in the developed and in the developing world, are looking for ways to reduce dependence on fossil fuels in electricity production and by doing so, reduce the emission of pollutants into

*The phrase Developing world refers to Non-OECD countries. For consistency, OECD includes all members of the organization as of September 1, 2010. As Israel became a member only on September 7, 2010 its statistics are not included in this report

the atmosphere.

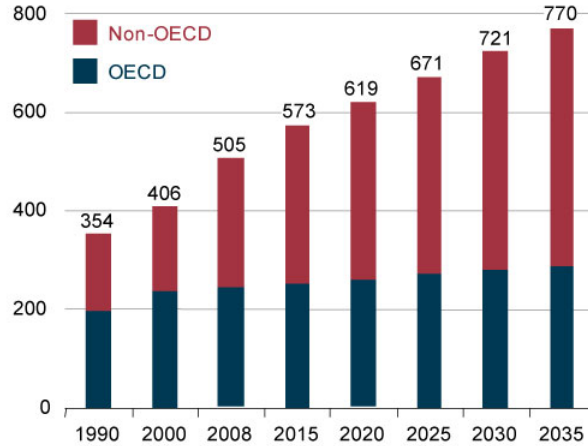


Figure 3.1: Non-OECD and OECD economies energy consumption 1990-2030. Source: (BP, 2011)

3.2.1 Fossil fuels and renewable energy market

Fossil fuel still has an economic advantage over renewable in spite of the trend in rising fossil fuel prices and the corresponding decrease in cost of renewable energy due to improvements in productivity and economies of scale (EIA, 2010b; Candelise, 2009). Price, economic development, and energy policy (the promotion of energy efficiency) play important roles in determining the energy technology used and obtaining the energy required to support continued economic growth (REN21, 2010).

As of 2010, about 16% of final global energy consumption came from renewable technology, with 10% coming from traditional biomass, which was mainly used for heating, and 3.4% from hydroelectricity. New renewable (small hydro, modern biomass, wind, solar, geothermal, and biofuel) accounted for just 2.8% of global energy consumption, but this sector is growing rapidly (REN21, 2010). In 2014, global primary energy

consumption increased by just 0.9%, a marked deceleration over 2013 (+2.0%) and well below the 10-year average of 2.1%. Growth in 2014 slowed for every fuel other than nuclear power, which was also the only fuel to grow at an above-average rate. Oil remained the world's leading fuel, with 32.6% of global energy consumption, but lost market share for the fifteenth consecutive year. The percentage change in renewable generation was somewhat slower than in 2012, despite record annual renewable deployment of nearly 123 gigawatts (GW) (BP, 2014).

Among renewable energy sources, solar photovoltaic capacity was added in over 100 countries during 2010, ensuring that PV remains the world's fastest growing power-generation technology. Worldwide an estimated 17 GW of PV capacity was added (compared to just under 7.3 GW in 2009), bringing the global total to about 40 GW, more than seven times the capacity that was in operation five years earlier (REN21, 2011).

In the Middle-East where many different types of renewable energy sources (RES) are available, the use of renewable energy has become a significant issue, not only for investors but also for governments. While there are many different sources of renewable energy (like geothermal, biofuel and tidal energy) on which to draw, in the Middle-East wind and solar energy are both more available and more accessible than any other type. The rapidly increasing demand for electrical energy and the high restriction on pollution levels have led to increasing interest in large-scale utilization of renewable energy in Morocco, Egypt, Israel, and Saudi Arabia (Mostafaeipour and Mostafaeipour, 2009).

3.2.2 Renewable energy market 2010-2015

Renewable energy technologies have become mainstream sources of energy, supported by targets and policies a key factor in order to develop a success and health market. Since grid parity has not achieved yet in most countries, and the economical advantages are not clear yet, the governments should continue their support of this market.

Luckily, most countries have enacted policies to regulate and promote renewables in the power generation. Strategies to promote renewable energy evolve and expand in many countries (REN21, 2015). In 2014, the European Union established new regulations governing the energy sector beyond 2020, setting a region-wide goal of a 27% renewable energy share by 2030 (Littlecott et al., 2014). Targets for renewable energy deployment were identified in 164 countries as of early 2015. In 2013, global renewable electricity generation rose by an estimated 240 terawatt hours (TWh) to reach nearly 5,070 TWh and accounted for almost 22% of total power generation (IEA, 2014). In 2014, solar power was the leading sector compared to other renewable energy sectors, in terms of money committed, accounting for USD 149.6 billion, or more than 55% of total new investment in renewable power and fuels. From this amount about 90% of solar power investment went to solar PV accounted for USD 135 billion (REN21, 2015).

3.2.2.1 Forecast of renewable energy generation

There is increasing awareness that in order to provide needed energy services in a climate-constrained environment, future energy systems need to be resilient and to maintain service under unpredictable conditions or climate changing (Christersson et al., 2015).

Therefore, the role of renewable energy in general and solar energy in particular play as decisive key-factor in future energy generation.

Despite recent falls in the cost of PV electricity, transitional policy support mechanisms will be needed in most markets to enable PV electricity costs to reach competitive levels. Appropriate regulatory frameworks and well-designed electricity markets, will be critical to achieve the vision increasing renewable energy generation. Based on the IEA assessments, over the medium term, global renewable electricity generation is projected to grow by almost 45%, or 2,245 TWh, to over 7,310 TWh in 2020 (+5.4% per year). Hydropower, including output from pumped storage, represents about 37%

of total growth, followed by onshore wind at 31% of the total growth see Figure 3.2 (IEA, 2014).

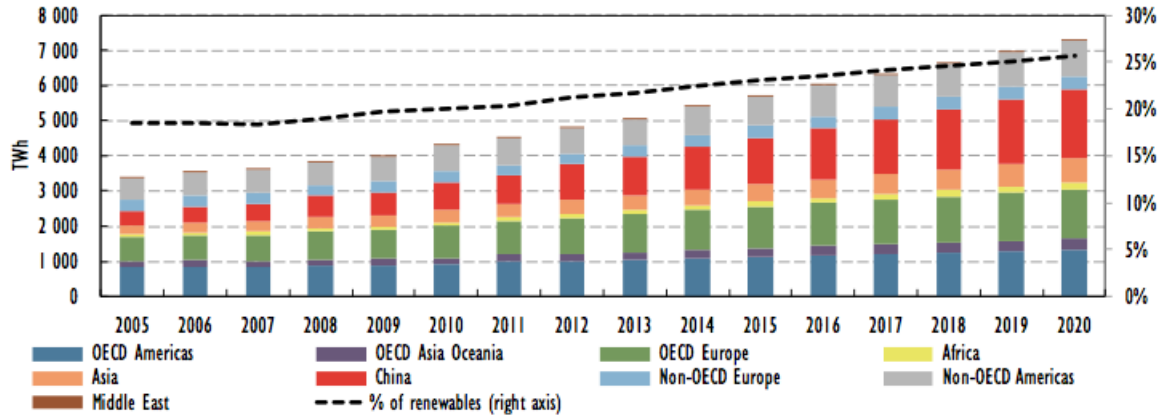


Figure 3.2: Global renewable electricity production by region, historical and projected. Source: (IEA, 2014)

3.2.3 Global and Regional Emissions

Greenhouse gas is an atmospheric gas that absorbs and emits radiation within the thermal infrared range. The primary greenhouse gases in the Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide, and ozone (Tans and Keeling, 2011).

Man-made greenhouse gases are derived from many sources such as: industry, transportation, reneries, agriculture, etc. Measurements by the Intergovernmental Panel on Climate Change (IPCC)) indicate constant growth in global greenhouse gas emissions between 1970 and 2000 (see Figure 3.3). The largest growth in CO_2 emissions is attributed to power generation and road transport, with industry, household, and service sectors maintaining the same approximate level as those measured between 1970 and 2004. The main factor contributing to atmospheric greenhouse gas are power plants whose growth rate has been greater than 70%. (Rogner et al., 2007).

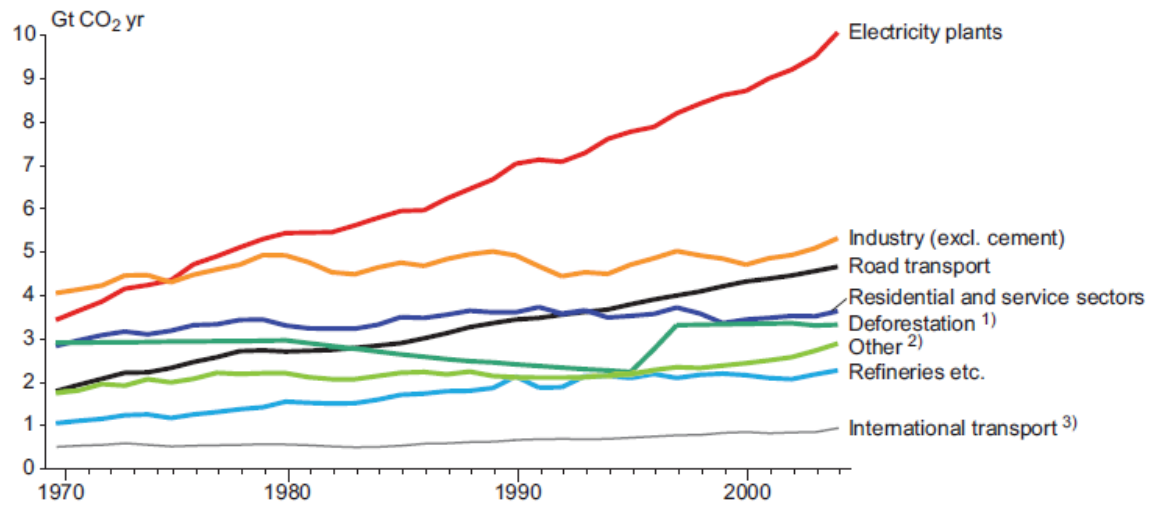


Figure 3.3: Sources of global CO_2 emissions, 1970-2004.

1. Including fuel-wood at 10% net contribution,
2. Other domestic surface transport, non-energetic use of fuels,
3. Including aviation and marine transport. Source: (Rogner et al., 2007)

Per capita emissions in industrialised countries are typically as much as ten times the average of developing countries. Due to China's fast economic development, its per capita emissions are quickly approaching the levels of those in the Annex I group of the Kyoto Protocol (Developed Countries). Other countries with fast growing emissions are South Korea, Iran, and Australia. While this is occurring in the developing world, per capita emissions by the EU-15 and the USA are gradually decreasing (Grubb et al., 2011).

In 2007, Israel emitted more than 76 million tons of greenhouse gas per year (CO_2 equivalent), ranking it 56th in the world in terms of emissions per capita, a rise of 20% since 1996 (CBS, 2009b; IEC, 2009). In contrast to the OECD countries whose greenhouse gas emissions are slowly decreasing, Israel's emissions are expected to increase under its "business as usual" scenario, largely due to the increase in its population (mostly through immigration) and its rise in standard of living (MEP, 2009; McKinsey and Company, 2009). Fuel combustion accounts for about 76% of Israel's greenhouse

gas emissions, of which 56% originates in electricity and energy production (42 million tons) and another 20% in vehicular emissions. Carbon dioxide is the main component of greenhouse gas emissions in Israel (87%), followed by methane which is largely emitted by landfills and nitrous oxide which is largely generated by agriculture and industry (IEC, 2009).

3.3 Energy Consumption in Cities

Cities with their high concentration of population and economic activity have become hot spots for energy demand and GHG emissions. By the end of the first decade of the 21st century more than half of the world's population lived in cities. This shift of population to cities is expected to increase even more in the next 50 years (Lin et al., 2010). In addition, more than 95% of the net increase in the global population will be in the cities of the developing world, which will approach the 80 industrialised nations today (Grimm et al., 2008).

Cities consume as much as 80 percent of energy production worldwide and account for a roughly equal share of global greenhouse gas emissions. As development proceeds, GHG emissions are driven less by industrial activities and more by the energy services required for lighting, heating, and cooling. Urban areas currently account for over 67 percent of energy-related global GHG, which is expected to rise to 74% by 2030. It is estimated that 89% of the increase in CO_2 from energy use will be from developing countries (IEA, 2008).

3.3.1 GHG emission, global warming and the urban environment

More than twenty years ago, a regression analysis examining the association between level of GHG emission and population size in 59 developing countries found that a 10% increase in population increased per capita energy consumption by 4.5%

(Jones, 1991).

Shi's 2003 research into energy use between 1975 and 1996 in 93 countries using level of affluence as a variable found that over the last two decades population growth has been a major driving force behind increasing carbon dioxide emissions worldwide and that on average a 1% increase in population was associated with a 1.42% increase in CO_2 emissions (Shi, 2003).

In examining the link between population size and emission of environmental pollutants in 86 countries during the period 1975 - 1998 Cole and Neumayer (2004) found that a 10% increase in urbanisation increases CO_2 emissions by 7% (Cole and Neumayer, 2004).

One of the best documented examples of anthropogenic climate modification is the Urban Heat Island (UHI) effect: cities tend to have higher air and surface temperatures than their rural surroundings, especially at night when wind which might disperse the heat is weak (Grimm et al., 2008).

Seasonally, UHI is seen during both summer and winter. The size and location of the city is crucial to the rate of temperature change (Oke, 1973). Studies also show that even in small cities the phenomenon persists. Oke (1973) shows that in a town of 1000 residents, the typical Urban Heat Island (UHI) effect is in the range of $2^{\circ}C$ to $2.5^{\circ}C$.

The main cause of the urban heat island is modification of the land surface by urban development that uses materials which effectively retain heat (Alpert and Kishcha, 2008). So collective changes in land cover and land use have an impact upon climate change.

With regard to Israel, Saaroni et al. (2000) tested changes in air temperature between the centre of the city of Tel-Aviv and its surrounding areas. Detection of the Urban Heat Island (UHI) was performed on rooftops and at the street level. The results showed variations from $3^{\circ}C$ to $5^{\circ}C$ between the city centre and the surrounding areas

(Saaroni et al., 2000).

A subsequent approach used satellite observations to characterise physical modifications resulting from urbanisation. In this study researchers used the Moderate Resolution Imaging Spectrophotometer (MODIS) satellite to get a better understanding of the climate impact of urbanisation (Jin et al., 2005). Their findings confirm that city centres act like heat islands. They found that city centres are 2.7°C to 5.1°C hotter than the rural areas surrounding them (Jin et al., 2005).

Hua et al. (2008) investigated the impact of urbanisation upon air temperature across China. They found that the strongest UHI effect reached 0.74K in winter over a large city. Furthermore, the cities with strong UHI effects were mainly located in regions that were undergoing rapid industrialization and economic growth (Hua et al., 2008).

Zeng et al. (2010) used MODIS images from 2005 to generate land surface temperature and surface characteristics for the Changsha-Zhuzhou- Xiangtan metropolitan area in China for three different seasons. They found that UHI effects were significant both in summer and in spring. Rural areas were 8°C to 10°C cooler than those in the city centre (Zeng et al., 2010).

3.3.2 Global and Local Dimming

Human activity and big cities have been linked not only to climate change but also to Global Dimming, the reduction in the amount of direct global irradiance from the Earth's surface that is probably due to increased presence of aerosols and other particulates in the atmosphere that are generated by human use and that absorb solar energy and reflect it back into space.

Year-to-year variation in annual radiation flux during the 25-year period 1964 - 1989

indicates that the larger the population the stronger the decline in surface solar radiation. In cities with a population density greater than 10 person/ km^2 , surface solar radiation decreased from $-0.05W/m^2/yr$ to $-0.32W/m^2/yr$ (Alpert and Kishcha, 2008).

The above mentioned studies suggest that urbanisation along with rapid economic development and population growth are causing dramatic changes in the environment especially in city centres. These are across-the-board changes and can be identified in many large cities such as small urban regional.

Temperature increases associated with increasing urbanisation and economic growth is a fact that should be considered early on in urban development planning by local authorities. Aside from improvements in energy efficiency, there are various technologies that can play a significant role in mitigating the intensity of climate change while satisfying electricity demand. These technologies include solar, wind, geothermal, biomass and clean fossil technologies. Climate change policy, if integrated into other governmental policies can contribute to sustainable economic growth in both developed and developing countries (Rogner et al., 2007; Gupta et al., 2007).

3.4 Computer Tools for Solar Energy Systems

The dramatic growth of PV systems in the last century (EPIA, 2011), has generated a need for sophisticated tools and mathematical models that can assess PV system electricity generating capacity and economic benefit. These tools have a similar basis for determining the amount of electricity generation in a given area for a given technology. The similarity includes their meteorological components: solar radiation, wind speed, temperature, and number of hours of daylight. All models calculate the amount of energy that can be generated in order to examine the economical feasibility of the system. This chapter reviews five main models that are in use by the majority of planners and the academic institutions across the globe: HOMER, EnergyPlan, RETscreen, ORCED

and LEAP. Each one of the models reviewed has been downloaded or purchased by more than 30,000 users.

3.4.0.1 HOMER

HOMER is a computer model that simplifies assessment of renewable energy used by a single-building, a local community, or a single-project. NERL started development of HOMER in 1993 and it has subsequently been used by corporations, NGO's, academic institutions and government agencies. HOMER allows planners to compare many different design options with respect to their technical and economic merit. It also assists in understanding and quantifying the effects of uncertainty or changes in inputs (Lambert et al., 2006).

3.4.0.2 EnergyPLAN

is a computer model for hour-by-hour simulations of complete regional or national energy systems including electricity, individual and district heating, cooling, industry and transportation (Lund, 2011)

3.4.0.3 ORCED

the Oak Ridge Competitive Electricity Dispatch (ORCED) model dispatches the power plants in a region to meet the electricity demands for any given year up to 2030. The model simulates a single region of the country for a given year, matching generation to demands and its be able to calculate a number of key financial and operating parameters for generating units, such as the average and marginal prices and generation adequacy (Hadley, 2008).

3.4.0.4 RETScreen

is a comparison tool between a base case, typically the conventional technology, and a proposed case study which is typically the clean energy technology. The comparison includes all costs and a number of economic index i.e. internal rate of return (IRR) and net present value (NPV). The software can be applied to any energy-system, ranging from individual projects to global applications. All thermal generation and renewable technologies can be accounted for using RETScreen and it can incorporate energy efficiency measures relatively easily (Thevenard et al., 2000; Connolly et al., 2010).

3.4.0.5 LEAP

is a software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute. LEAP is an integrated modelling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy. In addition, its designed around the concept of long-range scenario analysis. Using LEAP, policy analysts can create and then evaluate alternative scenarios by comparing their energy requirements, their social costs and benefits and their environmental impacts(Lazarus et al., 2008).

3.4.1 Summary of computer tools

HOMER primarily focuses on stand-alone applications of renewable energy, such as a single-building or a local community rather than on integrated systems. When the objective is to simulate a fully renewable energy system without a grid connection supply EnergyPLAN or LEAP are more appropriate than HOMER. EnergyPLAN uses time-steps of one hour or less, whereas LEAP employs annual time-steps. EnergyPLAN is the most effective tool for optimisation of renewable energy technology for the residential sector while RETScreen which includes all aspects of the heat and electricity

sector facilitates integration of renewable energy throughout the combined heat and power system. ORCED simulates dispatch of electricity from generator to end-user (Connolly et al., 2010). While all these tools analyse the electricity sector, there is considerable variation in the objectives of each tool.

None of the tools presented above has been adjusted for Israel in a satisfactory manner. Data used to calculate production capacity do not take into account the atmospheric conditions that prevail in Israel. While the calculations do consider annual average solar radiation and temperature, they do not take into account atmospheric optical thickness (AOT), which is the level of ground level pollution and losses in electricity generating capacity resulting from pollutants settling upon the photovoltaic panels.

3.4.2 Multi-criteria modelling: SURE-DSS

In coining the term Sustainable Livelihoods (SL) Chambers and Conway (1992) were referring to "A livelihood comprising the capabilities, assets and activities required for a means of living; a sustainable livelihood is one which can cope with and recover from stress and shocks, maintain or exchange its capabilities and assets, and provide sustainable livelihoods opportunities for the next generation, and which contributes net benefits to other livelihoods at the local and global levels and in the short and long-term" (Chambers and Conway, 1992). The SL approach has been adopted by the Food and Agricultural Organization (FAO) of the United Nations, the International Fund for Agricultural Development (IFAD), and UNDP (see e.g., Helmore and Singh, 2001), the World Food Programme of the United Nations (WFP). While the World Bank has never adopted the SL framework in its entirety, it does share some of the core principles of SLA in its policy (Fylaktos, 2010).

In 1997 the UK Department for International Development (DFID) published a White Paper on strategies to eliminate world poverty. According to the DFID people should be in the centre, by understanding people's priorities and livelihoods strategies. Based on the schematic presentation of the framework devised by Scoones (Scoones, 1998),

DFID produced its own framework to help understanding and analysis Figure 3.4. This representation has been widely utilised by other organisations trying to employ the SL approach (Hussein, 2002).

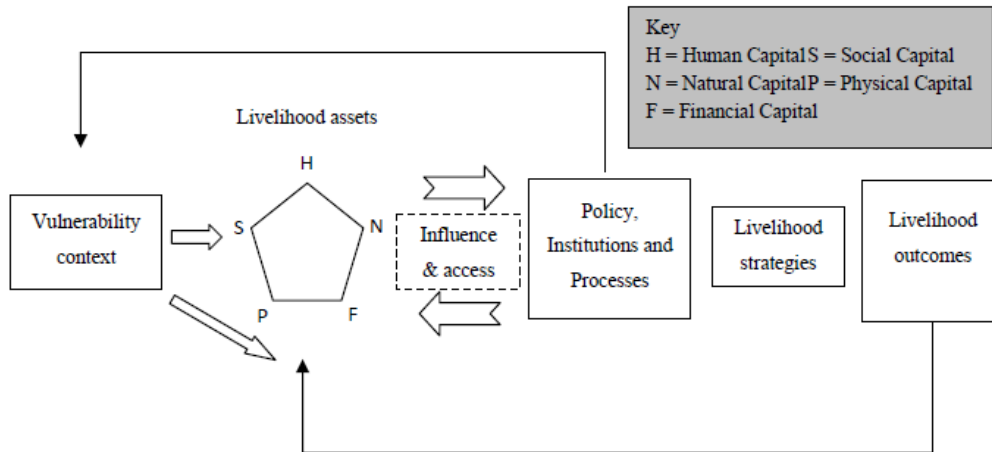


Figure 3.4: The Sustainable Livelihoods Framework according to DFID (2001)

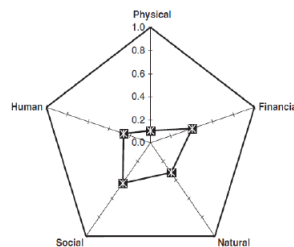


Figure 3.5: SL assets pentagon showing current (inside rectangle) and ideal (outer perimeter) accumulation of assets, Source: (Cherni et al., 2007)

Meikle and Bannister (2003) apply the Sustainable Livelihoods (sl) framework when assessing the interaction between energy and poverty in an urban environment. They also find SL to be a very useful in analysing the macro-meso-micro energy linkages, and the energy-poverty relationship (Meikle and Bannister, 2003). An alternative approach to all these types of analysis and models is presented by Cherni et al. (2007).

Their SURE model focuses on future energy development as a basis for enhancing rural livelihoods. Combining quantitative and qualitative criteria, the SURE approach enables the priorities of a group of prospective users to be considered in the analysis, unlike other existing rural energy decision-making software. The authors use the SL assets pentagon to represent the distance travelled from the centre of the pentagon, (figure 3.5) to its outer edge (Cherni et al., 2007).

The centre point of the pentagon represents zero accumulation of assets, a practically non-existent minimum since even the most deprived households possess some assets. The outside perimeter represents a theoretical measure that indicates maximum access to the assets depicted. SURE, the methodological package developed to use this idea calculates the initial asset state of a community (called the baseline) and using a multi-criteria decision approach forecasts the benefits of different energy solutions so as to find the best asset situation (Cherni et al., 2007).

This approach is noteworthy not only because it incorporates the formal SLA framework, but also because it tries to quantify the effects of energy on a given community (Fylaktos, 2010).

This approach is particularly suitable for poor rural areas where an electric system is non-existent. In these cases, this method could be significant in selecting the most appropriate technology using the above-mentioned parameters. In contrast to the SURE approach which aims at selecting optimum renewable energy solutions for enhancing energy supply in poor rural areas, the current study aims at designing larger power systems that can be implemented in modern small- to medium-sized cities. However, while the SURE tool itself is not suitable for the current study, its multidisciplinary approach is particularly relevant for prospective solar development in medium to small cities. So this thesis does draw upon its approach. In addition to a comprehensive assessment of the technical capacity of photovoltaic to generate electricity in urban contexts, the models designed here incorporate additional parameters: atmospheric, climate change-related emissions, financial, and regulatory information.

3.4.3 GIS Models for Solar Energy

Geographical Information System (GIS), is a system designed to capture, store, manipulate, analyse, and present all types of geographical data. The development of a solar energy planning system, consisting of a methodology and decision support software for planners and energy advisers is based upon customised geographic information. With respect to applications of photovoltaic systems in cities, most studies use GIS software combined with sophisticated algorithms in order to assess the total irradiation in a specific region so as to maximise utilisation of solar energy within urban areas. In addition, various simulation models and computer programs have been deployed to predict solar irradiance of buildings and increase the uptake of solar energy systems in urban areas. Mardaljevic and Rylatt (2003) detail a novel approach for evaluating total annual/monthly irradiation incident upon building facades in urban settings (Mardaljevic and Rylatt, 2003). Compagnon (2004) presents a method for quantifying the potential of urban facades and rooftops for active and passive solar heating, photovoltaic electricity production, and daylighting. The outcome of the research purports to indicate the fractions of the total facade or roof area that could make various kinds of solar energy techniques feasible. This method is expected to provide more detailed knowledge for planning effective solar cities. (Compagnon, 2004).

Izquierdo, and Rodrigues (2008) estimate the potential of roof-integrated photovoltaic systems based upon land use, population, building densities, and a statistically representative stratified sample of vectorial GIS maps. This method allows for definition of the roof area available for solar applications, the basic idea of which is to define appropriate representative building typologies in a specific area. This approach is particularly useful because the data together with their geographical distribution assist in determining the most efficient course for implementing an energy policy based upon solar-sourced electricity generation on buildings. However, limitations such as inclination, location, shading, plus the quality of the input data determine the relation between built-up and available roof-top area and this may influence the quality of the results. (Izquierdo et al., 2008).

Hofierka and Kanuk (2009) propose a methodology for assessment of photovoltaic potential in urban areas using open-source solar radiation tools and a 3-D city model implemented in a GIS. The applicability of the methodology has been demonstrated in a selected urban area of a small city in eastern Slovakia where it was found that contemporary PV technology can provide about two-thirds of the current electricity consumption in the city evaluated (Hofierka and Kanuk, 2009). Finally, Wiginton et al. (2010) demonstrate techniques for merging the capabilities of GIS and object-specific image recognition to determine the available rooftop area for PV deployment in south-eastern Ontario, Canada. Available rooftop area was estimated using a five step procedure: (1) sampling using Feature Analysis extraction software, (2) extrapolation using roof area-population relationships, (3) reduction for shading, (4) other uses and orientation, and (5) conversion to power and energy outputs. They find that 30% of Ontario's energy demand could be met by province-wide rooftop PV deployment (Wiginton et al., 2010).

The latest novel approaches, as discussed above are essential for evaluating the total irradiation and future ability of using solar technology in urban environments. However, these studies are not directly applicable to conditions in Israel because: (1) In Israel, most rooftops already have solar water heaters (SWH), thereby reducing the available rooftop area for PV systems. Hence, this situation requires a different GIS software calculation of the available rooftop area. (2) Israel has special characteristics distinguishing it from other countries in terms of irradiation and atmospheric conditions making the input data required different from that used in the above mentioned studies. (3) The articles cited above describe electricity demand in the region researched as a given. None of the studies deal with anticipated increase in demand for electricity as a consequence of population growth and growth in electricity consumption.

3.4.4 GIS Models for Solar Energy in Israel

PV modules are characterised under Standard Test Conditions (STC). These are: a light intensity of $1000W/m^2$, a module temperature of $25^{\circ}C$ and certain well-defined

spectral conditions designated $AM1.5$ (Luque and Hegedus, 2003). However, In Israel, the STC are almost never existing. the module temperature would normally be considerably higher than $25^{\circ}C$; perhaps even $50^{\circ}C$ in winter and $70^{\circ}C$ in summer. This means that in Israel a PV module would almost never operate at conditions that approximate STC because in most days panels' temperature would be greater than $25^{\circ}C$ (Faiman et al., 2000)

At present only two major works have employed GIS software to evaluate the total rooftop area available for PV use in Israel. The first study conducted by Faiman (2007) from the Ben-Gurion University in the Negev Desert estimates the total rooftop area of all residential buildings in Israel as follows: (a) assume an average family consisting of 4 persons living in an apartment of $80m^2$ floor area, in a 4-stories building, (b) the amount of roof area per person is $5m^2$ and (c) multiply this figure by the approximately 7 million, the population of Israel. Based on this calculation the total estimated residential roof area is $\approx 35km^2$. Since rooftops generally contain all sorts of structures and equipment (such as Solar Water Heaters (SWH)), only 10% of the total residential roof area would be unshaded and available for PV uses (Faiman, 2008).

In contrast to this methodology, Vardiomon (2011) assesses the available rooftop area in Israel using a complete set of GIS data covering the entire country and classifying all buildings in Israel by building type, size, town, and nationwide. Only buildings in seven categories that seem suitable for solar system installations are analysed (see Table 3.1). Based on Vardimon's study, the yearly electricity production potential when all rooftops are considered with only 30% of the rooftop area available for PV use is 15.9 T W h or 32% of the current national electricity demand (50.1 T W h). In addition, if only rooftops with areas higher than $800m^2$ are taken in consideration and only 50% of the rooftop area is available for PV use, the annual potential for electricity production is 3.3 TWh which is only 7% of current national electricity demand. (Vardimon, 2011).

However, even these studies are not a good fit for solar energy applications in medium-size cities because: (1) The ratio between the number of people living in private houses

Table 3.1: Total rooftop area and average rooftop area of all buildings summed up by building type

Building Type	Total Area (km^2)	Average area (m^2)
Residential	188.7	195
Industrial	24.0	954
Agricultural	23.8	393
Warehouse	6.5	35
Public	4.1	870
Educational	2.6	495
Mall	1.7	1064
Total	251.5	201

Source: Vardimon (2011)

to those living in high rise buildings is higher compared to the ratio in large cities, so the available area on residential rooftops and public buildings in small- to medium-size cities needs to be adjusted. (2) As mentioned above, it is necessary to check other parameters such as population growth, socio-economic status, economic implications, and atmospheric factors in order to determine implementation of solar energy in medium-size cities.

3.5 Conclusion

Population and income growth are the two most powerful driving forces behind the demand for energy. Cities with their high concentrations of both population and economic activity have become hot spots for energy demand and GHG emissions. This trend will only increase in the next 50 years. This review of the scientific literature regarding application and implementation of renewable energy in the urban environment highlights factors which could play a significant role in mitigating the intensity of climate change and reducing GHG emissions. Nevertheless, it also indicates that some critical information is still missing.

An examination of the best technology to be implemented in Israel should be based on the unique conditions prevailing there from the meteorological as well as the economic and social points of view.

None of the computer tools and planning models reviewed can be used for this study as it is impossible to insert additional dimensions such as: population growth, future increase in electricity consumption, and some specific atmospheric variables which this present research deals with.

4

Energy Market in Israel

4.1 Introduction

The objective of this chapter is to present the situation of Israel with regard to energy consumption, energy resources, and the government stance on renewable energy. Israel's situation is unique in the region because its energy reserves are relatively small and the amount of energy produced almost completely covers energy consumption. In addition, due to the sharp increase in both living standards and population growth as compared to the other countries in the OECD, Israel's increased electricity consumption goes against the declining trend in Western countries.

This chapter is divided into three sections; (a) resources, (b) supply and demand, and (c) renewable energy policy. The first section reviews the Israeli electricity market and its characteristics. The discussion of Israel's energy resources includes a special review of Natural Gas (NG), an energy resource discovered only in the last few years of exploration in the Mediterranean Sea.

The second section presents the role of supply and demand in the energy market which includes past and present consumption of electricity as well as projections for future use in both the household and industrial sectors.

The third section reviews government policy with regard to renewable energy. This includes the history of RE and an examination of public policy affecting climate change since Israel achieved independence in 1948 up to the present. It also includes a survey of regulatory bodies dealing with RE in Israel, RE tariffs, mandated goals set by the Israeli government to be in effect by 2020 as well as an overview of R& D relevant to the Israeli RE market.

4.2 Conventional Energy Resources in Israel

The Israeli electricity sector over the last decade has experienced rapid growth and constant demand (IEC, 2012). Israel's installed electricity capacity of 12,000 megawatts is based almost exclusively on fossil fuel (see Figure 4.1).

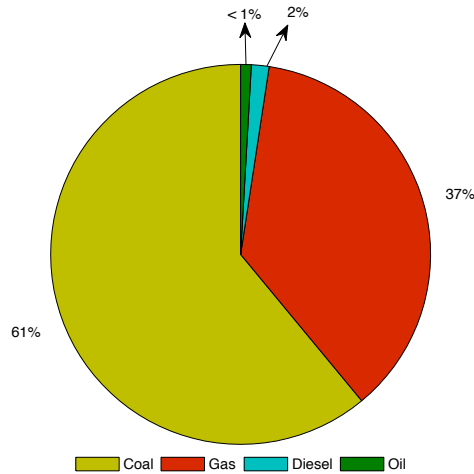


Figure 4.1: Electricity generation using fossil fuels in Israel, Source (IEC, 2012)

Total primary energy production relies heavily on imports to meet energy needs. Total primary energy consumption in 2011 was 285.5 TWh (0.974 quad), or 24.5 Mtoe (million tonne of oil equivalent) (EIA, 2013). In 2010 it was 45.59 TWh, while production was 53.55 TWh, generating a net export of 3.78 TWh (CIA, 2010). The installed generating capacity in 2009 was about 12 GW, almost all from hydrocarbon fuel plants, mostly coal and gas. Renewable energy accounts for a minor share of electricity production, with a small photovoltaic installed capacity. However, there are over 1.3 million solar water heaters installed as a result of mandatory solar water heating regulations.

4.2.1 Coal in Israel

The coal supplied to the Israel Electric Corporation (IEC) is obtained from Australia, South Africa, Columbia, Poland, and Russia. Coal purchased in accord with IEC requirements includes various types differentiated by composition of carbon, hydrogen, oxygen, and organic compounds. IEC purchases are made solely through reliable and established coal suppliers in the international coal market. The IEC handles coal

transportation from source countries to the two coal power stations in Hadera and Ashkelon based on contracts with shipping suppliers for leasing Panamax and Cape Size bulk carriers, each featuring a cargo capacity of approximately 80,000 and 170,000 tons, respectively (MITL, 2012). The IEC continuously strives to develop new sources of coal.

4.2.2 Oil in Israel

The Oil & Gas Journal estimates Israel's proven oil reserves as of January 2014 at 11.5 million barrels and its proven reserves of natural gas at 10.1 trillion cubic feet (Tcf). While neither figure places Israel in the top 40 globally, these totals are significantly higher than they were a few years ago (Mor, 2014).

Over 80% of oil imports are crude oil. In 2012, the majority of Israel's imports of crude oil came from Russia and Azerbaijan via tanker vessels. Israel plans to reduce its dependence upon oil imports through an expansion of its rapidly-growing natural gas sector.

Israel exports small quantities of refined products, but with domestic production being almost non-existent, imported oil meets nearly 99% of total demand. Export of refined petroleum products grew from approximately 66,000 billion barrel/day in 2000 to 84,000 billion barrel/day in 2010, with residual and distillate fuel oil accounting for approximately half of exports over that period (Mor, 2014).

4.2.3 Natural Gas in Israel

For most of its history, Israel was an energy-poor state, relying almost completely upon imported fossil fuel for its energy needs. Due to the conflict with most of its neighbours, Israel is an "energy island, unlinked to the energy infrastructure of neighbouring states,

with the exception of gas supplies from Egypt. However, Israeli energy independence has changed dramatically since mid-2000.

The eastern Mediterranean has recently experienced a "gas revolution." Historically, only limited exploration activity resulted in modest discoveries of hydrocarbon resources. However, the region is now a new frontier for onshore gas exploration in the Middle East and North Africa (MENA) (Darbouche et al., 2012). While a decade ago, the Israeli natural gas market was virtually non-existent, once the "Yam-Tethys" reserves went on-line in 2003 and a natural gas importing agreement was signed in 2005 with Egypt everything changed. Syria, Lebanon, and Israel have been engaged in offshore exploration for fossil fuel over the last few decades. Cyprus, by contrast, only began exploring hydrocarbon resources relatively recently. Since 1948, Israel has placed great emphasis upon exploration of potential energy resources from any source in order to reduce its dependence upon energy imports from other countries. Currently, Israel holds the longest record for hydrocarbon exploration in the region (Darbouche et al., 2012).

Initial gas finds were modest, with a breakthrough discovery in 1999 of some 32 BCM in the "Noa" and "Mari-B" fields off the Israeli coast (Shaffer, 2011). Another gas discovery was made by the BG Group in 2000 off the coast of the Gaza Strip. The outlook for gas production in the eastern Mediterranean region has been radically transformed since the discovery of large onshore reservoirs of natural gas. Between January 2009 and June 2010, licensing groups led by Noble Energy and Delek Group discovered natural gas fields of an estimated combined size of up to 810 BCM (29 Tcf), distributed between two large and three small to medium fields (see Table 4.1). In January 2009 a large gas reservoir was discovered in drilling "Tamar A" 90km west of Haifa. In March 2009, an additional discovery of natural gas was reported in "Dalit 1", 60km west of Hadera (Even, 2009). Nearly 3.1 Trillion Cubic Feet (TCF), of high-quality gas are estimated to be in both drilling sites. The gas is located at a depth of 4.9 km in an area 140 meters wide. The value of the gas is estimated at \$40 billion (Fendel, 2009).

In June 2010 the largest natural gas field, Leviathan located 135 km off northern Israel near Haifa was discovered. It has with a gross mean resource estimate of between 460 to 566 BCM (17-20 Tcf) found at a depth of 1.6 km (Darbouche et al., 2012).

Field	Date discover	Estimate Reserved (TCF)	First Gas Planned
Leviathan	2010	17-20	2016
Tamar	2009	9.7	2013
Aphrodite	2011	3-9	2017
Tanin	2012	1.2	—
Mari-B	2000	1.1	2004
Noa	1999	0.04	2012
Gaza Marine	2000	1	—
Dalit	2009	0.35-0.5	2013
Dolphin	2011	0.08	—
Simshom	2012	0.27-0.55	—

Table 4.1: East Med Gas Discover

These discoveries joined previous gas discoveries in the Mediterranean off the coast of Ashkelon and have ensured continued development of the natural gas sector (Even, 2010).

4.2.4 The role of NG in the electricity market

Since the start of production at Yam Tethys in 2005, natural gas has been part of the Israeli energy mix. Although its share in total primary energy supply is still well below that of oil and coal, the share of natural gas has risen sharply, reaching 16% in 2009. Israel's policy shift towards greater reliance on natural gas is due in part to the rising price of oil and coal. Moreover, environmental concerns about use of fossil fuel for power generation and Israel's commitment to international GHG emission agreements have resulted in a sharp increase in use of natural gas.

This growth in gas demand is likely to accelerate as a function of increasing electricity

demand. The Ministry of Energy and Water Resources expects consumption of natural gas to increase from about 5 BCM in 2010 to 12.5 BCM in 2020 and to 18 BCM by 2030, with 85% of gas used for electricity generation and industrial use (Darbouche et al., 2012). These projections are based on assumptions that electricity consumption will grow at an average of about 3% annually, use of heavy fuel oil in the power sector will be minimal, reliance upon coal power stations will remain the same as it is in the present, and renewable energy resources will reach the mandated 10% level by 2030 (Israel-Government-Decision-4450, 2009). These projections are based upon the assumption that by 2014 natural gas will become the primary fuel for electricity generation, reaching 60% of the power mix and 68% by 2040. The IEC's original opposition to having natural gas constitute more than 50% of the fuel mix so as to avoid over reliance on one source of fuel has been withdrawn (Shaffer, 2011) (see Figure 4.2).

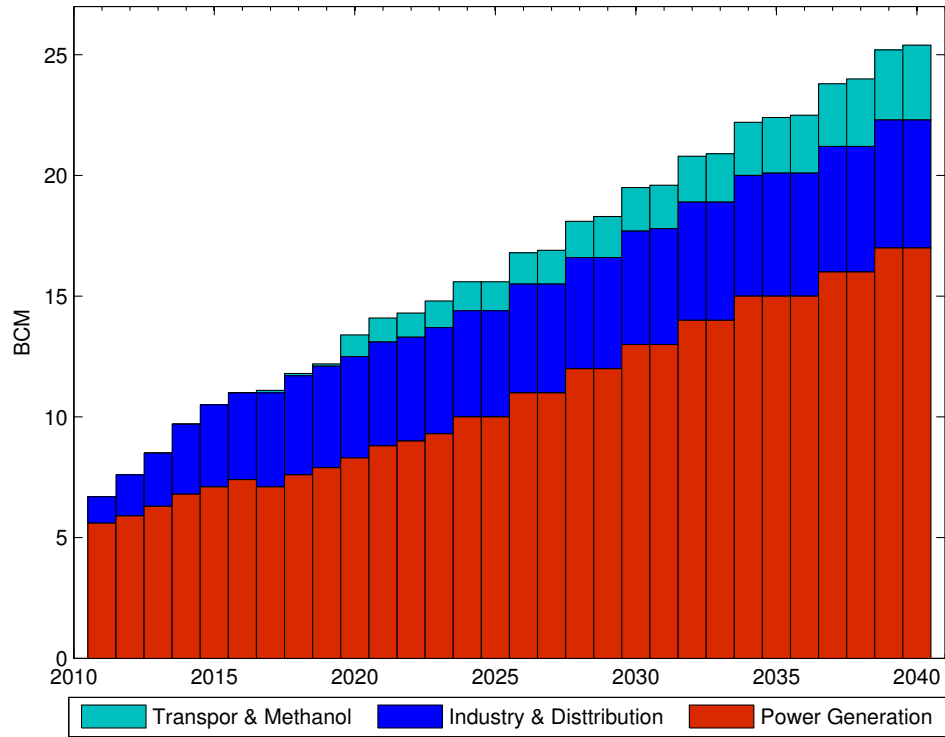


Figure 4.2: Israel Natural Gas Demand Forecast, no Coal Conversion and 10 % production by RES by 2040.

(Source: MNI 2012)

4.3 Supply and Demand for Energy

While experiencing relatively high economic growth rates, the Israel electricity market has not followed the trend of most of Europe countries toward declining energy intensity and greater energy efficiency. For example, Israel's per-capita energy usage has increased by 44% since 1990, while the EU average increased by only 15% (Mor and Seroussi, 2007). Israel's electricity consumption in 2007 was 49,323 Million kWh, 30.5% of which was residential, 29% was for the public and commercial sector, 22.7% was for industry, and 17.8% for the Palestinian Authority (see Table 4.2) (IEC, 2007).

Moreover, in the Middle East region Israeli electricity consumption is high when compared to that of Egypt, Cyprus, Greece, Lebanon, and Jordan. Electricity consumption per capita (kWh/capita) in several selected countries for 1990- 2010 is presented in 4.3 (Group, 2012).

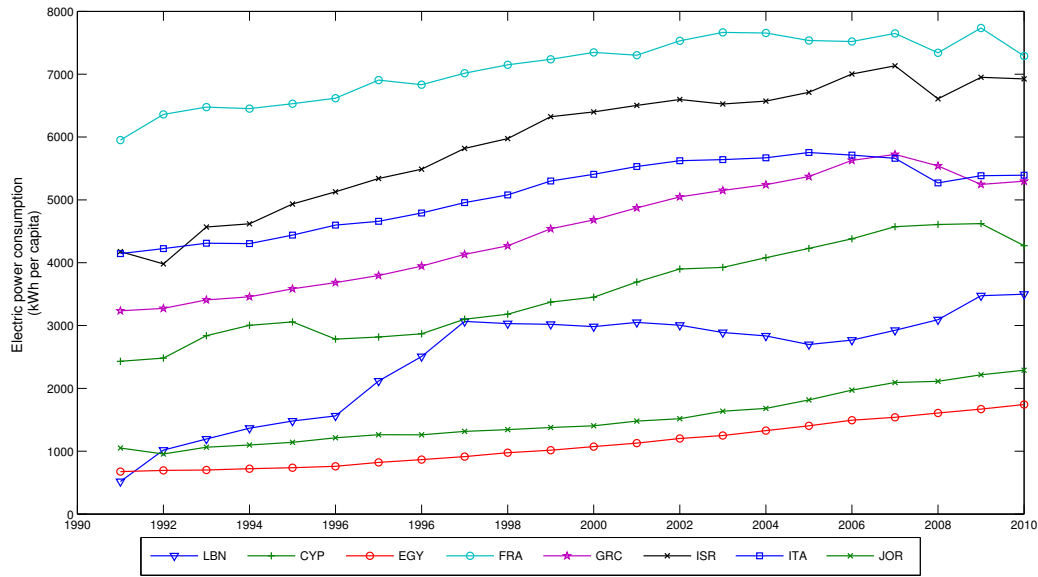


Figure 4.3: Electricity consumption in selected countries in the region between 1990-2010. Source: (World Bank, 2012)

With regard to the distribution of power in Israel from 1997 - 2009, there was a sharp increase in all sectors of electricity consumption: 137%, 158%, and 195% in the private sector, industry, and the Palestinian Authority, respectively along with an increase of 160% in the total electricity consumption. However, in 2007 -2008 the increase was only 1.7%. The global economic recession of 2008 hit all sectors but with different intensity. In 2009 consumption in the industrial sector fell by 7.9% and consumption in the agriculture sector fell by 7.5% as compared to 2008. (see Table 4.2). Total electricity consumption in 2009 decreased by 2.4% as compared to 2008. The only sectors that experienced increases were the public sector with an increase of 0.8% and

Table 4.2: Electricity consumption by sector between 1997 and 2009 (Million kWh)

Year	Res.	Public	Agri.	Ind.	Water P.	P.A & E.J	Total
1997	9513	7674	1397	8115	2356	1767	30822
1998	10080	8581	1488	8439	2511	1925	33025
1999	10296	9400	1561	8604	2318	2119	34298
2000	11873	10297	1603	9314	2318	2386	37791
2001	12319	11017	1584	9232	2202	2312	38665
2002	12747	11586	1621	9423	2242	2300	39920
2003	13365	11999	1674	9728	2501	2454	41721
2004	13517	12508	1701	9880	2728	2598	42933
2005	13719	13083	1699	10237	2708	2863	44309
2006	14313	13785	1755	10387	2838	3097	46175
2007	15049	14766	1852	11178	3021	3457	49323
2008	15201	15499	1827	11218	2749	3666	50161
2009	15117	15625	1690	10329	2404	3783	48947
1997	+9.5	+10.1	+5.2	+5.4	+2.6	+10.2	+7.8
1998	+6.0	+11.8	+6.5	+4.0	+6.5	+9.0	+7.1
1999	+2.1	+9.5	+4.9	+1.9	-7.7	+10.1	+3.9
2000	+15.3	+9.5	+2.7	+8.3	+0.0	+12.6	+10.2
2001	+3.8	+7.0	-1.2	-0.9	-5.0	-3.1	+2.3
2002	+3.5	+5.2	+2.4	+2.1	+1.8	-0.5	+3.2
2003	+4.8	+3.6	+3.2	+3.2	+11.6	+6.7	+4.5
2004	+1.1	+4.2	+1.7	+1.6	+9.1	+5.9	+2.9
2005	+1.5	+4.6	-0.1	+3.6	-0.7	+10.2	+3.2
2006	+4.3	+5.4	+3.3	+1.5	+4.8	+8.2	+4.2
2007	+5.1	+7.1	+5.5	+7.6	+6.4	+11.6	+6.8
2008	+1.0	+5.0	-1.4	+0.4	-9.0	+6.1	+1.7
2009	-0.6	+0.8	-7.5	-7.9	-12.5	+3.2	-2.4

Res.=Residential, Agri.=Agricultural, Ind.=Industrial, Water P.=Water Pumping and P.A & E.J=Palestinian Authority & East Jerusalem

At the bottom of the table given the annual change in percentage

Source: IEC, 2009

the Palestinian Authority with an increase of 3.2%. According to the BP annual report this trend was typical not only of Israel, but of primary energy consumption worldwide including oil, natural gas, coal, and nuclear fell by 1.1% in 2009, the first decline since 1982 and the largest decline in percentage terms since 1980 (BP, 2010).

4.3.1 Electricity Generation in Israel

Since 2004, the Israeli energy market has been moving toward a dramatic change in terms of fuel mix when intensive use of natural gas. This annually increasing component is expected to rise with development of the natural gas reserves in the Mediterranean Sea (see Section 4.2.3 on page 64). Figure 4.4 shows the Israeli fuel mix for electricity generation, 2001 - 2011. Up to the end of 2011 less than 1% of total electricity generation was produced by renewable energy sources. Based on MNI forecasts for 2030, 80% of total electricity generation will be by fossil fuel (65% natural gas and 15% coal), and 20% will be generated by renewable energy sources (MNI, 2010).

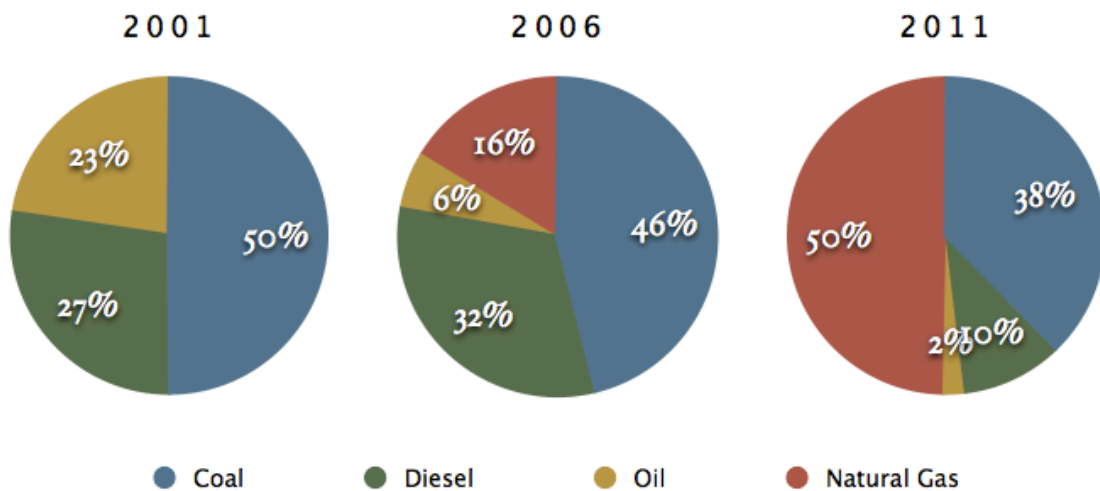


Figure 4.4: Fuel mix for electricity generation between 2001 and 2011. Source (IEC 2011)

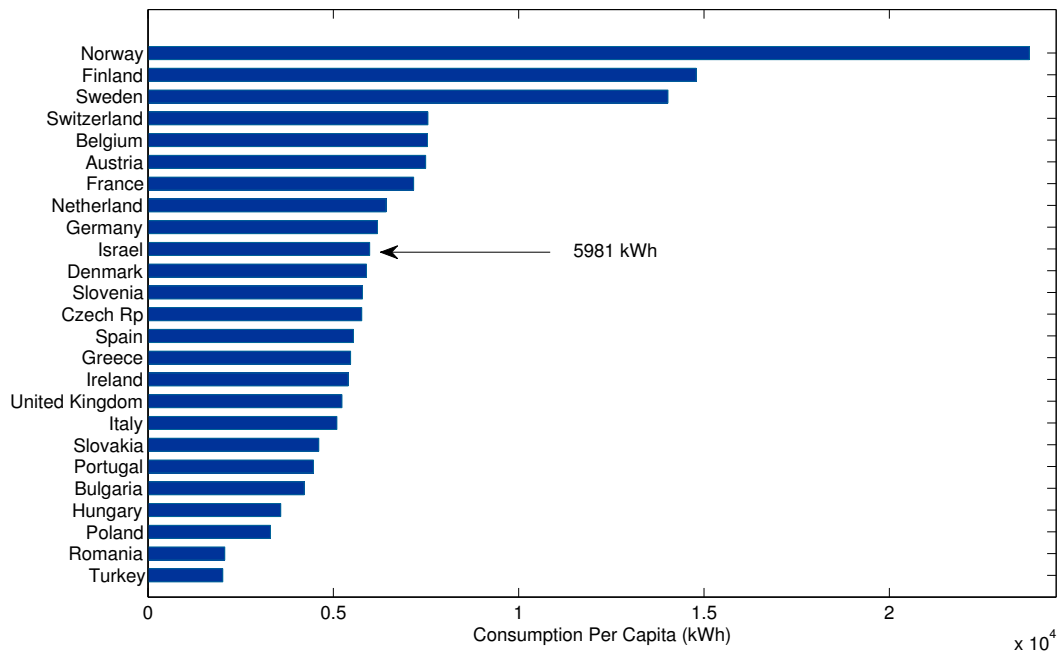


Figure 4.5: Total electricity consumption per capita (kWh) in 2009. Source (IEC 2011)

4.3.2 Electricity Consumption per capita

In 1970 electricity consumption per capita in Israel was 2288 kWh. In 2009 electricity consumption had jumped to 7000 kWh per capita, an increase of more than 300%. This rise in electricity consumption parallels the growth in GDP with a correlation of 0.98 (see Figure 4.6). The increase from the 70's to the 80's was 132%, the increase from the 80's to the 90's was 138%, and the increase from the 90's to 2000 was 151% (Figure 4.6) (Group, 2009).

The drop in consumption is explained by the increase in quality of electrical devices with a corresponding reduction in their energy requirements. In addition, the slowdown in consumption can also be attributed to increases in fuel prices and the impact of the

global economic crisis (BP, 2010).

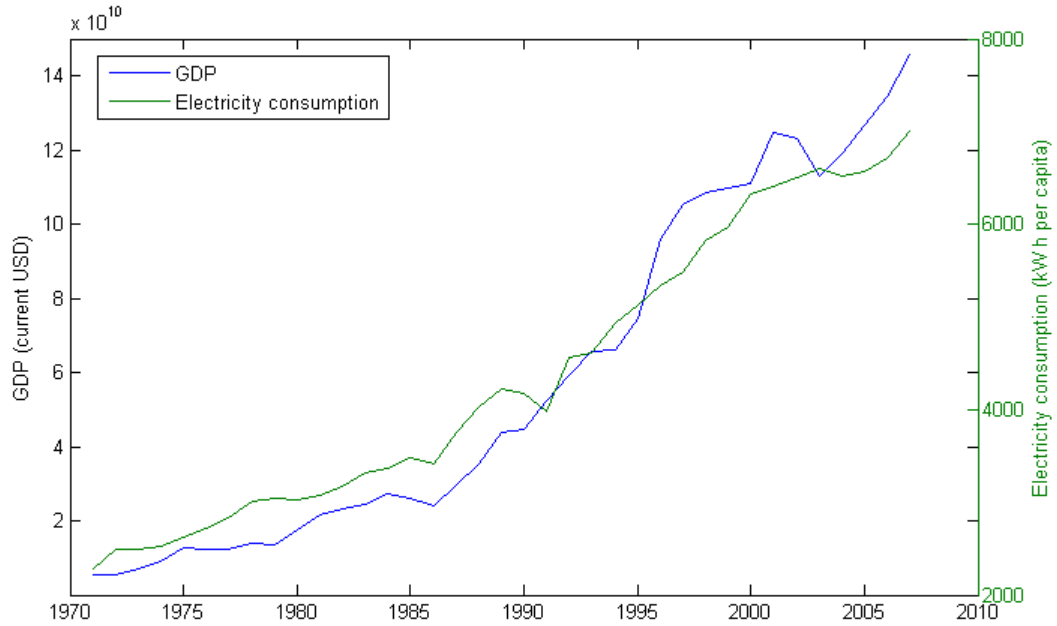


Figure 4.6: Energy consumption per capita compared to the GDP growth in Israel between the years 1970–2007. The left vertical axis represents the GDP in current USD while the right vertical axis represents the electricity consumption (kWh per capita). Source: (World Bank 2009)

Table 4.3: Electricity consumption per capita (kWh) between 1970 and 2007

Year	Electricity consumption	Rate of increase
1970	2288	100%
1980	3022	132%
1990	4176	138%
2000	6323	151%
2007	7000	110%

1970 is used as a starting point (100%). Figure refers to the rate of increase relative to the previous decade.

4.3.3 Forecasts of Electricity Consumption

Israel's current energy situation reflects a unique combination of European living standards tethered to rapid growth in fossil fuel-based energy demand. Israel has undergone rapid economic development during the past 10–15 years having attained an overall Gross Domestic Product (GDP) of approximately \$190 billion (Figure 4.7), Its GDP per-capita of approximately \$28 thousand is comparable to that of western and southern Europe. (WorldBank, 2009).

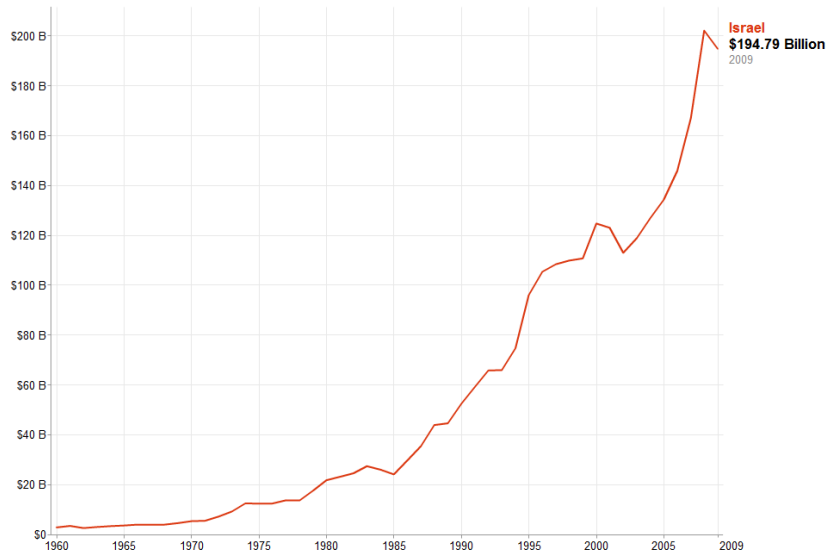


Figure 4.7: GDP in Israel, in current U.S. dollars (Dec. 2010)

Source: World Bank, World Development Indicators

Table 4.4: Gross domestic product based on purchasing-power-parity (PPP) per capita between 1990 and 2009

Year	PPP*	Percent Change
1990	13322.99	0.0788
1991	13983.122	0.0495
1992	14795.806	0.0581
1993	15114.123	0.0215
1994	15927.011	0.0538
1995	17316.32	0.0872
1996	18100.568	0.0453
1997	18451.232	0.0194
1998	18996.508	0.0296
1999	19467.267	0.0248
2000	21253.748	0.0918
2001	21280.761	0.0013
2002	21064.315	-0.0102
2003	21436.829	0.0177
2004	22712.525	0.0595
2005	24222.488	0.0665
2006	25872.711	0.0681
2007	27395.655	0.0589
2008	28473.779	0.0394
2009	28271.071	-0.0071

* PPP=GDP based on purchasing-power-parity per capita

Source: CIA 2010

4.3.4 Economic model for future consumption

Prediction of future energy demand requires formulation of a strategic economic plan, a process that contains methodological, conceptual, and technical difficulties. Using the statistical and economic model developed by Considine (2003) which assesses the impact of different economic growth and energy price scenarios upon electricity demand, the State of Israel and the Ministry of National Infrastructure formulated a policy to forecast electricity consumption through 2025. The model, containing relevant adjustments for the Israeli market was based upon econometric indicators that identify and measure energy consumption with regard to economic growth. Future

electricity prices for each sector were based upon three possible scenarios representing end-user energy demand in all economic sectors: households, manufacturing, services, agriculture, water pumping, and electric power generation (see Table 4.5), (Considine, 2003). The output of the model is given in Table 4.6.

Table 4.5: Scenarios of electricity consumption 2003-2025

Sector	Low	Medium	High
Total Electricity	2.1%	3.2%	5.6%
Residential	2.0%	3.1%	6.1%

Three scenarios projecting electricity growth rate for the residential sector and for the total electricity market. Source: (Considine, 2003)

4.3.5 Economic model results

Up to 2011, the model provides a reasonable prediction of electricity consumption compared to actual measurements. For example, in 2009 the overall electricity consumption was 48,947 million kWh, while the model's low scenario prediction for 2009 was 50,397 million kWh, a deviation of less than 0.78%. In addition, electricity consumption in the residential sector in 2009 was 15,117 million kWh while the model's low scenario prediction for 2009 was 14,533 million kWh, and 15,742 million kWh based on the medium scenario. These results reflect deviations of 1.04% and 0.96% respectively, (Figure 4.8)

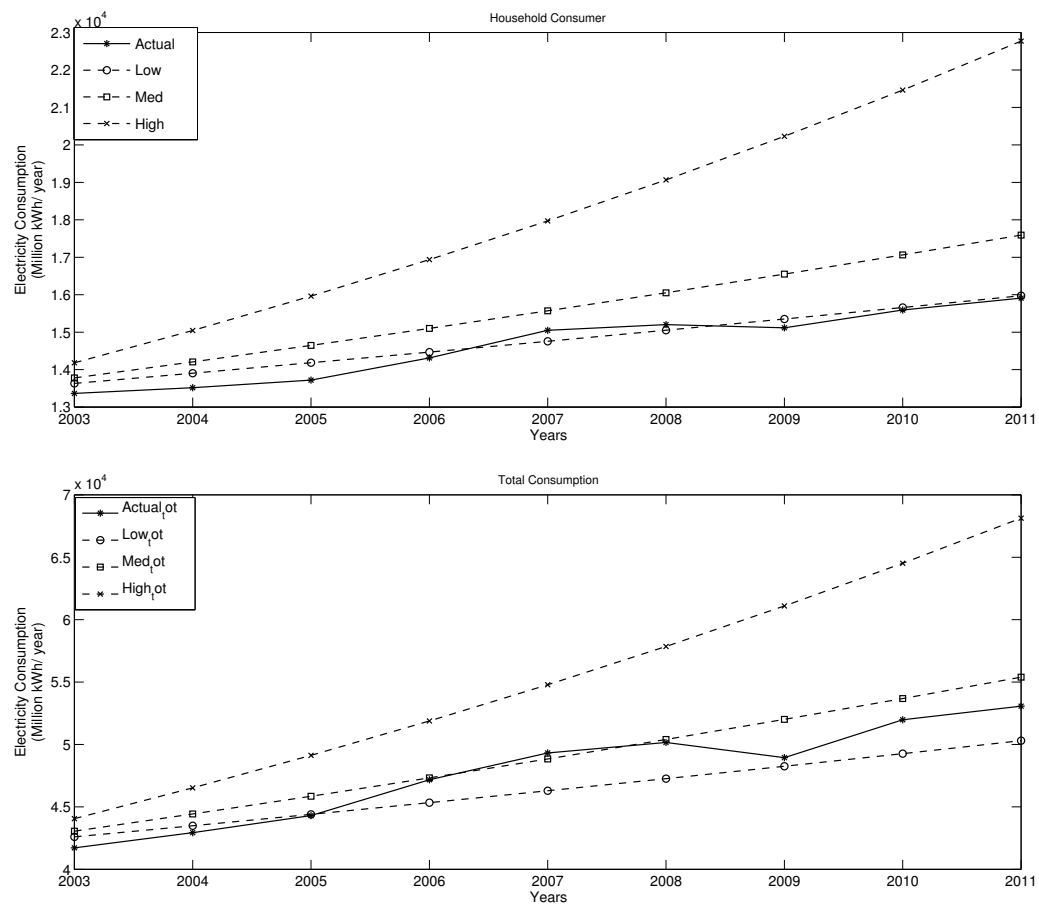


Figure 4.8: Measurements of electricity consumption in Israel compared to predictions for the residential sector (upper plot) and the total electricity sector (bottom plot): 2003-2011

Table 4.6: Electricity consumption forecasts (Million *kWh*) 2003-2025

Total Electricity	2001	2002	2005	2010	2015	2020	2025
Low	42678	43696	45574	51941	58361	65258	72871
Medium	42678	43820	46890	56305	67228	80166	95580
High	42678	43666	48646	66090	90918	125451	172730
Residential							
Low	12780	13183	13792	15788	17451	19212	21098
Medium	12780	13347	14371	17302	20250	23652	27587
High	12780	13205	15233	21737	30294	42149	58396

Model's result for three scenarios of electricity consumption(*kWh*) between 2002-2025. The top table represent the total electricity market and the bottom represent the residential sector.

Source: (Considine, 2003)

With the increase in electricity consumption, the Israeli government has the responsibility to provide creative solutions for meeting both growing demand and environmental degradation arising from this increased consumption.

4.4 Renewable Energy in Israel

4.4.1 History of Renewable Energy in Israel

Israel has historically led in the use of solar energy for domestic purposes. Interest in solar water heaters began even before Israel gained its independence in 1948. David Ben-Gurion, the first prime minister, installed a solar water heater in his home in 1958 (Stermann, 2009).

According to the historian Bacher, the Levy family first used solar energy in 1948. Levy, a mechanical engineer, painted his water heating tank black. Under his wife's

encouragement, Levy continued to research solar energy and in 1953 the family established the first commercial solar water heater company, "Ner-Yah". From 1953-1967 "Ner-Yah" sold 50,000 solar water heaters until June, 1967, the onset of the Six-day War (Li et al., 2000). The number of residents in Israel at that time was approx 2.5M, and the fact that it was a new technology indicates that the company was a commercial success. Due to its seizure of Egypt's Sinai oil fields, the June 1967 War made Israel a self-sufficient energy power. However, the consequences were catastrophic for Israeli solar-energy companies, for the economic justification for use of alternative energy was removed. In 1979 the Egyptian-Israeli Peace Treaty signed in Washington DC by Egyptian President Anwar El Sadat and Israeli Prime Minister Menachem Begin and witnessed by United States President Jimmy Carter (Kreith and Goswami, 2007) stipulated complete Israeli withdrawal from the Sinai Peninsula, including the captured Egyptian oil fields. This caused a surge in oil prices in Israel, encouraging development of a public policy for solar power (Li et al., 2000). As early as 1970, Israel established a solar energy market by law the groundbreaking and innovative "Article 9 of the Law of Planning and Building since 1970" (Shapira, 1970). This law has been the predominant government contribution to Israel's success in the field of solar technology. The law requires all contractors (not customers) to install solar water heating systems in new buildings of up to 8 floors. Based on manufacturer data, the average domestic solar water heater saves 1250kWh of electric power per year (McDonald, 2009). Today, 85% of Israel's 1,650,000 households use solar water heaters and the total energy saving amounts to about 2.065 billion kWh per year (McDonald, 2009).

4.4.2 Renewable Energy Policy

Israel, like most of its eastern Mediterranean neighbours is among the countries receiving the highest solar radiation in the world. Yet its solar industry has largely consisted of developing technologies rather than of manufacturing goods for export.

Despite success in domestic solar use, Israel has not adopted large-scale industrial solar power. Failure to internalise environmental and other externalised costs of fossil fuel

has resulted in solar energy costing two to three times as much as energy produced by coal or natural gas. The lack of policy for solar development has produced uncertainty that has only increased the cost of investment in Israel's industrial solar sector (Mor and Seroussi, 2007).

Until 2007, cumulative installed RE capacity amounted to about 2 MW p, the vast majority of systems being off-grid electrification applications (remote homes, agriculture, security and alarm systems, communications, and exterior lighting). However, recently considerable progress has been made as a result of intensive Government activity.

Israeli governments together with the Ministry of National Infrastructure have set a target of 10% of electricity supply from renewable energy by 2020 (6.4TWH of total electricity generation), with an interim target of 5% by 2014. At the present just about 0.1% of the country's electricity supply comes from renewable energy (Yaniv, 2010).

Feed-in tariffs (FIT) for distributing PV systems entered into effect in 2008, with an installation cap of 50 MW p over seven years. The tariffs are for up to 15 kWp for residential systems and up to 50 kWp for commercial systems and are guaranteed for 20 years. For systems starting operation in 2011 - 2015, the tariff will be reduced by 4% every year (PUA, 2008). The National Council for Planning and Construction has approved rules to accelerate approval by local authorities and to exempt roof-mounted systems from the need for building licenses and local taxes (Arbib, 2009).

The banking sector began financing PV systems by the end of last decade. In addition, special interest rates offered by some banks were significant in facilitating purchase of PV systems. For example, Bank Hapoalim offers financial solutions for both private and business customers in construction of solar systems due to the guarantees that individuals and business entities receive from the IEC for purchase of electrical power from solar energy facilities (Ankory, 2009). This has stimulated private investment in renewable energy. As a result, during 2007 - 2011 a large number of companies both in the planning and consulting sector as well as in construction were established.

During that period a large number of farmers who had area devoted to dairy or poultry found new revenue streams by installing PV systems on their property.

4.4.3 The Forecast for RE generation

In order to meet the 2020 target of 10% of electricity generation - 6.4TWH using renewable energy, the MNI set milestones (see Table 4.7), which forecast annual installed power in different renewable energy technologies.

Table 4.7: The forecast of production by various technologies by 2020

	Dec. 2014	2016-2017	2018-2019	2020	production (%)
Wind	0.61	0.98	1.47	1.96	30.04
Bio-mass	0.33	0.66	1.05	1.38	21.1
Thermo-solar	1.33	1.43	1.9	2.28	34.87
PV over 50 kWh	0.6	0.6	0.6	0.6	9.1
PV up to 50 kWh	0.32	0.32	0.32	0.32	4.89
Actual energy production	3.19	3.99	5.34	6.54	100

It is important to emphasize that the MNI's policy will be updated in 2014 depending on developments technological and economic changes in the demand forecast, source: MIN 2010.

Table 4.8: Estimation of production costs of renewable technologies for 1MW

	PV $\geq$ 50 Kw	PV $\leq$ 50 Kw	Thermo-solar	Wind	Bio mass
Constructon cost*	4.8	4.2	3.6	2	4.5
Annual operating cost*	0.152	0.055	0.008	0.022	0.022
Annual production**	1600	1700	1900	2455	6570
Plant life**	20	20	20	20	20
Requierd area (1000 m^2)	10	22	18	100(gross)	1.7

*Millons of USD per 1MW installed

**Estimation

Source: PUA 2008

Construction and Implementation Costs of RE

Up to the present, construction costs of RE technology are higher than those of power plants operates with fossil fuel (BP, 2010) . Table 4.8 summarises the cost of individual RE technologies. For example, construction costs of a thermo-solar facility is about \$3.6 million per MW installed. The annual operating cost is about \$8,000 per MW installed. In addition, every MW of thermo-solar technology installed is expected to produce 1900 MWH per year. Although the starting point for renewable technology in relation to conventional systems is lower, the policy of the MNI is to promote renewable energy, planning upon cost reductions in technology, technological improvements, and an expected decline in construction costs, all of which will make use of these technologies more economic in the future (MNI, 2010).

External Costs of Electricity Generation

In 2008 the Ministry of Environment Protection researched the external costs of pollutant emissions produced by electricity generation using fossil fuel, (see Table 4.9). The table shows values for emissions per ton for each of the main pollutants (PM , SO_2 , NO_x , CO_2). The price reflects pollution's cost in terms of health impairment and contribution to global warming. It is important to stress that the prices represent emission from a height over 100m that are typical of power plants. Low emission costs from vehicles may be much higher (MEP, 2009) .

Table 4.9: The external cost of pollutant emissions during electricity generation using fossil fuels

	Average amount of emission* (<i>kWh/gr</i>)	External cost for 1 ton (<i>t/USD</i>)	Emmision cost of production 1 <i>kWh</i> (<i>kWh/USD</i>)
<i>SO₂</i>	1.7	7420	0.012
<i>NO_x</i>	1.8	4297	0.007
<i>PM</i>	0.06	10590	0.0006
<i>CO₂</i>	741	22	0.0164
Sum			0.0375

*-Average amount emitted during the production of 1 kWh (*kWh/gr*)

Source: (MEP 2009)

4.4.4 Benefits of RE

The potential effect of RE upon Israel's economy is substantial. A recent study conducted by Eco Energy (Mor et al., 2005), assuming 2,000 MW and 500 MW of PV phased in by 2025 indicates that solar-generated electricity could reduce greenhouse gas emission by nearly 4 million tonnes and would increase steady state employment by nearly 3,200 per year. The overall benefits through 2025, taking into account employment, environment, avoided transmission and distribution (T& D) infrastructure, avoided pollutants, and improved balance of payment are between \$1.8 billion and \$2.7 billion, with ongoing post-construction benefits of \$200 million per year. In a different study performed by an Israeli developer of concentrated PV systems, the foreign currency expenditure saved by developing solar resources would be about \$130 billion, or \$3.25 billion per year, 33,700 jobs could be created over a 40-year period and another 20,000 jobs could be created in export industries, while reducing Israel's fossil fuel dependency to a mere 20%. These results are roughly consistent with Solel's estimate of savings of \$1.4 billion from purchase of 3.5 million tonnes of fossil fuel with the generation of 3, 000 MW of solar energy.

4.5 The RE Industry in Israel

Israel is home to world-class renewable energy innovators such as Ormat Technologies Inc., Solel, Solar Edge Inc., Zenith Energies, and BrightSource Inc. In 2009 Israel was ranked by a leading analyst to be in the top five Clean tech countries, just behind Denmark, Germany, Sweden, and the UK (Simon, 2009). Five Israeli companies were listed among the top 100 Clean tech companies based on a poll of corporate leaders. However, while Israeli renewable energy companies operate commercial projects worldwide, this is still not the case in Israel. The UNEP European Regional Director Christopher Bouvier called it the Israeli paradox: "While Israel was the foremost exporter of solar technology in the world and an incubator for solar technologies, it was last in actual production of electricity from solar energy (Zion, 2009).

Below is a list of Israeli solar energy companies and their products:

- *3GSolar Ltd.* Jerusalem is developing novel, dye-sensitized solar cell (DSC) modules. According to the company, DSC solar modules are less expensive and simpler to produce than current solar modules produced with current-generation poly silicon and thin-film solar technologies (Heller, 2009).
- *Solaris Synergy* is a developer of advanced cost-effective photovoltaic technology for medium and large-scale solar power generation. This brand new proprietary technology which integrates a number of innovative mechanical, optical, and thermal solutions is based upon medium-concentration solar units with photovoltaic elements cooled by evaporation. Solaris Synergy has developed floating solar panels that produce clean energy by utilising areas of natural water such as lakes, reservoirs, and tunnels. This unique technology enables high-efficiency solar panels on surfaces not currently utilised, preventing evaporation by covering store pool solar panels (Fisher, 2009).
- *BrightSource Energy* designs, develops, and deploys concentrated solar thermal technology to produce high-value steam for electric power, petroleum, and

industrial-processing markets worldwide. BrightSource combines breakthrough technology with world-class solar power plant design to generate clean energy reliably and responsibly (BrightSource, 2015).

4.6 Research & Development in Israel

In 2008, the Israeli government decided to invest government and private funds in research and development of Israeli renewable energy companies (Israel-Government-Decision-3954/hm122, 2008).

Encouragement of infrastructure research included: institutions of higher education, giving priority to curriculum development and academic study programs in renewable energy, graduate scholarship programs in renewable energy (NIS 7.5 million), academic research grants for research projects with commercial applicability (NIS 37.5 million), infrastructure investment in academic programs (NIS 5 million), and academic conferences to encourage R& D (NIS 2.5 million) (MEP, 2009).

The decision to make this cumulative investment of at least NIS 400 million in five years was intended to produce sales of NIS 500 M for Israeli technology, thereby moving Israeli operations from R & D to production and marketing.

The R&D division and the Chief Scientist's Bureau within the MNI implemented the government decision by (1) receiving and examining proposals for research, funding projects, and monitoring their execution. (2) giving advice regarding the formulation of policy for scientific and technological subjects, (3) advancing international cooperation, and (4) strengthening open research activities in order to build skilled pools of professionals (MNI, 2010)

Regarding solar research in academic centres, a relatively large number of research teams are involved in photovoltaic R& D. Many of these teams cooperate with leading

teams and universities worldwide. At university centres, the main focus areas are in materials studies, modelling solar devices and systems, energy conversion and storage, and concentrator photovoltaic. The following is a short list of university centres dealing with RE R& D:

- *Tel Aviv University*; The Solar Energy Laboratory conducts research in solar energy conversion in order to develop improved solutions for efficient and cost-effective conversion. The main goal of the research is to identify, demonstrate, and promote practical and competitive Renewable Energy solutions. Main research topics include: concentrating photovoltaic, high-performance photovoltaic cells, solar co-generation, solar concentrator optics, thermal storage, solar desalination and disinfection of water, and biofuel production from waste (Kribus and Mittelman, 2008)
- *Ben-Gurion University*; The Blaustein Laboratories (BGU-Blaustein) represents Israel within the framework of the IEA's Task 8 Photovoltaic Specialists Working Group, Very Large-Scale Photovoltaic (VLS- PV) Power Plants. In addition, the Blaustein Laboratories focus on conversion of solar energy to electricity and applied optics and large system design for solar energy (BGU, 2015).
- *Weizmann Institute of Science*; A project is underway to develop high-voltage semiconductor-sensitised nano porous cells. Recent advances made in very high-efficiency tandem cells, where three cells sensitive to different parts of the solar spectrum are built in series have resulted in efficiencies greater than 40% (Arbib, 2009).

4.7 Conclusion

Israel has experienced a high level of growth in electricity production and consumption over the last decade. The Israeli government has taken a number of steps to expand

energy independence as well as to increase electricity generation capacity by renewable energy.

In recent years, natural gas was discovered on the coast of Israel and that has reduced Israel's dependence upon fossil fuel imports from foreign countries. However, these discoveries have slowed the determination to promote electricity production using renewable energy.

With regard to RE generation capacity, although Israel has been a pioneer both in development and deployment of RE technology, less than 1% of current total electricity generation is by renewable energy. There was also a market failure in Israeli FIT policy between 2010 and 2015 with the decline in FIT larger than the decrease in production cost of RE technology. Application of an incorrect policy incentive caused a slow-down in the RE technology market during that period.

The following chapters, particularly Chapter 6 deals with this issue in detail and explains how the lack of decision-making or making wrong decisions with respect to assessing the market led to market failure.

5

Technical, Atmospheric and Environmental Analysis: the TEA Model for PV deployment

5.1 Introduction

The promotion of renewable energy, particularly solar represents a technological option both for reducing predictably rising carbon emissions and for addressing energy security, a condition that not only is contingent upon oil price, but also one that affects the entire Middle East. Elucidating the advantages and disadvantages of solar

technology, this chapter considers the overall potential of solar energy generation for Israel. It details aspects of the TEA Model, a linear model based upon the technical, environmental, and atmospheric parameters affecting the quality of energy able to be generated by solar technology. The objective of the TEA Model is to optimise the selection and application of solar energy technologies in urban areas. While similar to SURE-DSS in that it considers more than one factor in selecting optimum renewable energy solutions (see Section 3.4.2 on page 53). The five technical and non-technical parameters of SURE-DSS do not include the specific atmospheric conditions that the TEA model does. In addition, the TEA model examines three performance parameters of PV systems: Final yield (Y_F), reference yield (Y_R) and performance ratio (PR) which SURE-DSS does not. These calculations are significant as considerable solar energy can be lost due to unfavourable atmospheric conditions (see section 5.3.1 on page 91). A comparison with existing commercial models is then provided. The chapter concludes that the outcomes produced by the TEA pilot are encouraging.

The innovative aspect of this model is that this specific combination of atmospheric, technical, and environmental parameters has never been considered together as a whole before. The information generated should have definitive influence upon the uptake of the right solar energy technology in Israel.

5.2 Background

Of all sun's energy hitting the earth's atmosphere, approximately 30% is reflected back into outer space due to the earth's albedo effect. Once the remaining energy has passed through the earth's atmosphere, another large portion is lost by absorption or reflection due to gasses or particles within the earth's atmosphere (Dekker et al., 2012). Consequently, the amount of electricity generated by PV panels is significantly lower than that which might be expected simply by calculating the solar irradiance upon surfaces of PV panels. PV system performance is affected by overall loss due to module temperature, module efficiency, shading, Direct (DC) and Alternating Current(AC) losses,

and inverter losses. This research paper focuses on soiling loss generated by shading or energy scattering due to dust, air pollution, or gases on or above the surface of the PV modules. Although loss of energy by PV systems due to atmospheric components is of great interest to system owners, investors, and operators, the professional literature contains little information on these losses.

5.3 Solar Radiation

The solar constant, a measure of flux density, is the amount of incoming electromagnetic radiation (solar irradiance) from the sun per unit area incident upon a plane perpendicular to the sun's rays at a distance of one astronomical unit (1 AU roughly equals the mean distance between the sun and the earth). When measuring solar irradiance upon the outer Earth's atmosphere, measurements can be adjusted using the inverse square law to infer the magnitude of solar irradiance at 1 AU and thereby deduce the solar constant (Sellers, 2011). The intensity of solar radiation beyond the earth's atmosphere depends upon the distance between $1.47 \times 10^8 km$ and $1.52 \times 10^8 km$. Hence, irradiance, E_0 fluctuates between $1325 W/m^2$ and $1412 W/m^2$. The average value is referred to as the solar constant:

$$\text{Solar Constant : } E = 1367 W/m^2 \quad (5.3.1)$$

This level of irradiance though is not obtainable on the Earth's surface. The atmosphere reduces insolation through reflection, absorption, and scattering. At noon, under good weather conditions irradiance may reach $1000 W/m^2$ on the Earth's surface (Deutsche, 2008). This greatly depends upon the region, as shown in Figure 5.1. In some regions, like in Israel values can reach up to $2130 kWh/m^2$, (Kudish and Ianetz, 1992).

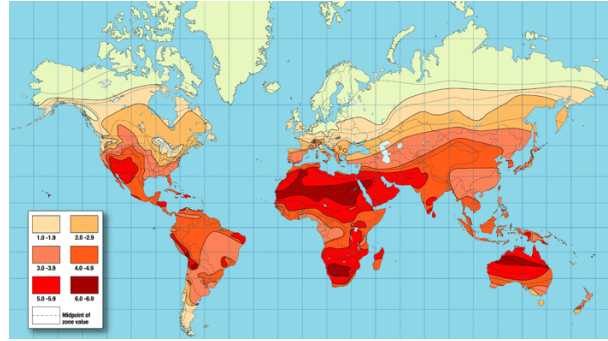


Figure 5.1: World wide distribution of annual solar irradiance in kWh/m^2 Source: Meteonorm software version 4.0

5.3.1 Factors affecting solar irradiance

Once Sun's energy hits the earth's atmosphere, approximately 30% of the total energy is reflected back towards space through what is known as the earth's albedo effect. Once the additional energy has passed through the earth's atmosphere, another large portion of the energy is lost where it is either absorbed or reflected by gasses or particles within the earth's atmosphere before it reaches the earth's surface. The main factors influencing solar irradiation on the earth's atmosphere and the measured values of solar irradiance at a particular point on earth's surface are: (a) Ozone (O_3). (b) Air molecules (i.e.: Oxygen, CO_2 and Nitrogen) (c) Aerosols -particles of varying shape and size suspended in the atmosphere, viz., sand, water vapour, mineral dust, fly ash, sulphate and nitrate aerosols. (d) Water vapour (H_2O) (e) Clouds and (f) Geographical location including latitude and elevation. (Dekker et al., 2012; Kishcha et al., 2007).

In this thesis five atmospheric components that affect electricity generation capacity are used:

1. Ambient Temperature: The temperature of the air near the surface measured by a standardised well ventilated white-painted instrument shelter. The thermometers positioned 2m above the ground.

2. Nitrogen Dioxide (NO_2)
3. Particulate Matter ($PM_{2.5}$)
4. Aerosols Optical Thickness (AOT): Aerosols are one of the important atmospheric geophysical parameters that determine the earth's energy balance. These suspended airborne particles scatter solar radiation back into the atmosphere, absorbing it, and shading the earth's surface (Luvchik, 2009). The source of these particles are natural (e.g. mineral dust, sea-salt and volcanic ash) as well as anthropogenic (i.e., air pollution). To evaluate the amount and concentration of these aerosols, data from the MODIS Terra Satellite was used. The MODIS satellite performs daily observations of the earth in a wide spectral range ($0.41 - 15\mu m$). It has been providing information on global aerosol distribution since 2000, including aerosol parameters such as Aerosol Optical Thickness (AOT) and fine mode fractions (f) (Remer et al., 2005).
5. Solar Radiation (SR)

Cloud cover presents the greatest potential loss in solar irradiation in the earth's atmosphere. In some instances it can lead to a $0W/m^2$ availability of solar irradiance (Schillings et al., 2004).

Table 5.1: Absorption and scattering under typical clear sky conditions source:(Michalsky 1988)

Factor	Percent absorbed	Percent scattered	Percent of total passing through the atmosphere
Ozone	0.02	0	
Water vapor	0.08	0.04	
Dry air	0.02	0.07	
Upper dust	0.02	0.03	
Lower dust	0	0	
Total absorbed or scattered	0.87	0.87	0.76

5.3.2 Production of Electricity Using Solar Systems

From a practical viewpoint, production of electrical power from solar energy systems can be implemented through two main technologies:

1. Solar-thermodynamic power plants, in which solar energy concentrated through a suitable mirror system is feed to a conventional power plant
2. Solar photovoltaic systems, in which energy is produced as a direct result of the conversion of the energy of solar rays, using the photovoltaic effect (Lesourd, 2001; Meyers, 1983).

A photovoltaic power generation system consists of multiple components like cells, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output. These systems are rated in peak kilowatts (kWp) which is an amount of electrical power that a system is expected to deliver when the sun is directly overhead on a clear day (Parida et al., 2011).

Crystalline silicon is currently the technology which is used in the majority of solar modules (Yeh, 2015). Depending on the level of refinement and manufacturing processes used, mono-crystalline or poly-crystalline.

Mono-crystalline silicon is created from materials that contain silicon like quartz sand and heated at high temperatures in excess of 1700°C in an electric arc furnace to purify the silicon and separate it from other elements and compounds with which it was originally mixed.

Poly-crystalline silicon process is similar to mono-crystalline silicon. The main difference in the steps to make a poly-crystalline solar cell occurs after using variations of the process to make poly-crystalline chunks (Wang et al., 2012). The poly-crystalline chunks are then melted and cast into a poly-crystalline block, which is then sawed into

square poly-crystalline wafers and finally processed into poly-crystalline cells (Tao, 2014).

Crystalline silicon offers an improved efficiency when compared to amorphous silicon while still using only a small amount of material. The commercially available multi-crystalline silicon solar cells have an efficiency around 1419% (Parida et al., 2011).

5.3.3 The PV system: Characteristics and Development

A photovoltaic system is an integrated assembly of modules and other components designed to convert solar energy into electricity. All the other components needed to build a PV system are called Balance Of System (BOS). There are many options for BOS equipment depending upon the design and purpose of the system. Technically, the main BOS components are: an Inverter that converts Direct Current (DC) to Alternating Current (AC) (Miles et al., 2005), a Converter that converts DC output from the PV array into a voltage suitable for the battery load, a battery for storage of power so that it can be released during non-daylight hours, and a Charge controller that regulates the current charge so as to prevent overcharging.

PV systems can have different applications which may be divided into the following categories:

- **Off grid or Stand-alone** (domestic or not domestic): PV systems which operate independently from a grid network and are mainly used for remote power applications. Frequent domestic use is found in rural areas, particularly in Israel. Farmers in the UK have installed these technologies on their crop-land, thereby reducing demand upon the national grid.
- **Grid-connected distributed**: PV systems connected to the public electricity grid via a suitable inverter. They can be installed on the top of a roof and integrated into the premises.

High efficiency multi-junction cells

The maximum theoretical efficiency that can be achieved from a single-junction solar cell consisting of one layer of semiconductor material is under the best conditions in the 30% range (Kazmerski, 2006). One way of extracting more power from the sun is a Multi-Junction (MJ) cell designed as a stack of semiconductors in which each junction is tailored to absorb a particular band gap. Higher band gap semiconductors are located on the top of the stack allowing photons of lesser energy to pass.

The materials used for the layers are far more expensive than the silicon materials, but they deliver efficiencies nearly doubling those of everyday solar panels. In particular, MJ cells have a significant advantage over conventional silicon cells in concentrator systems because fewer solar cells are required to achieve the same power output. Moreover, the efficiency limit of multi-junction cells with an infinite number of junctions is around 70% (Green, 2000). Efficiencies up to 32% (using the standard unconcentrated terrestrial solar spectrum) have been achieved in laboratory testing for a three-band gap stacked cell (Luque and Hegedus, 2003; Green et al., 2009).

Concentrating PV (CPV)

Concentrating PV (CPV) uses lenses or mirrors to focus sunlight onto a small amount of photovoltaic material. The system can concentrate light by a factor of between 100 and 1000. There are a wide variety of CPV options under development, according to the type of cell used (some use silicon-based cells, others use more expensive, higher efficiency devices) and the concentration level (from very low to very high). A common characteristic of both is the need for a tracking system. These systems only convert direct sunlight and must track the sun in order to keep the light focused on the cell (Candelise, 2009).

Scientists and academic institutions as well as private companies and R&D institutes

from all over the world are working on increasing the capacity and efficiency of electricity generation by all solar energy systems. In this research, the only technologies examined were first and second-generation as the purpose of the research is to provide guidelines for policy makers based on existing technologies rather than upon technologies which do not yet exist or whose cost is prohibitive.

5.4 Assessing Performance of PV Systems

Assessment of PV systems focuses on system performance which relates to the amount of energy produced. The professional literature cited in this section presents relevant studies on the impact of atmospheric elements such as dust and air pollution adhering to solar panels, thereby reducing electricity production.

Kimber et al. (2006), discussing the effect of dust on the power of PV systems in South-Western USA show that there is a marked decrease in module efficiency during the dry season when it is dustier. They also note that there is a significant difference between arid and non-arid (regions with a rainfall event at least once a month) regions. Systems located in non arid-regions do not show significant declines in performance. However, PV systems located in deserts are very susceptible to mineral aerosols, where average annual loss ranges from 1.5% to 6.2% (Kimber et al., 2006).

These figures have been confirmed by controlled experiments upon three systems in Los Angeles, CA (one washed, the other two not) with annual losses of 3.5% and 5.1% (Kimber, 2007). Kymakis et al. calculated the soiling losses based on a combination of statistical analysis and real measurements in Crete. The authors found that the annual average losses due to soiling and dirt is 5.8% (Kymakis et al., 2009). The California Energy Commission estimates losses from dirt and dust accumulation at 7% (Thevenard et al., 2010). Haeberling et al. conducted a research during four years of PV generator power located in Burgdorf, Switzerland. They found that electricity generation had decreased between 8% and 10% during the summer months due to air

pollution caused by train stations farms and silicon airborne from the Sahara desert (Häberlin et al., 1998).

All these studies are based upon measurement of dust particles and air pollution that settle on the panels themselves. Yet there are a number of other components present in the atmosphere which do not adhere to the solar panels. These components, such as aerosols, $PM_{2.5}$, and gases like NO and NO_2 absorb solar radiation, not allowing it to pass onto the panels. Thus, there needs to be a new method for determining capacity of electricity production in PV systems so that these other elements can be introduced into the basic system calculations. This thesis has in fact developed an approach that does include these factors so that the electricity generating potential of PV systems in a specific location can be calculated based on actual atmospheric and methodological measurements.

5.4.1 SMART and SEDES Models

The solar spectral distribution has a systematic influence on the performance of photovoltaic (PV) solar energy conversion systems: they both depend on weather condition, geographical location and time-of-day. In order to model the energy performance of a solar cell, precise spectral data is needed. This data can be measured using precise spectroradiometers on site besides other instruments used for global, direct and diffuse broad-band irradiance measurements, namely pyranometers and pyrhemometers.

SEDES2

The SEDES2 model uses numerical models in order to estimate and predict the solar spectral data by using easily accessible meteorological parameters such as total and diffuse broad-band irradiance, pressure, ambient temperature, relative humidity, and the geographical information such as longitude, latitude and elevation (Houshyani, 2007).

SMARTS2

The SMARTS2 model, is an extensive revision of SMARTS1, a spectral model used to calculate direct beam and diffuse radiation (Gueymard, 1993). SMARTS2 improved the previous model in several aspects such as; Improvement of the extraterrestrial spectrum used (accuracy and resolution), included highly accurate absorption coefficients from recent spectroscopic data, allowed the calculation of diffuse irradiance in the UV and some other improvements (Gueymard, 1995).

The SMARTS2 is intended to be used in a variety of applications, its accuracy is a critical factor and needs to be assessed under different atmospheric conditions, where spectral optical characteristics of both the tropospheric and stratospheric aerosols may change rapidly with time and with meteorological conditions.

However, input parameters such as Aerosol Optical Depth (AOD), and Albedo and Alpha (Angstrom exponent) are fixed in SEDES2 at 0.27, 0.2 and 1.14, respectively (Houshyani, 2007). The SMART model uses a simplified methodology considered only two different spectral regions, below and above $\lambda_0 = 0.5\mu m$ (Gueymard, 1995)

5.4.2 The TEA model rational

The objective of the TEA model is to measure the effect of atmospheric parameters on capacity of power production and to calculate PV system performance. This is necessary for both investors as well as the financial institutions that provide loans to this type of business. The more accurate the models are, the more accurate predictions of electricity generation can be, a factor that is important in reducing the uncertainty surrounding capacity. In recent years, a large number of simulation tools and computer models have been developed to analyse integration of renewable energy into the electricity grid in addition to stand-alone stations. These tools based upon existing meteorological data have no ability to add, modify, or change the atmospheric parameters or to change the weights assigned to them, something that this research does undertake. Here a model has been developed to allow changing or adding components based upon local atmospheric conditions and meteorological data. The TEA

(Technical, Environmental, and Atmospheric) model was developed with high level of flexibility in the interaction and weighting of different pollutants including Particulate Matter (PM), Nitrogen Dioxide (NO_2), natural aerosols, as well as other meteorological factors, such as wind speed, temperature, and solar irradiance. The innovation of the TEA model, in contrast to the SMART2 and SEDES2 models is that the TEA model uses accurate measurement of all the parameters mentioned above. For example, the TEA model using real time measurements of Aerosols Optical Thicknesses (AOT) which taking from an AERONET device located 6 km from the installed PV system (NASA, 2010). In addition, data from the MODIS Terra Satellite which since 2000 has been making daily, nearly global observations on aerosol distribution in a wide spectral range ($0.41 - 15\mu m$) has been providing daily global aerosol distribution since the year 2000.

It is essential to examine more than one parameter in calculating PV performance because in many cases one parameter is insufficient to obtain a clear picture of total performance loss due to air pollution. The TEA model, therefore, calculates three performance parameters of PV systems: final yield, reference yield, and performance ratio in order to determine PV system yield and losses attributable to air pollution and other gases in the atmosphere. Finally, the model calculates the GHG reduction in Israel obtained from usage of a PV system as compared to that of standard modes of electricity production.

5.5 TEA Model Methodology

The model uses the "Eureqa" package (Dubčáková, 2011) to run a linear regression in order to find the link between the atmospheric parameters and PV system performances as explained in section 5.6.

Figure 5.2 schematically shows TEA model behaviour and the links between the different phases of the model: (1) the multi-regression technique (2) the analysis of PV

system performance and (3) the environmental implications.

Phase 1– Atmospheric analysis

Phase 1 determines the impact of each of the atmospheric parameters and the overall effect on electricity generation loss and gain due to NO_2 , air pollution (PM and AOT), temperature, and wind speed using both daily and monthly datasets.

Phase 1 was run 10 times between 2010-2012, five times for the daily dataset and five times for the monthly dataset, each time with different atmospheric parameters (see Table 5.2).

Results were compared to average data obtained from four PV stations in Israel (see section 5.6.2). Functions 1 to 10 present the multi-regression analysis carried out by *Eureqa* package with Functions 1 - 5 representing the multi-regression analysis upon the daily dataset and Functions 6 -10 representing the multi-regression analysis upon the monthly dataset. Function 2 in the daily dataset and Function 8 in the monthly dataset include all parameters. Table 5.2 summarises the parameters included in each function.

Table 5.2: The parameters used for TEA model

Function	Parameter					
	Temp	WS	SR	$PM_{2.5}$	NO_2	AOT
1	x		x	x	x	
2	x	x	x	x	x	x
3	x		x			
4	x		x	x	x	
5			x			
6	x		x	x		x
7	x		x			x
8	x	x	x	x	x	x
9	x		x			
10	x	x	x			

Function 1-5 represent the daily database, functions 6-10 represent the monthly dataset.

- (1) $E = -0.03236 + -0.09889 \cdot NO_2 + 0.1075 \cdot T + 0.837 \cdot SR$
- (2) $E = -0.09284 + -0.012AOT + 0.07132 \cdot NO_2 +$
 $-0.08568 \cdot PM + 0.4742 \cdot T + 0.1111 \cdot W + 0.5824 \cdot SR$
- (3) $E = 0.0176 + 0.7693 \cdot SR + 0.0845 \cdot T - 0.3628 \cdot SR \cdot \sin(SR)$
- (4) $E = 1.13 \cdot SR + \cos(SR) - 0.97 + T + 0.11 - 0.088 \cdot PM - 0.09 \cdot NO_2$
- (5) $E = SR - 0.09903 \cdot \cos(4.695 \cdot NO_2) \cdot \sin(5.774 - 4.695 \cdot NO_2)$
- (6) $E = 0.01187 + -0.3381NO_2 + 0.1025 \cdot T + 0.02758 \cdot PM_{2.5} +$
 $0.5861 \cdot SR + -0.5649 \cdot AOT \cdot NO_2 + -0.7062 \cdot AOT \cdot T$
- (7) $E = 0.9267 \cdot SR + 0.2101 \cdot T - 0.0163 - 0.08506 \cdot AOT$
- (8) $E = 0.023 \cdot W + 0.01636 + -0.3933 \cdot NO_2 + 0.6138 \cdot SR +$
 $-0.5843 \cdot AOT \cdot NO_2 + -0.718 \cdot AOT \cdot T - 0.012 \cdot PM$
- (9) $E = 0.7553 \cdot SR + 0.3107 \cdot T$
- (10) $E = SR \cdot \sin(1.194 - SR) + -0.4773 \cdot T / (T - 2.095)$

Phase 2 – PV System Analysis

Three performance parameters established by the International Energy Agency (IEA) Photovoltaic Power System Program and described in the IEC standard 61724 (IEC, 1998). Final yield (Y_F), reference yield (Y_R) and performance ratio (PR). These normalised performance indicators are common to every PV system in the world. Regardless of location of a PV system, technology type, or meteorological condition the values of these indicators remain uniform, so it is possible to compare two PV systems operating under different conditions in two different places on the globe. Phase 2 aims to determine the values of these indicators.

The performance ratio of a PV systems is used to define overall system performance with respect to energy production, solar resources, and overall system loss. According to the above mentioned standard, PV system Performance ratio is defined:

$$PR = \frac{Y_F}{Y_R} \quad (5.5.1)$$

where:

$$Y_F = \frac{E}{P_n} [kWh/kW_p] \quad (5.5.2)$$

Final Yield

Y_F is the final PV system yield and indicates the net energy output produced by the PV arrays divided by the nameplate DC power of the installed system. It is also intended as an indicator of the number of hours that the PV plant would need to operate at its rated power to provide the same amount of energy.

Y_f = Equivalent hours (kWh/kWp);

E = Energy output of the PV system measured as AC output at the inverter (kWh);

P_n = total PV system power [kWp]

and

$$Y_R = \frac{H_m}{G_{STC}} [kWh/m^2] [1kW/m^2] \quad (5.5.3)$$

Y_R is the reference yield intended as the total in-plane irradiance divided by the reference irradiance G at STC conditions. It represents an equivalent number of hours at the reference irradiance $G = 1kW/m^2$ and defines the solar radiation source being a function of the location, orientation of the PV array and year-to-year weather variability;

- Y_r = equivalent hours in standard conditions STC;
- H_m = total in-plane irradiance (kWh/m^2);
- $G_{STC} = 1kW/m^2$, reference solar radiation in STC; For Equations (5.5.1),(5.5.2) and (5.5.3) the PR will be:

$$PR = \frac{E}{P_n} \times \frac{G_{STC}}{H_m} \quad (5.5.4)$$

With reference to equation 5.5.4 and being the module efficiency

$$\eta = \frac{P}{1000W/m^2 \cdot A_{mod}} \quad (5.5.5)$$

P = module nominal power (W); A_{mod} = module surface area (m^2); The PR can be calculated as:

$$PR = \frac{E}{\eta \cdot G_m} \quad (5.5.6)$$

where:

- E = Energy output of the PV system measured as AC output at the inverter (kWh).
- η = module efficiency.
- $G_m = H_m \cdot A_{mod}$ is the global in-plane radiance measured during the time T (kWh).

Phase 3 - Environmental Analysis

To calculate greenhouse gas reduction due to use of PV solar energy systems, a comparison of electricity production by fossil fuels and PV systems was conducted. To date 32.6% of electricity production in Israel is generated by natural gas and 64.7% by coal (CBS, 2009b). GHG reduction is an important consideration as that determines the actual value of a PV system, as total value is not just the amount of electricity generated but also to the amount of GHG prevention in terms of $KgCO_2/kWh$. By using this tool, a regulatory body taxed with determining the level of subsidies for renewable energy (feed-in tariff) can accurately calculate the meaning of each kWh of energy being produced.

Based on data from the MEP, the GHG emission coefficients for coal and natural gas in Israel are $880 gCO_2eq/kWh$ and $420 gCO_2eq/kWh$ respectively (MEP, 2009).

$$\Delta GHG_{emi} = \left\{ \sum_{k=1}^n E \cdot q_{ff}^k - \sum_{k=1}^n E \cdot q_{pv}^k \right\} \quad (5.5.7)$$

where, ΔGHG_{emi} is the difference between GHG emissions produced by usage of fossil fuel and GHG emissions produced by PV systems. q_{ff} and q_{pv} are the emission coefficient bulks, in units of $[gCO_2eq/kWh]$, for fossil fuels and for PV systems respectively. In this research $q_{pv} = 40grCO_2/kWh$ (Sherwani et al., 2010).

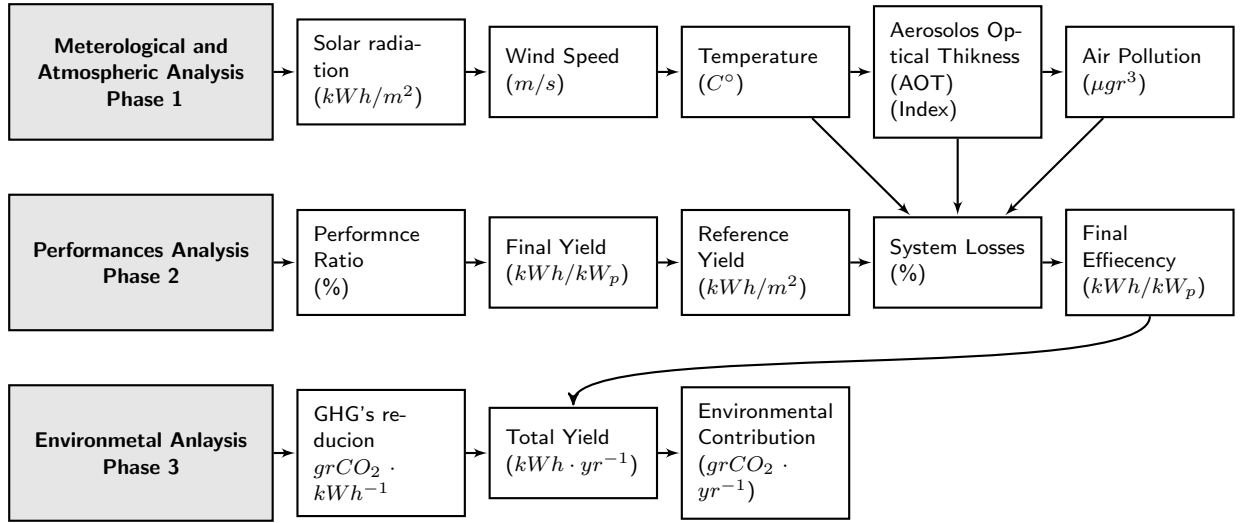


Figure 5.2: TEA Model structure

5.6 Data collection in the TEA model

Various data sources for atmospheric, meteorological, and PV system performances were used to run and operate the TEA model. Data on PV system performances as well as on atmospheric and meteorological parameters were collected on an hourly basis from January 2010 to December 2012 (see Table 5.3, 5.4), from sunrise to sunset.

5.6.1 Data Collection and Methodology: Phase 1

shows the parameters used for TEA model in phase 1.

1. **Particulate Matter** Particulate Matter (PM) originating from human activity such as emissions from vehicles, combustion of fossil fuels, and factory emissions was obtained from three Ground-based Stations (GBS) owned by MEP that are located less than 6 km from the PV station.
2. **Natural aerosols** Natural aerosols originating in volcanoes, dust storms, and sea spray was obtained from the ground-based AERONET (AErosol RObotic NETwork), a remote sensing station, established by NASA (NASA, 2010). Collaboration with AERONET has yielded globally distributed observations of spectral aerosol optical depth (AOD), inversion products, and precipitable water in diverse aerosol regimes (NASA, 2010). The AERONET station closest to the PV system is located in Nes Ziona in southern Israel, 6 km away. In addition, data from the MODIS Terra Satellite which since 2000 has been making daily, nearly global observations on aerosol distribution in a wide spectral range ($0.41 - 15\mu m$) and has been providing daily global aerosol distribution since the year 2000. This includes a list of aerosol parameters such as Aerosol Optical Thickness (AOT) and fine mode fractions (f) (Remer et al., 2005).
3. **Data on Nitrogen Dioxide (NO_2)**) produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures was obtained by a GBS owned by Israel MEP (MEP, 2009). The rest of the information relating to temperature, wind speed, and solar radiation was obtained from the Israeli Meteorological Service (IMS). Data obtained by the IMS was from an IMS station located in Biet-Gamliel, 6 km from the PV system station (see Figure 5.3)

Information on the above mentioned parameters was compared to PV system performances using the multi-regression technique implemented by the *Eureqa* software

package that performs multi-regressions using the genetic programming and analytic functions of a training dataset (Schmidt and Lipson, 2009).

Table 5.3: Atmospheric and Meteorological data used for Phase 1 in TEA Model

	Parameters	Acronym	Unit	Source
Meteorologic	Solar radiation	SR	kW/m^2	IMS, MEP
	Wind speed	WS	m/s	IMS
	Temperature	T	$^{\circ}C$	IMS
Atmospheric	Nitrogen Dioxide	NO_2	PPM	MEP
	Particulate Matter	PM	PPB	MEP
	Aerosols	AOT	AOT index	NASA

5.6.2 Data Collection and Methodology: Phase 2

Data on performance of the PV-connected systems were obtained from four $50kW_p$ stations during 2010 - 2012. The PV system stations were located around Gedera, a small city in southern Israel. The distance between these stations was less than 6 km, (see Figure 5.3). The data was analysed on a daily, monthly, and yearly basis. Table 5.4 shows the stations, module type and the efficiency of each panel under Standards Test Conditions (STC).

Table 5.4: Data of four PV systems used for phase 2 in TEA model

No.	Module Type	Area (m^2)	Efficiency (%)	No. of Module	Power (kW_p)
1	Sharp 115	1.42	8.1	432	49.68
2	Sharp 121	1.42	8.5	414	50.09
3	Sharp 115	1.42	8.1	432	49.68
4	Suntech 200-18	1.47	13.6	252	50.4



Figure 5.3: PV system, AERONET, IMS and MEP stations

5.6.3 Data Collection and Methodology for measuring GHG reduction: Phase 3

Data on GHG emissions from fossil fuel used in electricity generation and GHG emission from PV systems were gathered from the professional literature and verified using a report published by the MEP for emissions from fossil fuel combustion in Israel (MEP, 2009).

5.6.4 Model Validation

To validate the model, the 10 equations created in Phase 1 were tested against meteorological and atmospheric data gathered by two other PV models; PVGIS and the SAM model (see Section on 3.4 on page 50). The results of the validation presenting in Table 5.5 in page 112. The results for the daily data show an accurate correlation

between 0.61 and 0.93 depending on the number of atmospheric parameter taken into account. The monthly data showing even higher correlation for all functions above 0.9.

Then, the performance and energy loss of the four $50kWp$ PV systems (see section 5.5) were calculated. Finally, based on data obtained in the above two phases, GHG reduction as a result of PV system use in Israel was calculated.

5.7 Outcomes of the TEA Model

The outcomes obtained in this section were divided into the three phases of the model. Section 1 presents the results of Phase 1 - electricity generation capacity based on atmospheric and metrological measurements; Section 2 presents the result of Phase 2, PV system performance and the total energy loss in the PV system. Section 3 presents the third phase of the model - GHG reduction and the environmental contributions attributable to the PV system.

5.7.1 Outcomes of Phase 1: TEA model VS. measurements

Daily database analysis

For the daily data set, Function 2 which includes all parameters provided the best prediction of electricity production as compared to the actual measurements, having an R-square of 0.87 and a correlation coefficient of 0.933. Function 3 which includes only solar radiation and temperature provided the poorest prediction of electricity production as compared to the actual measurements, having an R-square of 0.37 and a correlation coefficient of 0.61. The average R square and the average correlation coefficient of all five functions are 0.75 and 0.838, respectively. These results support the hypothesis that atmospheric factors have a direct impact upon the electricity production capacity of PV systems. The implication is that the more parameters used in the

model, the more accurate it becomes. Even though, daily energy generation is much more difficult to predict than monthly energy generation, when the model inputs all five parameters its accuracy is high.

The top plot in Figure 5.4 shows the results of all functions against actual PV system performance based on on-site measurements.

Monthly database analysis

In the monthly dataset, all five functions of the TEA model yield accurate results when compared to measurements of actual electricity generation capacity by a PV system. However, Function 8 which includes all the atmospheric factors provides the lowest value for the Root Square Mean Error (RMSE), a statistic that calibrates the difference between values predicted by the model and the values actually observed. The lower the RMSE the better the prediction. The RMSE for Function 8 was 12.74 as compared to the value of 19.23 for the RMSE returned by Function 10. The average RMSE of all five functions is 15.2 and the average correlation coefficient is 0.983. The bottom plot in 5.4 shows the outcomes of all the predictive functions as compared to the actual measurements. Table 5.5 summarises the statistical results of both the daily and the monthly datasets.

5.7.2 TEA model VS. PVGIS and SAM model

The outcomes of Functions 8 and 10 of TEA model were compared to those of PVGIS and SAM(NERL) models for actual measurements of electricity generation by PV systems in Israel. The purpose of the comparison was to determine the accuracy of TEA model relative to the two other models. The outcomes show that during the cold months (i.e., January, February, November, and December), all three models provide

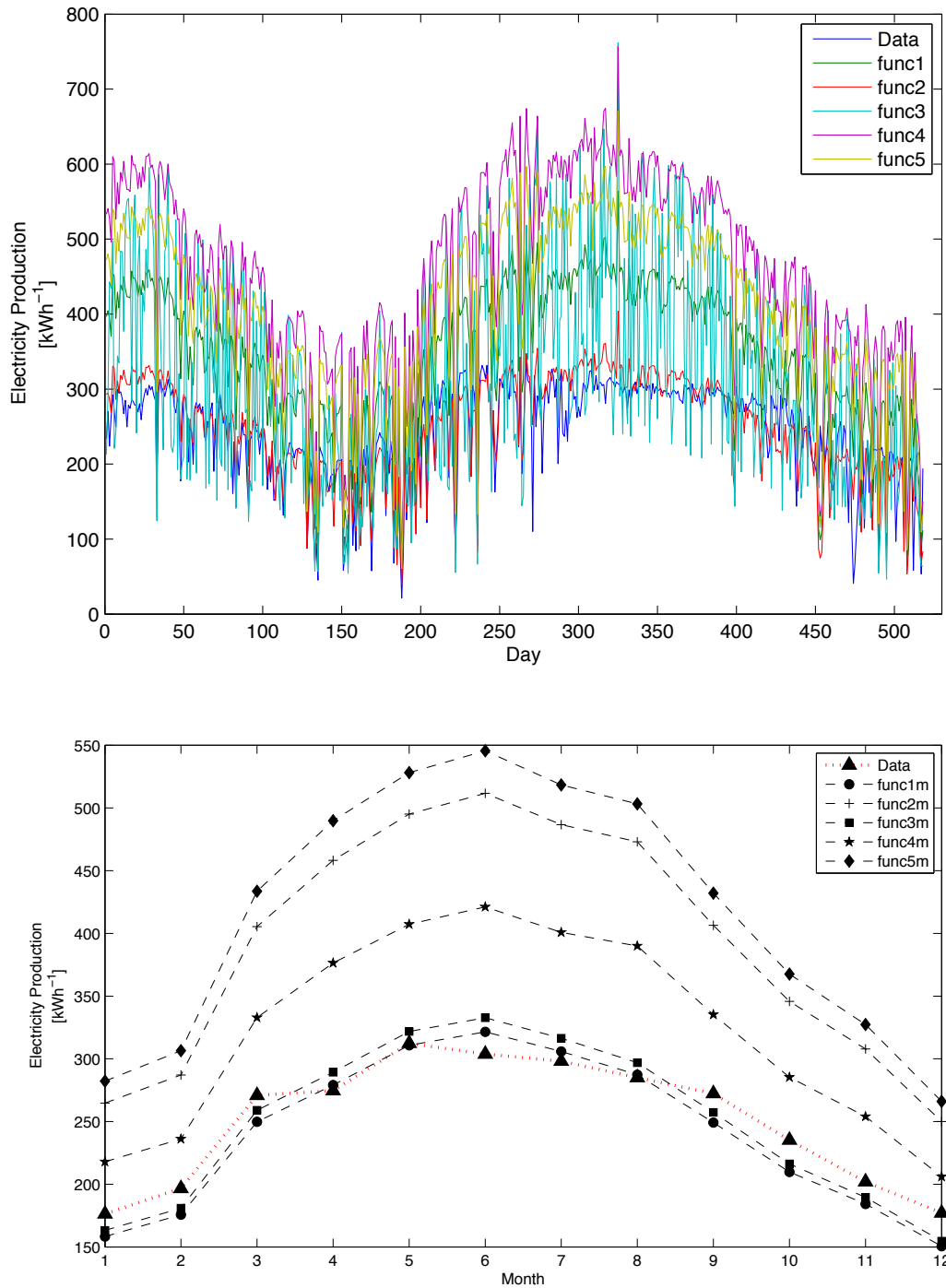


Figure 5.4: Comparison of average measured data to results of the TEA Model using 5 functions on both a daily (top plot) and monthly basis.

Table 5.5: Statistical outcomes of Phase 1: the TEA model measured against data collected on both a daily and monthly basis during 2010/2012

Dataset	Function	R-square	RMSE	Correlation
Daily	1	0.8669	32.51	0.93
	2	0.8712	22.87	0.93
	3	0.3712	115.3	0.61
	4	0.8664	43.63	0.91
	5	0.7862	46.65	0.81
Monthly	6	0.965	12.89	0.983
	7	0.97	17.48	0.985
	8	0.965	12.74	0.982
	9	0.971	14.06	0.986
	10	0.968	19.23	0.984

reasonable predictions when compared to the measured data. For example, in January the observed data showed a value of 175 kWh while the models predict a value between 160 and 180 kWh. However, during the hot months (March to October) both PVGIS and the SAM model underestimate the electricity generation. In June, for example, PVGIS and SAM predicted the daily average electricity production to be 263 and 162 kWh respectively, whereas observed data show values of 325 kWh. The predictions of PVGIS and SAM models represent an underestimation of 20% and 49% as compared to actual measurements. On the other hand, Function 8 of the TEA model predicted electricity generation to be 328 kWh (only 0.12% more) and Function 10 predicted electricity generation to be 347 kWh, or 6% more than the measured value.

Figure 5.5 shows the predictions of PVGIS model (indicated by the hollow diamond), the SAM model (indicated by a black star) and two versions of TEA Model (indicated by a black diamond and a black plus sign) against measurements of actual electricity generation by the PV system (indicated by a black circle). The figure represents one average day of electricity generation for each month.

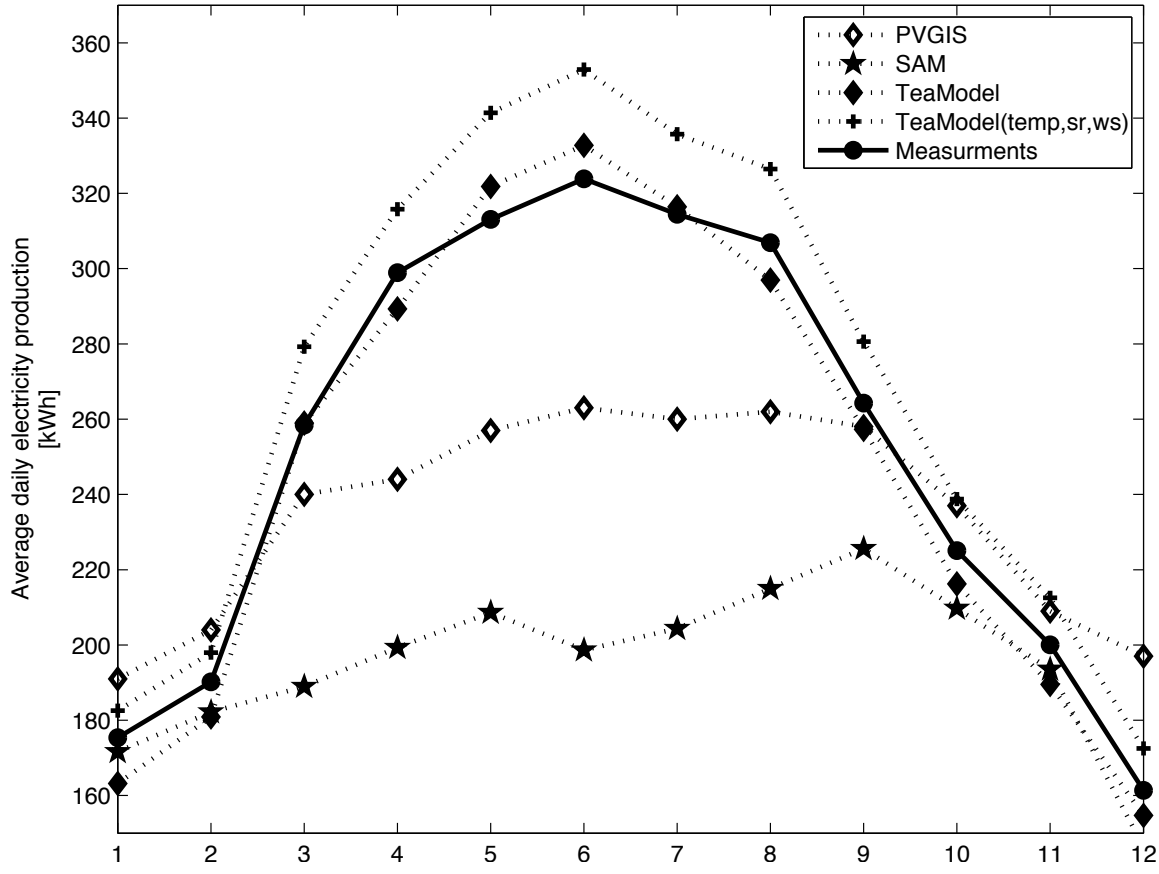


Figure 5.5: Monthly electricity generation compared with predictions made by various models

5.7.3 Phase 2 Results- PV system performances analysis

The final average annual yield for all four PV station was 1735 kWh/kWp . The highest value, 1850 kWh/kWp , was obtained by Station No. 4 and the lowest value, 1580 kWh/kWp , was obtained by Station No. 1. Average annual PR was 82.3% for all four PV systems. These results are significantly higher than the PV systems installed in Germany (Decker and Jahn, 1997), Ireland (Ayompe et al., 2011) and even around the Mediterranean Sea in Crete (Kymakis et al., 2009).

5.7.3.1 Temperature Losses (L_{tep})

One of the parameters determining PV panel efficiency is the temperature of the actual panel. As the temperature of a PV panels increases, its efficiency decreases with peak power output of PV panels being measured under Standard Test Condition (STC). The temperature loss coefficient is calculated by the following equation:

$$L_{tem} = 1 + \beta(T_c - 25) \quad (5.7.1)$$

where β is the temperature factor of the PV panel. PV cell temperature (T_c) is correlated with ambient temperature (T_a) as given by the following equation:

$$T_c = T_a + \frac{NOCT - 20}{80}(G) \quad (5.7.2)$$

where Nominal Operating Cell Temperature NOCT is defined as the temperature reached by open-circuit cells under STC. G is the power density on PV panels (Al-Rawi et al., 1994). In this research, the average annual loss due to temperature at all four PV stations was 9%. During the summer, average loss was 10.4% while during the winter average loss was 2.1%. In summer months (i.e., June, July, and August) average ambient temperature (T_a) in 2010-2012 was 30, 31, 31°C respectively (see Figure 5.6), and the cell temperature (T_c) was 46, 47, 47°C respectively. In winter months (i.e., December, January and February) the average ambient temperature, in years 2010-2012 was 15, 16, 17°C respectively and the cell temperature was 24, 26, 27°C respectively.

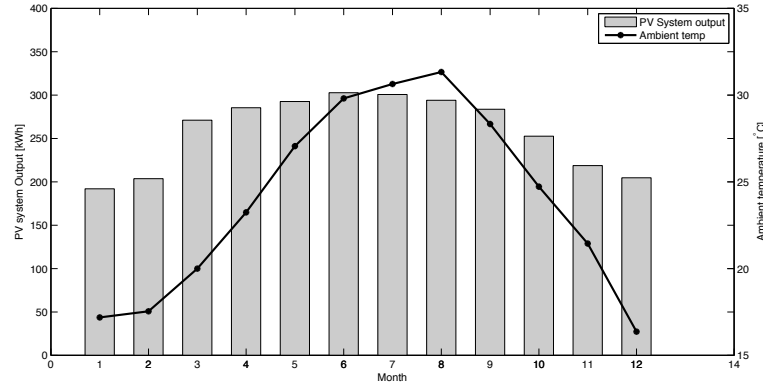


Figure 5.6: Average ambient temperature and average electricity generation for 2010-2012. Source: (IMS, 2012)

5.7.4 Aerosols and Air pollution losses (L_{aer})

Loss in electricity generation due to Aerosols and Air pollution (L_{aer}) was calculated using the formula:

$$E = H_t \cdot A_{arr} \cdot \eta \cdot L_{arr} \quad (5.7.3)$$

where, E is the annual or monthly energy output of the PV array. η is the panels efficiency, H_m is the total in-plane solar insolation and A_{arr} is the total area of the array (m^2). L_{arr} is the the total losses of the PV array.

$$L_{arr} = \sum L_{deg} + L_{tem} + L_{aer} \quad (5.7.4)$$

where, L_{deg} is losses due to degradation, L_{tem} is losses due to temperature and L_{aer} is losses due to aerosols and:

$$L_{aer} = \frac{E}{H_m \cdot A_{arr} \cdot \eta \cdot (L_{deg} \cdot L_{tem})} \quad (5.7.5)$$

According to equation 5.7.5, the average annual loss due to aerosols and air pollution in all four PV stations is 12.5%. This is the combined loss as a result of aerosols, $PM_{2.5}$ and NO_2 together. This number is relatively high as compared to studies which estimate loss to be between 5% (Kymakis et al., 2009) and 7% (Thevenard et al., 2010). Figures 5.7, 5.8 and 5.9 show that trends in electricity production when compared to NO_2 , Aerosols and PM are similar. The higher the electricity generation, the lower the values of aerosols and other air pollution components.

Figure 5.7 presents the electricity generation at all four PV systems compared to the concentration of NO_2 . Figure 5.8 shows the average monthly performance ratio of the PV systems plotted against the AOT index for 2010-2012. In both figures, the trend of electricity production is shown to be inverse to the concentration of particles in the atmosphere.

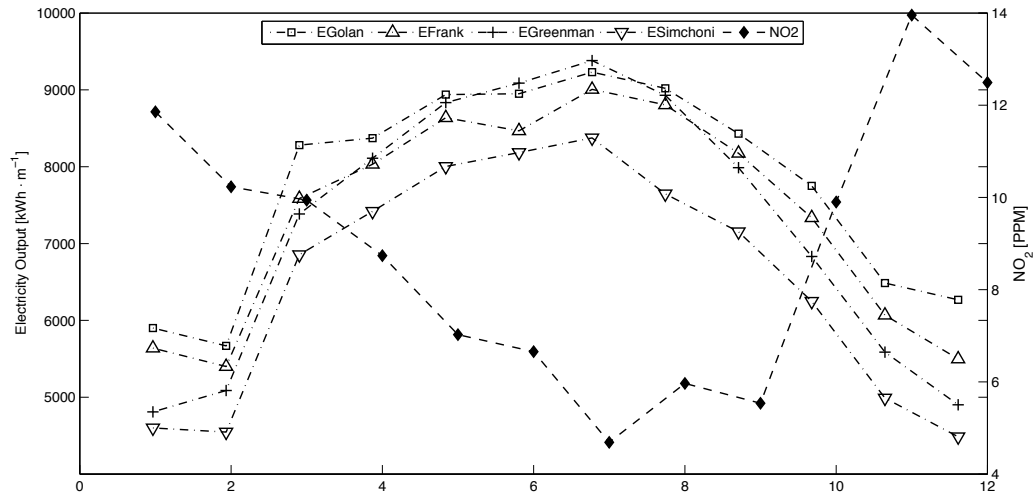


Figure 5.7: Comparison of Electricity production for four PV station against NO_2 measurements [Parts per Million (PPM)]

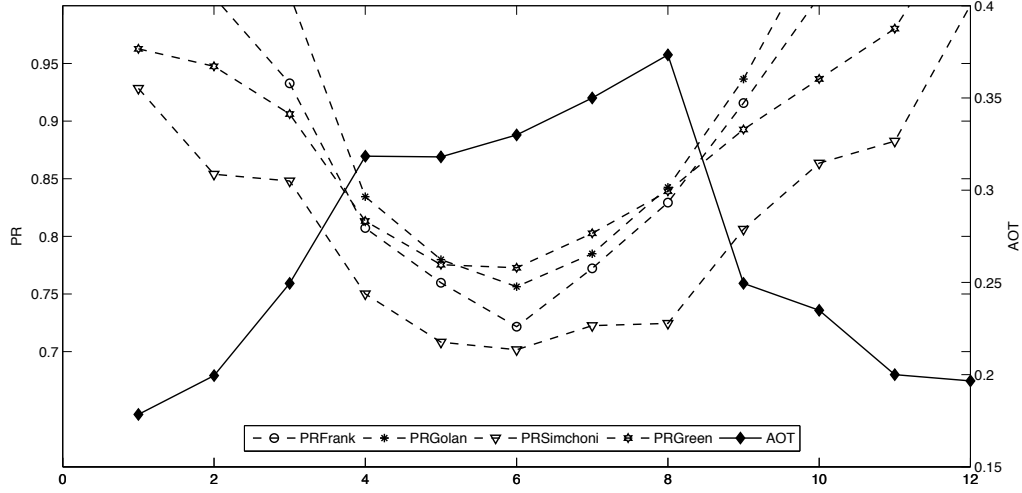


Figure 5.8: Performance ratio of 4 PV systems stations against AOT index

With respect to $PM_{2.5}$ concentration, more electricity was generated when the lowest $PM_{2.5}$ values were obtained. For example, in March the value of $PM_{2.5}$ was $26 \mu\text{gr}/\text{m}^3$ while the value of electricity production was 6500 kWh . However, in April when $PM_{2.5}$ value decreased to $22 \mu\text{gr}/\text{m}^3$, electricity generation increase to more than 7500 kWh (see Figure 5.9). This increase is due to the decrease in $PM_{2.5}$ concentration and not to the increase in solar radiation between March and April, a difference of less than 5%, in those two months. The change in electricity generation was 12%, a difference precisely equal to the measured change in $PM_{2.5}$ concentration.

5.7.5 Outcomes of Phase 3

In Israel, GHG emissions per unit of electricity (kWh) generated by standard natural gas and coal power plants is $560 \text{ grCO}_2/\text{kWh}$ (see equation 5.5.7). However, the GHG emission per one unit of electricity generated by PV panels can be varied from $15 \text{ grCO}_2/\text{kWh}$ to $50 \text{ grCO}_2/\text{kWh}$ depending upon the type, life time, efficiency and the location of the panels (Sherwani et al., 2010). Based on the outcomes of the TEA

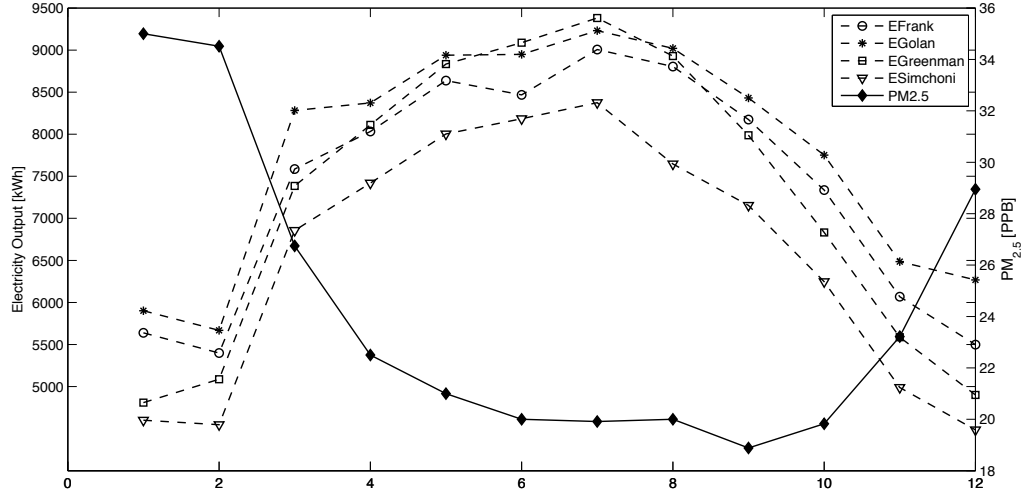


Figure 5.9: Electricity production against $PM_{2.5}$ concentration [$\mu gr/m^3$]

model, as well as on the system analysis, the reduction in greenhouse gases by the use of solar energy is $520 grCO_2/kWh$. That means than one system of $50kW_p$ produces an average of $88,000 kWh \cdot yr^{-1}$, so one system prevents emission of $46,000 kgCO_2 \cdot yr^{-1}$ compared to electricity generation by standard fossil fuel power plants.

5.8 Summary

The TEA model measures the effect of atmospheric parameters on capacity of power production and calculates PV system performance. Using a multiple regression based on historical measurements of electricity generation capacity (2010-2012) and measurements of several atmospheric components, the TEA model draws upon a multi-criteria approach as more than one factor may affect the quality of energy that solar technology is able to generate (see section 3.4.2 and 5.1).

As the TEA model was developed to optimise the selection and the application of solar energy technology in Israel, determine system performance, and GHG reduction, the

following conclusions can be drawn:

The TEA model provides accurate predictions of electricity generation capacity compared to existing commercial models with an over-estimation of less than 0.5%. It was also found that the average annual energy output is $1735 kWh/kW_p$ and the average annual performance ratio is 82.3%. With regard to atmospheric pollution, it was found that increases in air pollution yield decreases in electricity generation. It was also found that each PV system in Israel can prevent $520 grCO_2/kWh$ of GHG emissions.

The next chapter (Chapter 6) of this thesis aims to find the optimal Feed In Tariff (FIT) for PV system in Israel, in order to develop the RE market. Chapter 6 uses a mathematical model including Linear Program (LP) to optimise the level of the subsidise. The model in Chapter 6 uses the output from TEA model as the basis of the general electricity capacity in Israel. This policy model uses a multi-parameter regression in order to gather all the relative information, based on historical data to determine optimal FIT based on the following parameters; price of PV system, share of loan, initial costs, O&M costs, and operational system factors.

6

Design of Model for Analysis of RET Policy: The case of Israel

6.1 Introduction

After hydro and wind power, photovoltaic technology is the third most important source of renewable energy for electricity generation in terms of its worldwide installed capacity. Improvements in technology and economies of scale have spurred steady cost reductions and these are predicted to continue in the coming years as the PV industry progresses toward competitiveness with conventional energy sources.

However, the renewable energy industry could not exist without government support. Governments have implemented policies to promote both consumption and production of clean energy in general and solar energy in particular. Subsidies are the primary instrument for encouraging development of solar energy in almost every country in the world. These subsidies assume many forms: investment grants or capacity payments, output- or production-based payments, and soft loans (e.g., interest subsidies) (Timilsina et al., 2012). Policies to promote renewable energy technologies have a long tradition in many OECD countries. Even before carbon-pricing instruments to reduce carbon emissions were implemented, many countries used subsidies, Feed In Tariffs (FIT) or public research and development grants to promote renewable energy (Kalkuhl et al., 2013). However, these policies vary considerably across countries and time periods all of which contribute to regulatory uncertainty (Haley and Schuler, 2011).

Institutional investment is deterred both the uncertainty surrounding government policy and general lack of expertise with renewable energy.

Uncertainty in the solar energy sector arises because volume of global demand is unclear. This can be attributed to the uncertainty surrounding the size of government subsidies that the industry as a whole may receive. This uncertainty causes fluctuation in the cost of technology since the quantity of PV panels produced in factories around the world is not constant. Likewise, due to frequent cost changes, demand for this technology is uncertain and this in turn promotes lack of clarity concerning this sector's economic feasibility. In addition, the cost of production of electricity by conventional means such as natural gas and other fossil fuels is changing. In Israel, for example, the recent discovery of large reservoirs of natural gas has dramatically changed electricity pricing causing subsidies for solar energy to change as well.

Even with regard to subsidies for renewable energy, there is an internal conflict between public interest and the interests of private investors. While private investors always seek to maximise profits and increase revenues from each kWh of electricity produced by PV systems, this opposes the public interest which has subsidised the cost of renewable

energy technology, either through taxation or the payment of higher electricity rates.

This chapter indicates a direction for resolving this conflict via use of mathematical and economic models. The model presented here uses several different methodologies such as Monte Carlo simulation to create different scenarios of initial cost. It uses a linear program to find the minimum and maximum rates for FIT and an economic model to find the payback period for return on investment and overall profitability.

6.2 Global PV Prices

By the end of 2009, cumulative installed PV capacity was close to 23 Gigawatt (GW) worldwide. In 2010 it was 40 GW worldwide and by 2011, over 69 GW worldwide. This amount of PV capacity was able to produce 85 TWh of electricity every year (EPIA, 2011). The growth rate of installed PV technologies during 2011 reached almost 70%, an outstanding level among all renewable technologies (see Figure 6.1).

Since then renewable energy continued to grow and in 2014 against the backdrop of increasing global energy consumption, particularly in developing countries, and a dramatic decline in oil prices during the second half of the year. Globally, there is growing awareness that increased deployment of renewable energy (and energy efficiency) is critical for addressing climate change, creating new economic opportunities, and providing energy access to the billions of people still living without modern energy services.

In 2014, renewables represented approximately 58.5% of net additions to global power capacity, with significant growth in all regions. By year's end, renewables comprised an estimated 27.7% of the world's power generating capacity, enough to supply an estimated 22.8% of global electricity (REN21, 2015).

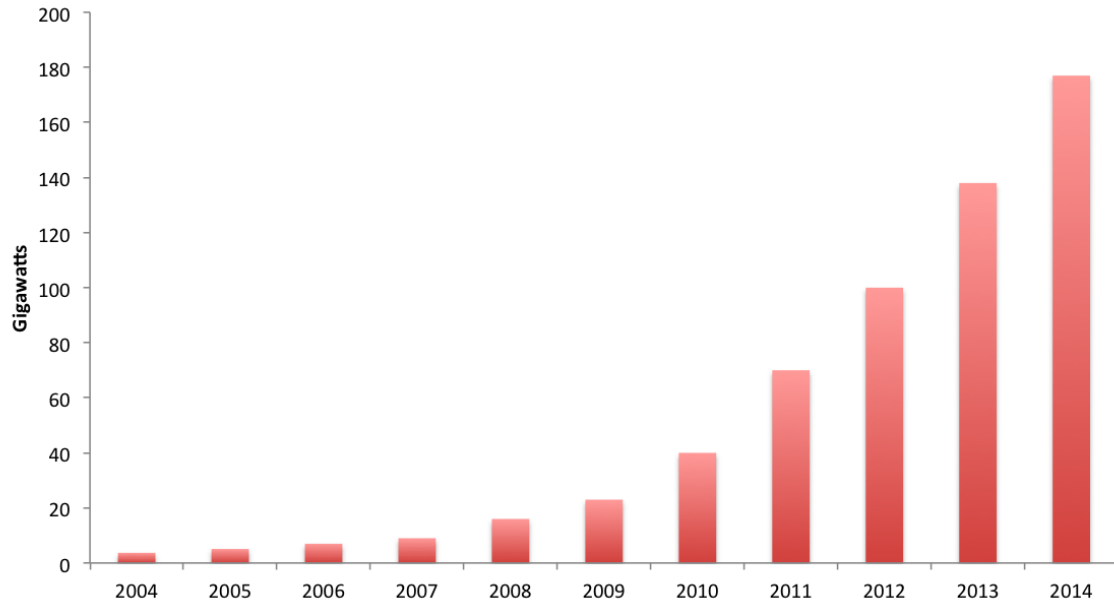


Figure 6.1: Global cumulative installed capacity 2004-2014 (GWp), Source: (REN21, 2015)

6.2.1 Cost reduction of PV systems

Since 2009, prices of installed PV systems have fallen precipitously. During 2010 and 2011, prices fell by $\$0.72/Wp$ (11%) for systems of $10kWp$ or smaller, $\$0.89/Wp$ (14%) for systems of $10 - 100kWp$, and $\$0.77/Wp$ (14%) for systems larger than $100kWp$.

The massive growth in the solar energy market was caused by a sharp fall in cost of PV technology. The solar PV industry recovery, which began in 2013, continued in 2014 thanks to strong global demand. Average module prices fell during 2014, with multicrystalline silicon module spot prices down about 14% year over year to USD $0.6/Watt$ (Chandramohan et al., 2015). The drop in spot price was driven by incremental module production cost reduction, lower regional price levels, and weaker-than-expected demand (REN21, 2015).

In Israel prices* of PV systems in the private and residential sector fell from \$3.4/W_p in 2010 to \$2.86/W_p in 2011 to \$1.99/W_p in 2012.

Increased device efficiency, large-scale silicon production, and market demand were the major drivers of cost reductions, accounting for 30% and 40% of the reduction respectively (Candelise et al., 2012).

Technology improvements and economies of scale have spurred steady cost reduction, which will continue in coming years as the PV industry progresses toward competitiveness with conventional energy sources (EPIA, 2011). Table 6.1 summarises the rate of decline in PV system prices (at the bottom) between 2010 - 2015 and the FIT for those years. As shown in Table 6.1, the FIT declined by 26% in 2011 and by 40.4% in 2012, while the system prices decline by 16% and 41.1%. Similarly, the drop in tariffs from 2012 and 2013 was negligible at 0.09%, while during these years was an average decrease of 7% of PV system price. This imbalance leads to the Israeli taxpayer, (indirectly by raising electricity prices) to pay for renewable energy higher prices compared to the global PV market trends.

6.3 Development of RET in Israel: technology, markets and policy

A large number of policy instruments have been implemented to support solar PV technology including feed in tariffs, investment tax credits, subsidies, favourable financing, mandatory access and purchase, renewable energy portfolio standards, and public investment (Haley and Schuler, 2011).

Many developed countries like UK, Germany, Sweden, Italy, and Israel have set penetration targets at national or state/provincial levels to influence the mix of renewable energy in the total electricity supply. Electricity suppliers (e.g., utilities, distributors)

*Based on 412 PV systems of 30 – 50kW_p

Year	FIT\$/ <i>kWh</i>	Change (prev. year)	Change (compared to 2010)
2010	\$ 0.51	—	—
2011	\$ 0.377	26.0%	26.0%
2012	\$ 0.225	40.4%	55.8%
2013	\$ 0.223	0.09%	56%
2014	\$ 0.18	0.2%	64%
2015	\$ 0.16	0.11%	68%
	I_c \$/ <i>kWp</i>	Change(prev. year)	Change (from 2010)
2010	\$ 3405	—	—
2011	\$ 2863	16.0%	16.0%
2012	\$ 1992	30.4%	41.1%
2013	\$ 1870	7.2%	45.1%
2014	\$ 1870	—%	45.1%
2015	\$ 1650	11.8%	52.3%

Table 6.1: Average FIT(\$/*kWp*) and an average of the total cost of 50 kWp PV system (\$/*kWp*) in Israel, 2010-2015

have been mandated to derive a certain percentage of their electricity supply from renewable energy sources. These standards are commonly known as renewable energy portfolio standards (RPS) or Tradable Green Certificate schemes (TGC) in Europe. These standards create a trading regime wherein utilities with no or low renewable electricity content in their overall supply portfolio purchase credits from those with high renewable electricity content (Haley and Schuler, 2011).

6.3.1 Feed In Tariff

The main idea behind feed in tariff policies is the offer of guaranteed pricing for electricity produced by Renewable Energy Sources (RES) over fixed periods of time (mostly 20 - 25 years). The prices for kWh of electricity generated can be modified according to type of technology, size of installation, and location of the system (Fouquet and Johansson, 2008; Couture and Gagnon, 2010).

The FIT policy framework has been evaluated in relation to other energy and climate

policy mechanisms. Verbruggen and Lauber (2012) find that well well-designed FIT frameworks yield better results than Green Certificate policies. Nevertheless, the FIT support scheme has been subject to considerable public debate, and a common argument against it is the high cost to general consumers who fund these technologies through an extra tax on their electricity bill (Verbruggen and Lauber, 2012).

On the other hand, FIT can significantly reduce the risks of investing in renewable energy technology and thus create conditions conducive to rapid market growth (Lipp, 2007; Couture and Gagnon, 2010). This mechanism provides a high degree of security with regard to future cash flows which in turn enables investors to raise money from banks and other financial institutions. FIT is considered to be more effective and entailing lower cost than alternative policy mechanisms (Lipp, 2007; Couture and Gagnon, 2010). Ensuring that FIT payments are adequate to recover project costs over the lifetime of the project while allowing for a reasonable return on investment remains one of the central challenges of a successful FIT policy.

Remuneration should cover electricity generation costs and provide a reasonable profit to investors. On the other hand, the cost of FIT subsidies is generally transferred to electricity consumers in the form of higher electricity pricing. While high FIT may lead to high investor return, it also places a greater burden upon society (i.e. electricity consumers) (Klein et al., 2010). The great challenge, for the policy makers, is to determine the appropriate level of FITs that will generate increased market share while keeping costs of electricity consumption at a moderate level.

6.3.2 FIT in Israel

To meet government targets, Israel has developed RE subsidy systems for large solar and wind plants, as well as for a mixture of small biomass and PV systems. The Public Utility Authority (PUA) is responsible for issuing licenses and setting RE tariffs (Mor and Seroussi, 2007).

Tariffs for solar thermal generation are differentiated by size, reflecting the economies of scale inherent in solar technology. Solar thermal units with installed capacities under $100MW$ receive a higher tariff than units with installed capacities of $100MW$ or more. The tariffs are also differentiated by the time periods for which they are effective the first 20 years and the next 10 years. According to government policy, solar thermal units may retain their classification as fossil-fuel backup for up to 30% of their installed capacity and are compensated according to relevant fuel prices. The tariff upon units with less than $100MW$ capacity and units with at least $100MW$ capacity are currently set at 20.7 \$ cents and 16.5 \$ cents per kWh respectively. The PUA projects that at least $200MW$ of additional solar thermal capacity will be developed during the coming years (PUA, 2008; Kravetz, 2008).

This chapter reviews and analyses the different FIT mechanisms employed in Israel and determines how to find the optimal FIT that balances investor interest against the public interest.

6.4 Model Design- Methodology

The Methodology is divided into four steps:

1. The first step including the definition of an optimal FIT where a target of a profit margin should have to the PV system owner as explained in Section 6.4.1 on page 128.
2. The second step is to model the uncertainty in PV system price. This step including a Monte-Carlo simulation in order to generate a multiply scenarios of PV system prices. The main idea behind this step is to take into account unpredicted changes of PV prices due to; technological breakthrough, changes in the global PV market or regulatory changes.
3. The third step of this model uses a linear program based on historical data.

The model follow the price evaluation and taking into account the profit margin required by the PV system owners.

4. Finally a two-stage model was build to calculate the optimal FIT including all scenarios for technology price changes, electricity price changes, and different types of loans. The two-stages model determine one number for optimal FIT based on all the analysis and calculation made by the model in three steps above. This result should provide the decision-makers, a very close approximation what should be the optimal FIT considering all possible scenarios. These scenarios take into account changes in electricity prices, changes in PV systems price, a breakthrough or a technological leap and changes in the global PV market.

A summary of the methodological approach is presented as a schematic flow chart in figure 6.3 in section 6.4.5.

6.4.1 Definition of Optimal FIT

In order to run a mathematical model to determine what should be the optimal FIT, it is necessary to determine what is an optimal profit margin for the investors in PV system market in Israel. Since the Israeli Electrical Corporation (IEC) load the electricity output to the grid and there is a contract between the IEC and the investors for 20 years there is high level of certainty in this business and the level of risk is relatively low. Therefore, optimal FIT consider when the return on investment (ROI) accepted after 6-7 years with 95% exceedence probability.

6.4.2 Collection and Input Data

Data from 412 PV systems installed in Israel during 2010 - 2015 form the basis of this analysis. They contain the Initial price (I_c) of PV systems which includes the price of modules, inverters, infrastructure, consulting, engineering, wiring, and system installation. For the economic analysis, the average of the total price ($\bar{I}$) was calculated

separately for 2010–2015 based on more than 400 PV system installed in Israel during that time of period. In addition, the average FIT ($\overline{FIT}_{(j)}$) was calculated separately for each year, as shown in Table 6.1. All the assumptions and the data presented in Table 6.1 are based on a data which collected from PV system owners, banking rates, the average rate in Israel as published by the Bank of Israel,

Figure 6.2 presents the average share of each part involving of building a PV system.

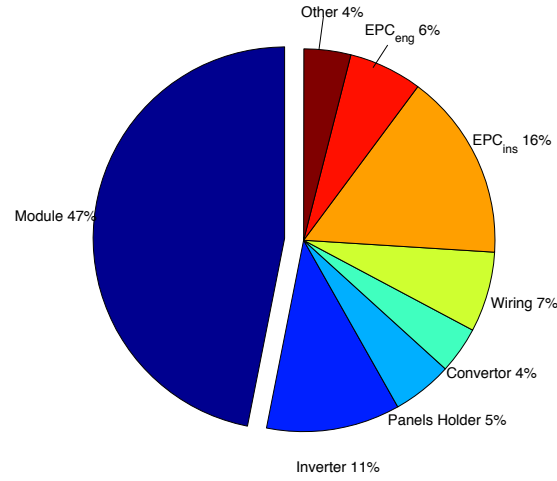


Figure 6.2: The distribution cost of a 50kWp PV system

Sector	Acronym	Value	Unit	Data Source
Systems Data	Yearly yield (Y)	1700	kWh/kWp	TEA Model
	Installed capacity	50	kWp	—
Expenses	Insurance	0.5	% (of the total price)	S.O
	O & M	850	US \$ per year	S.O
	Panels' degradation	0.5	% per year	S.O and Manufacture Info
	Discount Rate	2.5	%	Bank of Israel
	Inflation	0.5	%	Bank of Israel
Financing Data	Tax	25 ^b	% per year	Bank of Israel and Tax authority
	Funding rate	50–80	% (of the total cost)	—
	Interest rate ^c	7.4	% per year	Average banking rate
	Loan period	20	Years	S.O

^a System Owner- Based on average of 412 System Owners.

^b The tax for solar panels in Israel paid from the fifth year onwards.

^c Interest rate is linked to a tracker

Table 6.2: Input data for the economical analysis

6.4.3 Monte-Carlo Simulation

The Monte Carlo simulations functioning as a crucial step when this model was built. The Monte-Carlo simulation helps to consider many scenarios as needed in order to take into account all the possibilities for unexpected changes in many variables such as; the initial price of a PV system, global changes in the PV market, the price of conventional electricity, insurance premiums and the ability of the IEC to upload electricity to the grid. This is the reason for the relatively high variance results obtained from running the model as explained in Section 6.5.1 on page 138. However, it is important to consider all possible scenarios in order to get a big picture to determine the long-term policy options of solar energy subsidisation in Israel.

The Stochastic Model

$$\Delta x_t = \alpha(\mu - x_t)\Delta t + \sigma dz_t, \text{ where } dz_t \sim N(0, \sqrt{\Delta t}) \quad (6.4.1)$$

α = Mean Reversion Rate

μ = Mean level

σ = Volatility

This model can be calibrated to historical data by performing a linear regression between log prices and their first differential. Specifically, the equation can be rewritten as:

$$\frac{\Delta x_t}{\Delta t} = -\alpha x_t + \alpha\mu + \frac{\sigma}{\Delta t} dz_t \quad (6.4.2)$$

This is a model that supposes Initial price (I_c) is fairly stable and can be well predicted

through factors α and that the FIT fluctuates around it (Rampertshammer, 2007).

Calibration Parameters

The reversion rate and mean level can be calculated from the coefficients of a linear fit between log prices and their first differential scaled by the time interval parameter. All quantities are specified on an annual scale using the following code:

```
x = log(Ic);
dx = diff(x);
dt = 1/250;
dxdt = dx/dt;
x(end) = [];

Fit a linear trend to estimate mean reversion parameters
coeff = polyfit(x, dxdt, 1);
res = dxdt - polyval(coeff, x);

revRate    = -coeff(1)
meanLevel  = coeff(2)/revRate
vol         = std(res) * sqrt(dt)
```

6.4.4 Linear Program

In order to calculate the optimal FIT in Israel a Linear Program (LP) which minimises the FIT to its optimal level was used. As FIT is a function of electricity price (P_e), technology price (P_t) and a constant representing the price of building a PV system regardless of the changing PV market, FIT was calculated according to the formula below:

$$FIT(P_e, P_t) = \alpha + \beta P_e + \gamma P_t \quad (6.4.3)$$

Linear Program:

$$\begin{aligned} & \min [\alpha + P_t \cdot x_1 + \beta x_2] Y \cdot S - \alpha \cdot S \\ & \min \quad c^T x \quad \text{such that} = \begin{cases} A \cdot x \leq b \\ A_{eq} \cdot x = b_{eq} \\ lb \leq x \leq ub \end{cases} \end{aligned} \quad (6.4.4)$$

Constrains:

$$\begin{aligned} \alpha + x_2 p_t &\geq x_1 p_e \\ x_1 p_e - x_2 p_t &\leq \alpha \\ A &= [0 \quad p_e \quad -p_t] \\ b &= [\alpha] \\ lb &= (\max(D, \text{target})) \end{aligned}$$

Where, α is a constant which represents the basic investments involved in building a solar PV system (see Equation 6.4.5, regardless of variability in PV market prices (see Figure 6.2). β is a coefficient of the electricity prices and γ is a coefficient of the PV prices. Y is the yearly yield of a PV system in Israel (kWh/kWp) and S is the size of the system (kWp)

$$\alpha = E_c + O\&M + W_c + C_c + F_c + E_c \quad (6.4.5)$$

Table 6.3 presents the symbols and values used in the input of the Linear Program. The value of α was determined by the Stochastic Model as explained in section 6.4.3.

Symbol	Definition	Value	Unit
α	The price of a PV system without the panels	rand no.	\$ /kWp
β	Coefficient cost of electricity generation by fossil fuels		\$ /kWh
γ	Coefficient cost of electricity generation by RET		\$ /kWp
Y	Yearly yield	1750	kWh
D	Total demand of electricity (gas+coal+re) in 2020	$2.76 \cdot 10^7$	kWp
P_e	Electricity price to an average household consumer	0.127	\$ /kWh
P_t	Price of RE technology (i.e., PV panels)	1000	\$ /kWp
C_s	The Cost of a PV system ($\alpha + P_t$)	1940	\$ /kWp
E_c	EPC (Engineering, Procurement and Construction) costs		
$O\&M^a$	Operation, maintenance and insurance costs	850	\$
W_c	Wiring, cables and converters price	1400	\$ /kWp
C_c	Consulting price	120	\$ /hr
F_c	Funding cost	share of loan	\$

^a including panels degradation

Table 6.3: Symbols and values which used as an input data to the Linear Program

Two Stage Model

In order to reduce uncertainty in the pricing of solar energy technology and the FIT, a two-stage stochastic model is used. The basic idea behind two-stage stochastic programming is that optimal decisions are based upon data available at the time decisions are made and not upon future observations. With regard to FIT pricing, decision-makers take some action in the first stage, after which a random event affecting the outcome of the first stage decision occurs. This means that optimal FIT is determined by using historical data as input into the linear program for each of the parameters. Then only one solution is obtained for all the possible scenarios

6.4.5 Economic Parameters

With regard to its financial aspects, the cost and revenue for a 50kWp PV system is analysed, based both on historical and current data (more details can be found in the section 6.4.2). The analysis was performed for the years 2010–2015 under four different

levels of funding: 50%, 60%, 70%, and 80%. The economic parameters used in the analysis were: Net Present Value (NPV), Internal return rate (IRR), annual yield, and the period of time required to return the initial investment. These parameters were calculated based on prices of an average 50kWp PV system . and the average FIT that was paid during each year (see table 6.1)

NPV is an indicator of how much value an investment or project adds to a firm or company. With a particular project, if R_t is positive, it means that the project has a positive cash inflow at time t . If is negative, it means that the project has a discounted cash outflow at time t . Net present values are determined for the PV system considered in each interest rate scenario and for each location. The NPV of an investment is the sum of the present worth of annual net cash flow (revenues-expenses) generated by the project (Mitscher and Rther, 2012). The NPV is mostly used in long-term projects to account for the so called "time value of money" by transforming cash flows into their values at specific points in time.

$$NPV(i) = \sum_{t=1}^N \frac{R_t}{(1+i)^t} \quad (6.4.6)$$

To ensure that the capital investment of a PV system is fully recoverable with an acceptable rate of return over the system life cycle, it is necessary to perform the financial analysis for the PV system by considering the system investment price and the annual revenue from selling PV generated power and O&M cost. Because the performance of PV panels degrades over years of operation, the analysis applies a derating factor in order to obtain the decrease PV energy yield. The resulting NPV of a PV system in the final year is obtained by summing the annual present values of all cash flows, including capital investment, O&M costs, and revenue generated by the PV system over its life cycle. A project is considered financially feasible only if the resulting NPV is positive. The NPV of an investment can be calculated according to:

$$NPV = -I + \sum_{j=1}^N \frac{CF_j}{(1+i)^j} \quad (6.4.7)$$

where I represents the initial investment. CF_j represents the cash flow in year j with an i discount rate.

The net cash CF calculated by Equation 6.4.8.

$$CF_j = FIT \cdot Y \cdot (i)^j - O\&M \cdot (1+f)^j - T \cdot (1+f)^j \quad (6.4.8)$$

where

FIT	The price of electricity selling to the grid (\$/kWh)
Y	Annual generation of electricity- Yearly Yield kW_p (kWh/kWp)
i	Discount rate of PV energy price
$O\&M$	The cost of operation and maintenance ^a (\$/year)
T	Tax for energy from PV systems (\$/year)
f	inflation rate (%)

^a including panels degradation, insurance and the cost of replacement of inverter after 10 years.

Internal Rate of Return (IRR) indicates the financial return based upon alternative returns that could have been obtained with the same investment. The IRR is the discount rate that creates a zero net present value. The IRR is based on the NPV formula (6.4.7), and is solved iteratively for $NPV = 0$.

$$NPV(0) = -I + \sum_{j=1}^N \frac{FCF_j}{(1+IRR)^j} \quad (6.4.9)$$

Discount Factor $DF(t)$, is the factor by which a future cash flow must be multiplied in order to obtain the present value where i is the discount rate for the cash flow at time t , the discount factor is calculated by:

$$DF(t) = \frac{1}{(1+i)^t} \quad (6.4.10)$$

The discount rate is the percentage by which the value of a cash flow in a discounted cash flow (DCF) valuation is reduced for each time period by which it is removed from the present.

$$i = \frac{LR + f}{1 - f} \quad (6.4.11)$$

Where LR is the loan rate and f is the inflation rate.

Summary of Methodology

Flow chart 6.3 summarises the behaviour of the FIT Model. The chart shows how the data been processed at each stage of the model from the data collection at the beginning phase through the analysis to the obtaining of conclusions.

The conclusions presents in the Chapter 6.6 on page 144 are based on the outcomes obtained by the FIT Model.

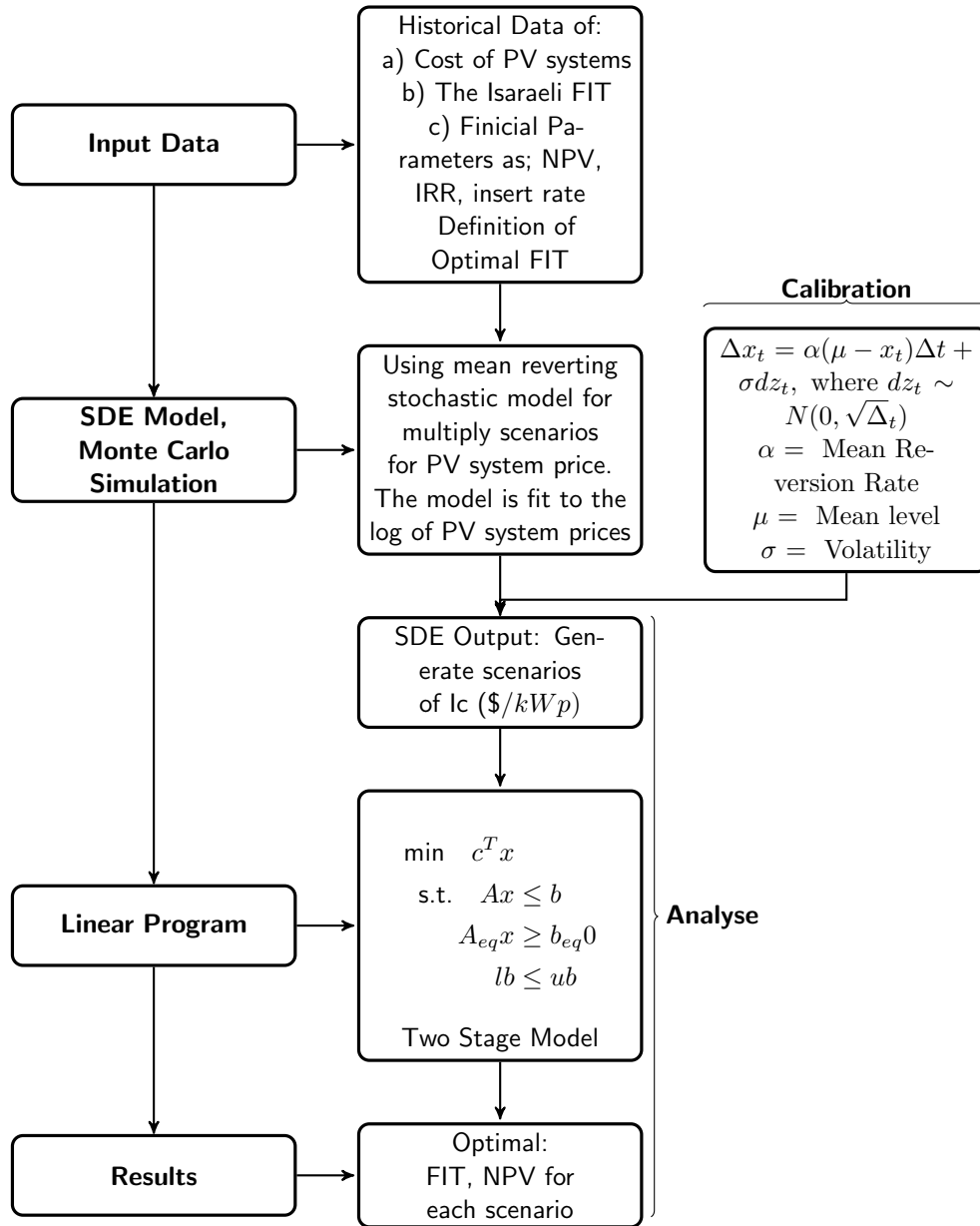


Figure 6.3: FIT Model description

6.5 Results of Policy Analysis

6.5.1 Monte Carlo Simulation- SDE Results

The model defined above can be simulated with the Stochastic differential equation (SDE) object to generate multiple log price paths. These are exponentiated to compute simulated PV system prices. Figure 6.4 shows 100 paths simulated 500 days into the future. The upper plot (line plot) presents 4000 scenarios of Initial Price (I_c) of a PV system based on historic data obtained from the 412 PV systems installed in Israel between 2010–2015. The bottom plot (bar plot) shows the results of the scenarios. The costs of a PV system vary from \$1000 to \$3500 per kWp and the mean value of the simulation is \$2240 per kWp . These results are very close to the actual initial price of a PV system in Israel.

The results of this phase of the model enable the generation of an optimal FIT based on various initial prices.

6.5.2 Linear Program Results- An Optimal FIT

After the SDE model generated the I_c database, the linear program solved the optimal FIT for each I_c based on Equation 6.4.3. Figure 6.5 presents the results for NPV and optimal FIT for each type of loan (50%–80%) for the 4000 scenarios of I_c . The optimal FIT varies from \$0.08 per kWp at a 50% loan share to \$0.2 per kWp for an 80% loan share.

Table 6.4 shows the mean value of each one of the parameters obtained by the LP model. As expected, the higher NPV obtained when the highest loan was taken. Rates of 50% and 60% are negative which means it is not economical to install PV system at that loan level. However, at the 70% or 80% loan share level NPV becomes

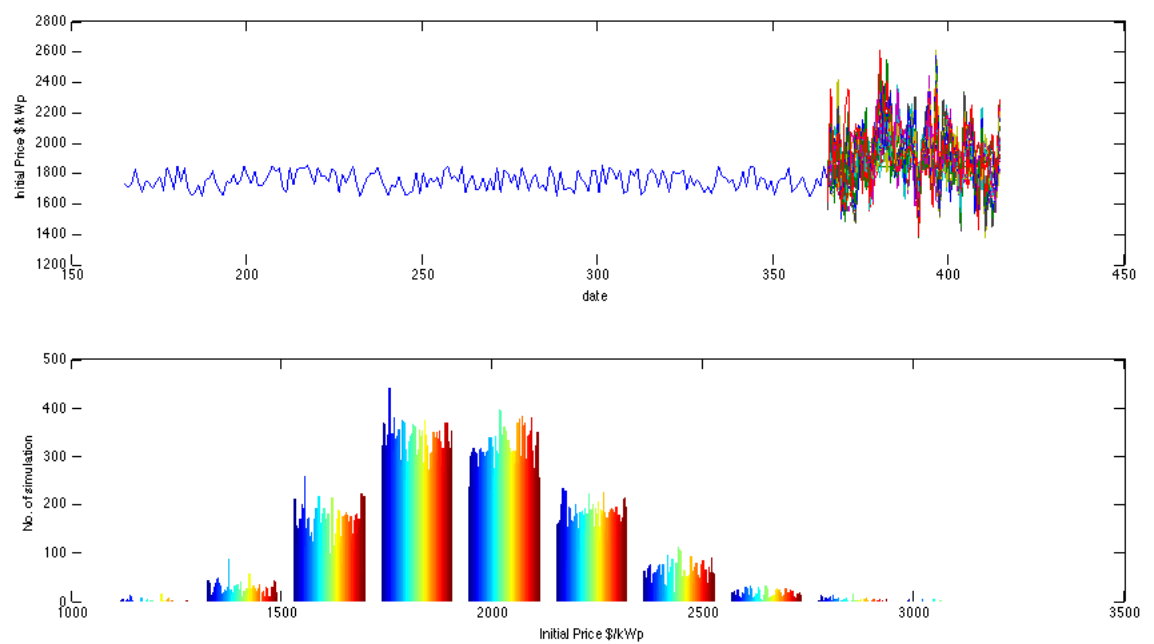


Figure 6.4: Monte-Carlo Simulation results of 4000 run using historical data of PV systems installed in Israel

positive so it is economical to install PV systems in Israel at that level of loan share.

Share of Loan	NPV	IC	FIT
0.5	-1.627e+03	2.04e+03	0.1136
0.6	-526	2.075e+03	0.111
0.7	4.25e+03	2.02e+03	0.112
0.8	9.92e+03	2.012e+03	0.09

Table 6.4: The average results of 4000 runs for four different scenarios of share loan of the FIT Policy Model

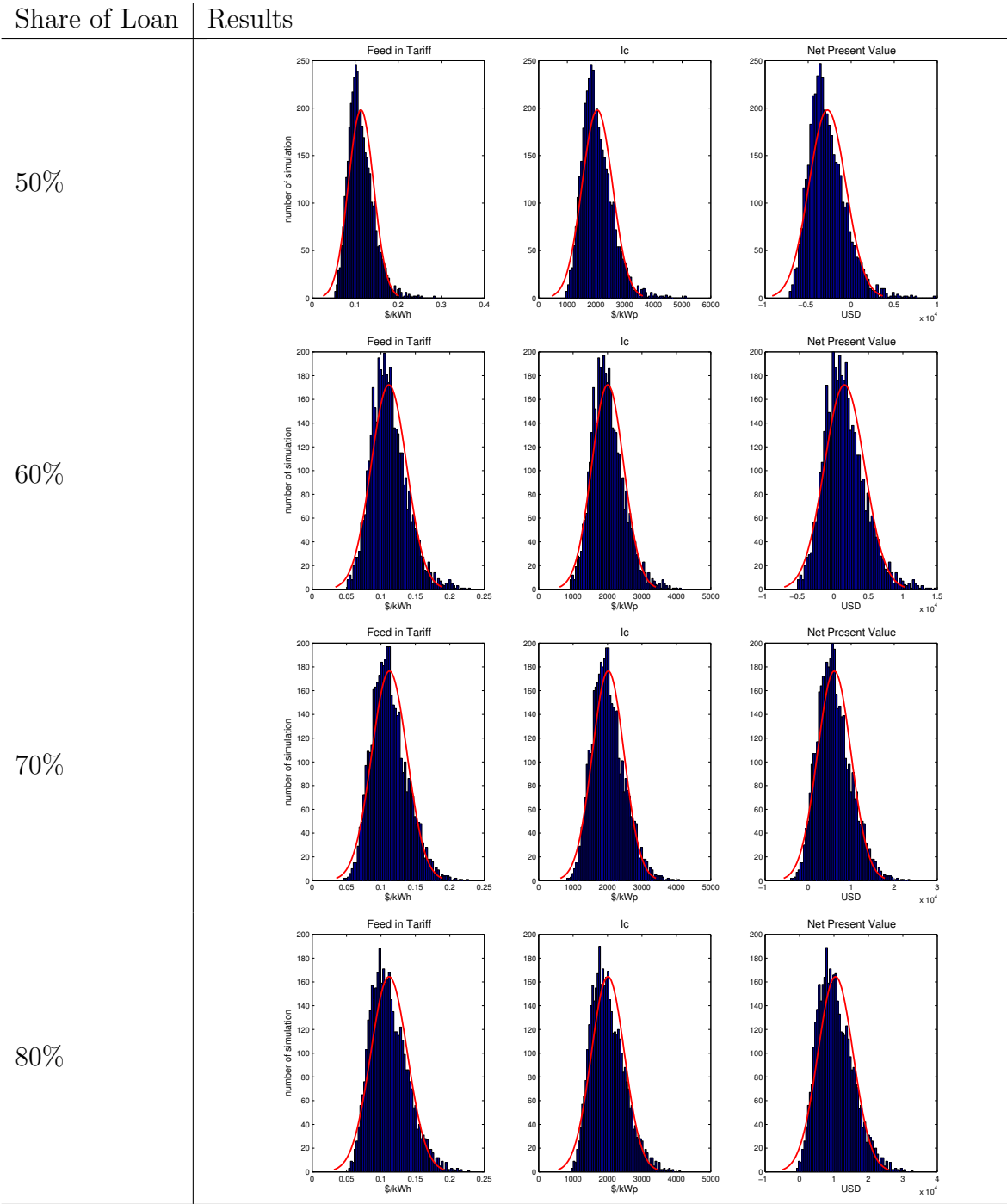


Table 6.5: Optimal FIT, Initial costs and NPV results for four scenarios of share loan

Figure 6.5 shows the cash flow during life cycle of a PV system with four scenarios of loan shares (50% - 80%) using the outcomes of the FIT Policy model. The 'X' axes represent the time (years) and the 'Y' axes represent the cash flow for the project (\$). There are four colours in the graph for each type of loan. It is important to emphasise that after 10 years there is a on-time decrease of the cash flow. This is due to the need to replace inventors during the life cycle of a PV system. At a 50% loan share the return on the investment will occur only after 12.8 years, at a 60% loan share only after 9 years, at a 70% loan share only after 7 years, and at an 80% loan share only after 6.7 years. Since the directive of the model defined return on investment within seven years at the most, the NPV is negative when ROI is more than 7 years, otherwise is positive.

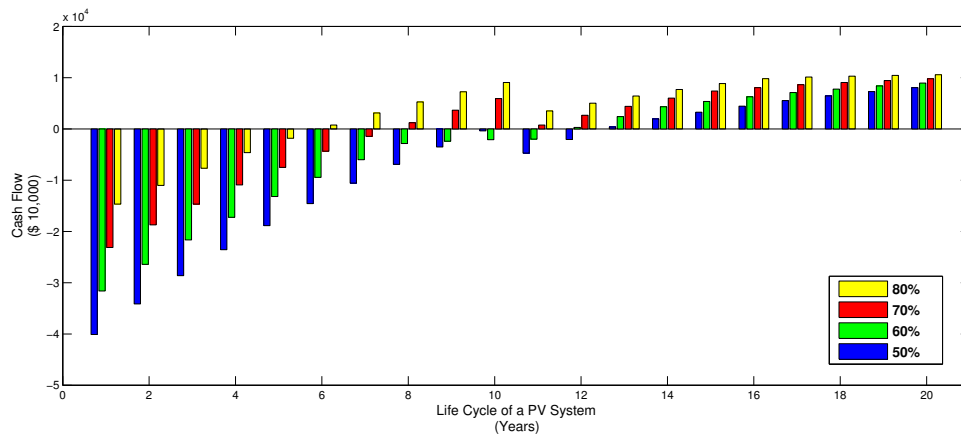


Figure 6.5: Cash Flow (10,000 USD) of a 50 kWp PV system based on an optimal FIT, with four different scenarios of loan types, 20-80%.

6.5.3 Linear program results compared the actual data

This section describe the results of LP model compared to actual data. In other words, it can be seen what were the actual FIT paid between 2010 and 2015, compared with optimal FIT tariffs if the Israeli decision makers were using the model presented in this research.

It is important to emphasise that the results presented in this section related to the 80% share loan option only. The reason for this is that most PV systems owners have actually chosen this method of financing because of the high economic viability, attractive interest rates from Israeli banks and the need to recruit a relatively small amount of money from equity to finance PV project.

Table 6.6 presents the results of the optimal FIT versus the actual FIT for the years 2010–2015. The 'FIT actual' represented the average FIT been paid in Israel for each year for 50kWp PV system. For example in 2010 the actual FIT was \$0.51/kWh and in 2013 it was \$0.0.223/kWh. The next column represented the model results. For example in 2010 the optimal FIT was supposed to be only \$0.22/kWh and in 2013 \$0.158/kWh. The table also presented the return of investment (ROI) for each one of the options (actual and optimal FIT). As can be seen in the 'ROI optimal' column in all years the results are in the range of 6 to 7 years with 95% likelihood.

Year	Ic Actual	FIT Actual	FIT Optimal	Ratio	ROI (years) Actual	ROI (years) Optimal
2010	3405 (\$/kWp)	0.51	0.22	240%	2.1	6.5-6.9
2011	2863 (\$/kWp)	0.377	0.19	179%	3.1	6.7-6.9
2012	1991 (\$/kWp)	0.225	0.16	140%	3.4	6.5-6.8
2013	1870 (\$/kWp)	0.223	0.158	140%	3.3	6.5-6.8
2014	1870 (\$/kWp)	0.18	0.158	140%	3.3	6.5-6.7
2015	1650 (\$/kWp)	0.165	0.152	140%	3.1	6.5-6.9

Table 6.6: The optimal FIT compared to the actual FIT for the years 2010-2015

6.5.4 Outcome of the Two-stage model

The two-stage methodology enables a reduction in the uncertainty surrounding optimal pricing for FIT as the cost of FIT is affected by panel price, cost of electricity, and interest rates, all of which are variable. The two-stages methodology fuses all these parameters into one number. The model found that optimal FIT in Israel need to

be \$0.14 per *kWh*. This outcome is significantly lower than the 2015 outcome of the linear program for the first stage as presented in Table 6.6. This number includes all the uncertainty in the PV energy sector such as; technology price changes due to technological breakthrough, electricity price, and different types of loans for each one of the economical parameters mentioned above. This means that in Israel in 2015, based on historical data of initial price of PV system and model results, optimal FIT very close to grid parity. Today, based on IEC, electricity price for the residential sector is \$0.127/*kwh* (IEC, 2015).

6.6 Conclusions

As renewable energy continues to develop to meet the challenges of mitigating climate change, increasing energy security, and reducing exposure to volatility in fossil fuel pricing, it is expected that FIT policies will continue to be used as a policy option to drive development of renewable energy. It would be worthwhile to invest in a solar PV system and connect it to a grid when the total cost associated with its installation and operation is most nearly equal to the revenue that could be collected from the electricity generated throughout the system lifetime. In this chapter the optimal FIT was calculated using a Monte-Carlo Simulation, a Linear program, and historical data on PV system prices. It was found that the optimal FIT should be \$0.152 per kWh based on 4000 scenarios of Initial price (*Ic*) in 2015. In addition it was found that the FIT paid during 2010 - 2015 is much higher then the optimal FIT computed by this model.

However, when using the two-stages method the cost of FIT should be even lower reaching \$0.14 per kWh.

This Optimal FIT is relatively close to grid parity (a differnt of 10%). This means that if the Israeli decision makers would have adopted the methodology presented here, Israel can fall in line with other Western countries in promoting renewable energy and

an undertaking represents preparation for the international climate conference in Paris in December 2015.

7

Conclusion & Discussion

7.1 Introduction

This research explores the potential for deploying renewable solar energy technology in Israel so that energy dependence and greenhouse gas emissions might be reduced. The purpose of the research was to conceive of an approach and design models both to maximise output of renewable energy and provide guidelines based on policy and financial scenarios to promote low carbon energy technology that could contribute to the national electricity supply in Israel.

This research has employed an integrated approach, structuring the thesis as a combination of three interdisciplinary areas: 1. A review of the literature and the Israeli renewable energy market (Chapters 3 and 4) 2. An assessment of PV capacity based on atmospheric and meteorological input (Chapter 5) and 3. A policy analysis (Chapter 6).

These three areas of work are interrelated in that the first two provide insights and inputs to the third which examines technical, economic, and policy conditions affecting end user incentives to invest in PV systems. The policy analysis tool has been used to assess the profitability of a range of PV system investments.

This chapter presents the main finding obtained by this research and how this thesis answers the research question. It also presents the lessons that can be learnt from combining meteorological and atmospheric indicators as used in TEA model and how the result from each chapter function together for a better understanding of the main problem this research aimed to explore.

7.2 Main finding of this research

7.2.1 Literature review

The literature review examines different aspects related to this work starting with a review of global energy demand and the reasons for its increase. It examines the most dominant environmental consequences of fossil fuel consumption in the last decades. Worldwide energy consumption is projected to grow by 53% between 2008 and 2035, with much of the increase driven by strong economic growth in China and India (EIA, 2010b). The two most powerful forces behind energy demand are population and income growth (see subsection 3.2). With regards to the Middle East, electricity demand is projected to grow by 2.5 percent per year, from 0.7 trillion *kWh* in 2008 to 1.4 trillion *kWh* in 2035 (EIA, 2010b).

Chapter 3 introduces the environmental problems resulting from increased use of fossil fuels and the way other countries in world deal with the issue, mainly by increasing the capacity of electricity generation by PV technology (see section 5.2).

PV technologies and markets

The worldwide PV sector has experienced unprecedented growth in the last decade. PV technologies have been increasingly deployed for grid-connected applications within developed energy systems. Recent years have seen increasing industry investment and capacity expansion as well as a diversity of products researched and commercialised (see section 5.3.3). While wafer-based crystalline silicon technologies (1st generation) have the biggest market share at present, they are rapidly being challenged by thin-film technologies (2nd generation) for which investment and production capacity are dramatically increasing. The medium- and long-term will see the emergence of 3rd generation technologies which encompass a wide range of products that are still at the R&D stage, but appear very promising in terms of technical performance, variety of application, and possible cost reductions. The range of grid-connected PV system options has also been increasing.

Computer tools and mathematical models for RE technology

At the end of the literature review the latest computer tools, GIS models, and other software used for RE in general and solar energy in particular (see section 3.4) are presented.

The literature review indicates that while in recent years a lot of work in computing, modelling, and software for power generation by solar energy technology has been done, none of these models are suitable for this study since it is impossible to set additional properties or modify the parameters for Israel. In addition, these models do not include

all the atmospheric and meteorological parameters contained in the model constructed for this study 5.5).

Chapter 3 essentially provides the justification for the building a new model that is more effective and comprehensive as compared to models so far in use.

7.2.2 The energy market in Israel

Chapter 4 reviews the case of Israel in relation to three primary issues in the energy market: (a) resources, (b) supply and demand, and (c) policies for promoting renewable energy.

The natural gas discovered o the coast of Israel in recent years could only be described as a gas revolution that radically transforms the outlook for gas production in the Eastern Mediterranean region. Between January 2009 and June 2010, licensing groups led by Noble Energy and the Delek Group have discovered two large and three small to medium natural gas fields whose combined size is estimated at up to 810 BCM (29 Tcf) (see section 4.2.3)

These discoveries have changed the energy market in Israel. For the first time in its short history, Israel has achieved independence from petroleum imports. In addition, the expected income from the gas discovery can change the situation of the Israeli economy and reduce the electricity prices. But, the strongest impact of the Mediterranean gas discoveries is the reduction of subsidies for renewable energy technology. These discoveries will decrease government's willingness and determination to promote production of electricity by solar energy.

Renewable energy market in Israel

With regard to RE generation capacity, although Israel was a pioneer in both development and deployment of RE technology, its total capacity for electricity generation by these means is very small. Today less than 1% of its total electricity generation is obtained from renewable energy technology (see section 4.2.3). However, the Israeli governments has set a goal of producing at least 10% of its total energy by RE technology by 2020.

Many governments around the world, especially in the West have implemented policies to promote the use of renewable energy production. The Israeli government has also adopted these policies. FIT's can significantly reduce the risk of investing in renewable energy technology and thus create conditions conducive to rapid market growth. This mechanism provides a high degree of security with regard to future cash flow. This is very important for investor ability to raise money from banks and other financial institutions (see section 6.3.1).

Based on this research, it was found that there is a market failure with respect to the Israeli FIT policy. The subsidy paid to investors in 2010 was higher than that paid in 2011 and 2012. In addition, between 2011 and 2012 there was a larger decline in FIT as compared to reductions in cost of technology during those years. This means that investors who bought the technology in 2010 received a higher return on investment as compared to investors in 2011 and 2012. The incorrect policy incentive caused a slowdown in the overall RE technology market in Israel (see section 4.4.2 and 6.3.1).

These findings have increased the need to build a mathematical model that accurately calculates the level of subsidy according to various changes in initial cost of investment (technology price), fuel price, and interest rates. In addition, the model calculates payback and economic feasibility of investments (see chapter 6 and section 6.4).

7.2.3 The TEA model methodology analysis

The technical analysis of PV performance used in the TEA model enables calculation of solar energy capacity in Israel (see Chapter 5).

The methodology for constructing the model relies on the understanding that it is necessary to build a model that takes into account a large number of atmospheric parameters relative to existing models so that more accurate results for production capacity can be obtained for a specific area. In this context, three pollutants are examined: PM , NO_x and Aerosols in order to find their impact upon radiation transformation and electricity generation. This method has never been applied before and the outcomes as presented in 5.7, indicate high levels of accuracy as compared to other commercial models.

There are several lessons to be learned from the combination of meteorological and atmospheric parameters:

- Data Collection: In most places, meteorological data (i.e. wind speed, solar radiation, temperature) are more available. Atmospheric data (i.e. NO_x , PM and Aerosols) are more difficult to monitor and are therefore less available. In addition, instruments that measure these parameters are expensive and therefore there are less measurements made on the ground (see section 5.5). In places where atmospheric data are missing, the TEA model can not be applied while other models still can.
- The combination of parameters: Although it may not be obvious to conduct research that includes a regression and the construction of a mathematical model using these parameters, yet there is a strong synergy among the parameters. For example, high wind speed lowers aerosol concentration. In building the model it became necessary to counteract the synergy effect so the impact of parameters would not be calculated twice.

- Time and space: The variation in atmospheric as well as in meteorological data is highly dependent upon time and space. For example, the time for particles or some kind of aerosols to sink to the ground can range from a few hours to a few days depending upon the nature of parameter, its size, location, and wind speed. Therefore, the model needs to be based on a short interval time measurements (one hour maximum) otherwise outcomes will not be accurate (see section 5.6).

TEA model outcome analysis

It was found that the TEA model provide accurate predictions of electricity generation capacity compared to existing commercial models with an over estimation of less than 0.5%. It was also found that the average annual energy output is $1735 kWh/kW_p$ and the annual average of performance ratio is 82.3%. With respect to atmospheric pollution, it was found that an increase in air pollution causes a decrease in electricity generation (see section 5.7). It was also found that a single PV system of $1kW_p$ in Israel could prevent the emission of $520 grCO_2/kWh$. In one year the amount of prevention comes to $902,200 grCO_2/yr$ (see section 5.7). This figure is relatively higher than in other countries such as the UK (prevention of $416,000 grCO_2/yr$), Germany ($520,000 grCO_2/yr$) and southern Italy ($624,000 grCO_2/yr$).

7.2.4 Policy framework analysis

This research places major emphasis upon demand-pull policies, i.e. those aimed at increasing demand for a particular technology, hence increasing its market share. This is motivated by the study goal of understanding the conditions for deployment of PV technology within the Israeli market. The research shows that further technological development and cost reductions are crucial for guaranteeing future PV market expansion. However, government support for renewable energy projects is also critical.

This study examines the implications of FIT adjustment based on technology prices and other variables as described in Chapter 6. The results are consistent with the conclusions of the 2013 inter-ministerial committee set up to examine the FIT issue. At that time the Prime Minister's office established the Kandel Committee to determine optimal FIT in Israel for renewable energy technologies. The committee's conclusions of goals and quotas were intended to allow a gradual transition that would integrate renewable energy into the electricity sector on the basis of benefit to the economy. Acting out of a desire to create a system that allows long-term integration of renewable energy on an economic basis while controlling excess economic cost, the Commission pursued the simple translation of standards and policy instruments. This system distinguished between different technologies based on their benefit to the economy and reduced uncertainty for private entrepreneurs and government entities

The committee focused on four different areas of benefits arising from a combination of renewable energy sources in the electricity sector.

1. Direct benefits for the electricity sector by reducing fuel consumption and use of capital for the construction of conventional production facilities.
2. Reducing environmental damage from emissions generated by combustion of fossil fuels.
3. Effects on Israel's energy security, including the threat to the continuity of the supply and cost of systems needing backup.
4. Effects on regional economic development and employment.

After examining all the external benefits the Commission determined that the FIT should be 0.162 \$/kWh (PMO, 2013).

In this thesis the calculation of FIT is based on scenarios that considered different costs of PV systems. The optimal FIT was calculated by Monte-Carlo Simulation,

Linear programming, and historical data on PV system prices. It was found that the optimal FIT should be 0.152 \$/kWh based on 4000 scenarios of Ic. In addition it was found that the FIT paid during 2010 -2012 was much higher than the optimal FIT determined in this model.

However, when using the two-stage method it was found that the cost of FIT should be even higher than the above figure, reaching \$0.14/kWh. This figure includes all the uncertainty factors and unexpected deviations in price of technology. If the government were to adopt this rate it would insure itself against changes in electricity futures on the one hand and encourage private entrepreneurs to invest in renewable energy on the other.

7.3 Summary of the main findings

The research questions that were the basis for this work are:

1. What is the potential capacity of solar energy in Israel?
2. What are the main factors affecting the ability to generate electricity by solar energy?
3. What is the best method to increase deployment of solar energy in Israel?
4. What should be the FIT paid by the government to increase the use of solar energy in Israel?

While this study has limitations like any other research, it nevertheless constitutes an important basis for understanding the application and use of solar energy in Israel.

7.4 Research limitations and further work

The complexity of the topics analysed and discussed in this research make it open to certain limitations and leaves scope for future work.

7.4.1 Limitations of the PV system analysis

As often noted in this research, the range of PV system technology has increased in recent years. In particular, the PV industry is exploring innovative third generation options (in particular thin-film technologies) and is looking for new ways to integrate PV technology into building structures. Cost and performance data for newer solutions, such as PV roofing membranes have not been easy to obtain because such products are new niche applications. This makes cost data non-homogeneous and often subject to confidentiality. In addition, the actual PV system performance data are often too case study or country specific. Consequently this analysis has not focused on these more innovative system options. It is believed that a comprehensive survey of reliable data on innovative PV system solutions differentiated by country, cost, and performance is needed to fully assess the potential of these solutions in the building environment. Such data could then be used within the model developed in this research to assess potential PV capacity in Israel.

The main renewable energy source in Israel is the sun. Using the model built in this thesis, future research will be able to explore power production capabilities through various renewable technologies other than solar technology.

7.4.2 Limitations of the policy analysis

With respect to the policy analysis, there are some limitations upon the calculation of the tariff. Apart from economic parameters affecting FIT, there are positive ex-

ternalities when considering the level of FIT. For example, use of renewable energy resources reduces incidence of respiratory disease from emissions of pollutants into the atmosphere. This is a positive externalities that provides economic value to the economy and therefore should be included in the feed rates for renewable energy. Another example of positive economic value is the meeting of international commitments for reduction of pollutants in the atmosphere. Meeting these goals opens the Israeli economy to trade possibilities with European Union and other Western countries. The impact of this should also be taken into account when calculating tariffs for renewable energy generation.

Future research can expand and refine the results obtained in this thesis by including the above mentioned external factors when calculating FIT. This can be done by using the economic and policy analysis model built into this work.

All of these factors should be included when decision makers determine the level of remuneration. Future research can expand and refine the results obtained in this thesis by including the above mentioned external factors when calculating FIT. This can be done by using the economic and policy analysis model built in this work.

Bibliography

- Al-Rawi, N., Al-Kaisi, M., and Asfer, D. (1994). Reliability of photovoltaic modules i. theoretical considerations. *Solar energy materials and solar cells*, 31(4):455–468.
- Alpert, P. and Kishcha, P. (2008). Quantification of the effect of urbanization on solar dimming. *Geophys. Res. Lett*, 35(8).
- Ankory, M. (2009). Government and bank hapoalim will encourage solar energy transition. Globes Magazine. <http://www.globes.co.il/news/article.aspx?did=100050169830.09.2009>.
- Arbib, A. (2009). Pv technology status and prospects: an update. IEA - PVPS annual report.
- Ayompe, L., Duffy, A., McCormack, S., and Conlon, M. (2011). Measured performance of a 1.72 kw rooftop grid connected photovoltaic system in ireland. *Energy Conversion and Management*, 52(2):816–825.
- BGU (2015). Solar energy and environmental physics research topics. access date: Aug. 2015.
- BP (2010). Bp statistical review of world energy 2010. Website. <http://www.bp.com>.
- BP (2011). Energy outlook 2030. *BP, London*.
- BP (2014). Bp statistical review of world energy 2014. Website. <http://www.bp.com>.
- BrightSource (2015). Comapny website. access date: Aug. 2015.

- Candelise, C. (2009). *Technical and regulatory developments needed to foster grid-connected photovoltaic (PV) within the UK electricity sector*. PhD thesis, Imperial College, London.
- Candelise, C., Winkelb, M., and Gross, R. (2012). The dynamics of solar pv costs and prices as a challenge for technology forecasting. Submitted to Renewable and Sustainable Energy Review Journal.
- CBS (2009a). Central bureau of statistics of israel. in: Statistical abstract of israel 2009 – no. 60. Website. <http://www.cbs.gov.il/reader/>, access date: 17 Aug. 2013.
- CBS (2009b). Central bureau of statistics of israel. in: Statistical abstract of israel 2009 – no. 60. Website. <http://www.cbs.gov.il/reader/>, access date: 17 Aug. 2010.
- Chambers, R. and Conway, G. R. (1992). *Sustainable rural livelihoods: practical concepts for the 21st century*. Institute of development studies Brighton, UK.
- Chandramohan, A., Williams, I. B., and Creatore, M. (2015). Plasma-assisted deposition of aluminium-doped zinc oxide: Investigating early stage growth mechanisms and evolution of film properties.
- Cherni, J. A., Dyner, I., Henao, F., Jaramillo, P., Smith, R., and Font, R. O. (2007). Energy supply for sustainable rural livelihoods. a multi-criteria decision-support system. *Energy Policy*, 35(3):1493 – 1504.
- Christersson, M., Vimpari, J., and Junnila, S. (2015). Assessment of financial potential of real estate energy efficiency investments—a discounted cash flow approach. *Sustainable Cities and Society*, 18:66–73.
- CIA, W. F. (2010). The world factbook, central intelligence agency, the state of israel - economy overview. Website. <https://www.cia.gov/library/publications/the-world-factbook/> date of access: 18 Dec. 2013.
- Cole, M. A. and Neumayer, E. (2004). Examining the impact of demographic factors on air pollution. *Population & Environment*, 26:5–21.
- Compagnon, R. (2004). Solar and daylight availability in the urban fabric. *Energy and Buildings*, 36(4):321–328.

- Connolly, D., Lund, H., Mathiesen, B. V., and Leahy, M. (2010). A review of computer tools for analysing the integration of renewable energy into various energy systems. *Applied Energy*, 87(4):1059–1082.
- Considine, T. J. (2003). *An energy demand model for Israel and the market potential for natural gas*. <http://www.mni.gov.il/mni/he-il/Energy/EnergyGeneral/DemandForecast/Default.htm>.
- Couture, T. and Gagnon, Y. (2010). An analysis of feed-in tariff remuneration models: Implications for renewable energy investment. *Energy Policy*, 38(2):955 – 965.
- Darbouche, H., El-Katiri, L., and Fattouh, B. (2012). *East Mediterranean Gas: what kind of a game-changer?* Oxford Institute for Energy Studies.
- Decker, B. and Jahn, U. (1997). Performance of 170 grid connected pv plants in northern germanyanalysis of yields and optimization potentials. *Solar Energy*, 59(4):127–133.
- Dekker, J., Nthontho, M., Chowdhury, S., and Chowdhury, S. (2012). Investigating the effects of solar modelling using different solar irradiation data sets and sources within South Africa. *Solar Energy*, 86(9):2354–2365.
- Deutsche, Gesellschaft, S. (2008). *Planning and installing photovoltaic systems :a guide for installers, architects and engineers*. James, London, UK.
- Dubčáková, R. (2011). Eureka: software review. *Genetic programming and evolvable machines*, 12(2):173–178.
- EIA (2010a). *International Energy Outlook, 2010*. Energy Information Administration.
- EIA (2013). U.s. energy information administration, country analysis. US Energy Information Administration.
- EIA, U. (2010b). Annual energy outlook 2010. *Report#: DOE/EIA-0383*.
- EPIA (2011). Global market outlook for photovoltaics until 2016. Technical report. European Photovoltaic Industry Association (EPIA).

- EPIA (2014). Global market outlook for photovoltaics 2014–2018. Technical report. European Photovoltaic Industry Association (EPIA).
- Even, S. (2009). Historical development of the natural gas industry in israel: Economic and strategies implications. *INSS - The Institute for National Security Studies*, 100:1–3. <http://www.inss.org.il>.
- Even, S. (2010). Israel's natural gas resources: Economic and strategic significance. *INSS - The Institute for National Security Studies*, 13:4–9. <http://www.inss.org.il>.
- Faiman, D. (2008). Assessing the outdoor operating temperature of photovoltaic modules. *Progress in Photovoltaics: Research and Applications*, 16(4):307–315.
- Faiman, D., Feuermann, D., Ibbetson, P., Medwed, B., and Zemel, A. (2000). Pv systems for Israel's cities: How large should they be? a design guide.
- Faiman, D., Feuermann, D., Ibbetson, P., Medwed, B., Zemel, A., Ianetz, A., Liubansky, V., Setter, I., and Suraqui, S. (2004). The Negev radiation survey. *Journal of Solar Energy Engineering*, 126(3):906–914.
- Fendel, H. (2009). Israel discovers gas. [url http://www.Israelnationalnews.com/News/News](http://www.Israelnationalnews.com/News/News). access date 12 Dec. 2010.
- Fisher, Y. (2009). New cost-effective concentrated photovoltaic technology for medium and large-scale solar power generation. Website. <http://www.ises.org.il/75>access date: 12 De. 2010.
- Fouquet, D. and Johansson, T. B. (2008). European renewable energy policy at crossroadsfocus on electricity support mechanisms. *Energy Policy*, 36(11):4079 – 4092. [jce:title;Transition towards Sustainable Energy Systemsj/ce:title;.](#)
- Fylaktos, N. (2010). *The effect of the use of Solar Home Systemson the income-generating capabilitiesof rural households of developing countries: Evidence from South Africa*. PhD thesis, Imperial College London.
- Green, M. A. (2000). Photovoltaics: technology overview. *Energy Policy*, 28(14):989 – 998.

- Green, M. A., Emery, K., Hishikawa, Y., and Warta, W. (2009). Short communication solar cell efficiency tables (version 33). *Progress in Photovoltaics: Research and Applications*, 17(1):85–94.
- Grimm, N., Faeth, S., Golubiewski, N., Redman, C., Wu, J., Bai, X., and Briggs, J. (2008). Global change and the ecology of cities. *science*, 319(5864):756.
- Group, W. B. D. D. (2009). *World Development Indicators 2012, Development Data Group*. World Bank-free PDF.
- Group, W. B. D. D. (2012). *World Development Indicators 2012, Development Data Group*. World Bank-free PDF.
- Grubb, M., Laing, T., Counsell, T., and Willan, C. (2011). Global carbon mechanisms: lessons and implications. *Climatic Change*, pages 1–35.
- Gueymard, C. (1993). Critical analysis and performance assessment of clear sky solar irradiance models using theoretical and measured data. *Solar Energy*, 51(2):121–138.
- Gueymard, C. (1995). *SMARTS2: a simple model of the atmospheric radiative transfer of sunshine: algorithms and performance assessment*. Florida Solar Energy Center Cocoa, FL.
- Gupta, S., Tirpak, D. A., Burger, N., and Gupta, J. (2007). Policies, instruments and co-operative arrangements. *Climate change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.
- Häberlin, H., Graf, J., and Fachhochschule, B. (1998). Gradual reduction of pv generator yield due to pollution. *Power [W]*, 1200:1400.
- Hadley, S. W. (2008). The oak ridge competitive electricity dispatch (orced) model. *ORNL/TM-2007/230, Oak Ridge National Laboratory, June*.
- Haines, A., McMichael, A. J., Smith, K. R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B. G., Campbell-Lendrum, D., Dangour, A. D., and Davies (2010). Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. *The Lancet*, 374(9707):2104–2114.

- Haley, U. C. and Schuler, D. A. (2011). Government policy and firm strategy in the solar photovoltaic industry. *California Management Review*, 54(1):17.
- Heller, E. (2009). Third generation dye solar cell (dsc) pv developer. Website. <http://www.ises.org.il/119> access date: 19 Dec. 2010.
- Hofierka, J. and Kanuk, J. (2009). Assessment of photovoltaic potential in urban areas using open-source solar radiation tools. *Renewable Energy*, 34(10):2206 – 2214.
- Houshyani, B. (2007). Sedes2 spectral model validation. *A comparative study of*.
- Hua, L., Ma, Z., and Guo, W. (2008). The impact of urbanization on air temperature across china. *Theoretical and Applied Climatology*, 93(3):179–194.
- Hussein, K. (2002). Livelihoods approaches compared. *London, Department for International Development*.
- IEA (2008). World energy outlook 2008. *IEA (International Energy Agency), Paris*.
- IEA (2014). Renewable energy market analysis and forecasts to 2020 medium-term market report. *International Energy Agency (IEA), Paris*.
- IEC (1998). *Photovoltaic System Performance Monitoring: Guidelines for Measurement, Data Exchange and Analysis*. International Electrotechnical Commission.
- IEC (2007). Israel electric corporation ltd. statistical report. Statistics and Market Research Department, www.Israel-electric.co.il.
- IEC (2009). Israel electric corporation ltd. environmental report for 2009. Website. http://www.iec.co.il/Static/WorkFolder/Environmet/svivaty_report_2009.pdf access date: 15 Dec. 2010.
- IEC (2012). Israel electric corporation ltd. statistical report for 2011. Website. <http://www.iec.co.il/investors/Documents/Heb'2011'Stat.pdf>.
- IEC (2015). Israel electric corporation ltd. statistical report for 2015. Website. <https://www.iec.co.il/homeclients/pages/currenttariffs.aspx>.

- Israel-Government-Decision-250 (2009). the committee of environmental protection on climate change preparations. Government Archives. Government Decision of 24.05.2009 numbered 250.
- Israel-Government-Decision-3954/hm122 (2008). Research and development in power generation technologies by re. Government Archives. Government Decision of 21.08.2008 numbered 3954.
- Israel-Government-Decision-4450 (2009). Setting a guideline formulation of tools to promote renewable energy in israel. Government Archives. Government Decision of 29.01.2009 numbered 4450.
- Izquierdo, S., Rodrigues, M., and Fueyo, N. (2008). A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations. *Solar Energy*, 82(10):929 – 939.
- Jin, M., Dickinson, R. E., and Zhang, D. (2005). The footprint of urban areas on global climate as characterized by modis. *Journal of Climate*, 18(10):1551–1565.
- Jones, D. W. (1991). How urbanization affects energy-use in developing countries. *Energy Policy*, 19(7):621 – 630.
- Kalkuhl, M., Edenhofer, O., and Lessmann, K. (2013). Renewable energy subsidies: Second-best policy or fatal aberration for mitigation? *Resource and Energy Economics*.
- Kazmerski, L. L. (2006). Solar photovoltaics r&d at the tipping point: A 2005 technology overview. *Journal of Electron Spectroscopy and Related Phenomena*, 150(2-3):105 – 135. Science and Spectroscopy of Environmentally Important Interfaces.
- Kimber, A. (2007). The effect of soiling on photovoltaic systems located in arid climates. In *Proceedings 22nd European Photovoltaic Solar Energy Conference*.
- Kimber, A., Mitchell, L., Nogradi, S., and Wenger, H. (2006). The effect of soiling on large grid-connected photovoltaic systems in california and the southwest region of the united states. In *Photovoltaic Energy Conversion, Conference Record of the 2006 IEEE 4th World Conference on*, volume 2, pages 2391 –2395.

- Kishcha, P., Starobinets, B., and Alpert, P. (2007). Latitudinal variations of cloud and aerosol optical thickness trends based on modis satellite data. *Geophysical research letters*, 34(5):5810.
- Klein, A., Merkel, E., Pfluger, B., Held, A., Ragwitz, M., Resch, G., and Busch, S. (2010). Evaluation of different feed-in tariff design options—best practice paper for the international feed-in cooperation, update by december 2010. *Nature Conservation and Nuclear Safety (BMU)*, Verfügbar unter: http://www.feed-in-cooperation.org/wDefault_7/download-files/research/Best_practice_Paper_3rd_edition.pdf, Abgerufen am, 6:2011.
- Kravetz, A. (2008). Global solar report cards, energy program compiled by global green usa. Website. <http://globalgreen.org/docs/publication-96-1.pdf> access date: 24 Nov. 2010.
- Kreith, F. and Goswami, D. Y. (2007). *Handbook of energy efficiency and renewable energy*. CRC.
- Kribus, A. and Mittelman, G. (2008). Potential of polygeneration with solar thermal and photovoltaic systems. *Journal of Solar Energy Engineering*, 130(1):011001.
- Kudish, A. and Ianetz, A. (1992). Analysis of the solar radiation data for beer sheva, israel, and its environs. *Solar Energy*, 48(2):97 – 106.
- Kymakis, E., Kalykakis, S., and Papazoglou, T. (2009). Performance analysis of a grid connected photovoltaic park on the island of crete. *Energy Conversion and Management*, 50(3):433–438.
- Lambert, T., Gilman, P., and Lilienthal, P. (2006). Micropower system modeling with homer.
- Lazarus, M., Heaps, C., and Raskin, P. (2008). Leap long-range energy alternatives planning system. *Stockholm Environmental Institute, Boston, Massachusetts*.
- Lesourd, J.-B. (2001). Solar photovoltaic systems: the economics of a renewable energy resource. *Environmental Modelling and Software*, 16(2):147 – 156.

- Li, W., Rubin, T. H., and Onyina, P. A. (2000). Comparing solar water heater popularization policies in china, israel and australia: The roles of governments in adopting green innovations. *Sustainable Development*, 21(3):160–170.
- Lin, J., Cao, B., Cui, S., Wang, W., and Bai, X. (2010). Evaluating the effectiveness of urban energy conservation and ghg mitigation measures: the case of xiamen city, china. *Energy Policy*, 38(9):5123–5132.
- Lipp, J. (2007). Lessons for effective renewable electricity policy from denmark, germany and the united kingdom. *Energy Policy*, 35(11):5481 – 5495.
- Littlecott, C., Scott, V., Haszeldine, R. S., Director, S., and House, M. (2014). Carbon capture and storage in the eus 2030 climate and energy framework.
- Lund, H. (2011). Energyplan-advanced energy systems analysis computer model-documentation version 7.0-<http://www.energyplan.eu>. *Aalborg University, Aalborg, Denmark*.
- Luque, A. and Hegedus, S. (2003). *Handbook of photovoltaic science and engineering*. John Wiley & Sons Inc.
- Luvchik, A. (2009). Modeling of sea-salt aerosols over the mediterranean sea. Master’s thesis, Tel-Aviv University.
- Mardaljevic, J. and Rylatt, M. (2003). Irradiation mapping of complex urban environments: an image-based approach. *Energy and buildings*, 35(1):27–35.
- Mcdonald, O. (2009). Solar water heater- energy saving. <http://www.doosh.co.ill>. access date 14 Dec. 2010.
- McKinsey and Company (2009). Greenhouse gas abatement potential in israel. Israels GHG abatement cost curve Translated executive summary, November 2009.
- Meikle, S. and Bannister, A. (2003). *Energy, Poverty and Sustainable Urban Livelihoods*.
- MEP (2009). Ministry of environmental protection, participation of the israeli delegation in the copenhagen summit. Website. access date Nov. 2010.

- Meyers, R. (1983). *Handbook of energy technology and economics*. John Wiley and Sons, New York, NY.
- Miles, R., Hynes, K., and Forbes, I. (2005). Photovoltaic solar cells: An overview of state-of-the-art cell development and environmental issues. *Progress in Crystal Growth and Characterization of Materials*, 51(1-3):1 – 42.
- MITL (2012). Ministry of industry, trade and labor: National plan for energy efficiency 2010–2012. Translated from Hebrew by the author.
- Mitscher, M. and Rther, R. (2012). Economic performance and policies for grid-connected residential solar photovoltaic systems in brazil. *Energy Policy*, 49(0):688 – 694. [jce:title;Special Section: Fuel Poverty Comes of Age: Commemorating 21 Years of Research and Policy;|/ce:title;.](#)
- MNI (2010). Renewable energy integration policy formation in electricity production. Ministry of National Infrastructures. <http://www.mni.gov.il/NR/rdonlyres/D2E4FE39-80D6-4E05-AC44-E9C0BCDE5FEB/0/renewables.pdf> access date: 12 Dec. 2010.
- Mor, A. and Seroussi, S. (2007). Energy efficiency and renewable energy israel - national study. Website. http://www.planbleu.org/publications/atelier_energie/IL.pdf.
- Mor, A., Seroussi, S., and Ainspan, M. (2005). Large scale utilization of solar energy in israel economic and social impacts. Website. <http://www.ecoenergy.co.il/Portals/0/Solar>
- Mor, S. (2014). Noble makes gas discovery offshore Israel. <http://www.ogj.com/index.html>.
- Mostafaeipour, A. and Mostafaeipour, N. (2009). Renewable energy issues and electricity production in middle east compared with Iran. *Renewable and Sustainable Energy Reviews*, 13(6):1641–1645.
- NASA (2010). Aeront data synergy tool.

- Oke, T. (1973). City size and the urban heat island. *Atmospheric Environment* (1967), 7(8):769 – 779.
- Olivier, J. G., Peters, J. A., and Janssens-Maenhout, G. (2012). *Trends in global co2 emissions 2012 report*. PBL Netherlands Environmental Assessment Agency.
- Parida, B., Iniyar, S., and Goic, R. (2011). A review of solar photovoltaic technologies. *Renewable and sustainable energy reviews*, 15(3):1625–1636.
- PMO (2013). Recommendations of the inter-ministerial to examine the economic benefits of renewable energy. Prime Minister Office. <http://www.tashtiot.co.il> access date: 12 Dec. 2010.
- PUA (2008). Pua decision. Public Utility Authority Decision No. 177. <http://www.pua.gov.il> access date:11 Nov. 2010.
- Rampertshammer, S. (2007). An ornstein-uhlenbeck framework for pairs trading. *Preprint. Available at* <http://www.ms.unimelb.edu.au/publications/RampertshammerStefan.pdf>.
- Remer, L. A., Kaufman, Y. J., Tanr, D., Mattoo, S., Chu, D. A., Martins, J. V., Li, R.-R., Ichoku, C., Levy, R. C., Kleidman, R. G., Eck, T. F., Vermote, E., and Holben, B. N. (2005). The modis aerosol algorithm, products, and validation. *Journal of the Atmospheric Sciences*, 62(4):947–973.
- REN21 (2010). Renewables 2010 global status report. Website. http://www.ren21.net/globalstatusreport/REN21_GSR_2010_full.pdf1.
- REN21 (2011). Renewables 2011 global status report. Website. http://www.ren21.net/Portals/97/documents/GSR/REN21_GSR2011.pdf1.
- REN21 (2015). Renewables 2015 global status report. Website. <http://www.ren21.net/Portals/0/documents/e-paper/GSR2015/epaper/ausgabe.pdf?rnd=55b78e72a84101>.
- Rogner, H., Zhou, D., Crabbé, R. B. P., Edenhofer, O., et al. (2007). Introduction. *Climate change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.

- Saaroni, H., Ben-Dor, E., Bitan, A., and Potchter, O. (2000). Spatial distribution and microscale characteristics of the urban heat island in tel-aviv, israel. *Landscape and Urban Planning*, 48(1-2):1 – 18.
- Schmidt, M. and Lipson, H. (2009). Distilling free-form natural laws from experimental data. *science*, 324(5923):81–85.
- Scoones, I. (1998). Sustainable rural livelihoods: a framework for analysis.
- Sellers, W. D. (2011). A global climatic model based on the energy balance of the earth-atmosphere system. *The Warming Papers*, page 125.
- Shaffer, B. (2011). Israel new natural gas producer in the mediterranean. *Energy Policy*, 39(9):5379–5387.
- Shapira, H. (1970). Installation of solar water heating systems (1970). Government Archives, Interior Minister. The Law of Planning and Building–5730/1970, Article 9.
- Sherwani, A., Usmani, J., and Varun (2010). Life cycle assessment of solar pv based electricity generation systems: A review. *Renewable and Sustainable Energy Reviews*, 14(1):540 – 544.
- Shi, A. (2003). The impact of population pressure on global carbon dioxide emissions, 1975-1996: evidence from pooled cross-country data. *Ecological Economics*, 44(1):29 – 42.
- Siderer, Y. (2012). Photovoltaic systems in israel. Technical report.
- Simon, L. (2009). The top 10 cleantech countries of 2009. access date: January 2011.
- Sterman, D. (2009). Israel’s solar industry: Reclaiming a legacy of success.
- Tans, P. and Keeling, R. (2011). Trends in atmospheric carbon dioxide. *NOAA Earth Systems Research Laboratory*. Accessed December.
- Tao, M. (2014). *Pathways to Terawatt Solar Photovoltaics*. Springer.

- Thevenard, D., Driesse, A., Pelland, S., Turcotte, D., and Poissant, Y. (2010). *Uncertainty in long-term photovoltaic yield predictions*. Natural Resources Canada.
- Thevenard, D., Leng, G., and Martel, S. (2000). The RETScreen model for assessing potential PV projects. In *Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eighth IEEE*.
- Timilsina, G. R., Kurdgelashvili, L., and Narbel, P. A. (2012). Solar energy: Markets, economics and policies. *Renewable and Sustainable Energy Reviews*, 16(1):449–465.
- Vardimon, R. (2011). Assessment of the potential for distributed photovoltaic electricity production in Israel. *Renewable Energy*, 36(2):591–594.
- Verbruggen, A. and Lauber, V. (2012). Assessing the performance of renewable electricity support instruments. *Energy policy*, 45:635–644.
- Wang, X., Byrne, J., Kurdgelashvili, L., and Barnett, A. (2012). High efficiency photovoltaics: on the way to becoming a major electricity source. *Wiley Interdisciplinary Reviews: Energy and Environment*, 1(2):132–151.
- Wiginton, L., Nguyen, H., and Pearce, J. (2010). Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. *Computers, Environment and Urban Systems*, 34(4):345 – 357. Geospatial Cyberinfrastructure.
- WorldBank (2009). World bank data on israel. Website. <http://www.ddp-ext.worldbank.org/ext/ddpreports1> access date: 18 Dec. 2010.
- Yaniv, R. (2010). Setting a guideline to promote renewable energy –monitoring the implementation of government decision no. 4450. *Internal Affairs and Environment Committee*, pages 22–25.
- Yeh, N. (2015). Common pv technologies - features and benefits. <http://www.civicsolar.com/resource/most-common-pv-technology-and-their-benefits-0>.
- Zeng, Y., Huang, W., Zhan, F., Zhang, H., and Liu, H. (2010). Study on the urban heat island effects and its relationship with surface biophysical characteristics using modis imageries. *Geo-Spatial Information Science*, 13(1):1–7.

Zion, E. (2009). United Nation Environmental Protection (UNEP), Europe head ponders "The solar paradox in Israel". Jerusalem Post. (11/9/09).