

The Role of Climate Policy Decision Support Tools for
Bridging the Land Sector Emissions Gap:
The Intersection of NDCs, the Land Sector, and Climate
Calculators

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Acronyms and Abbreviations

<i>AFOLU</i>	Agriculture, Forestry and Other Land Uses
<i>BAU</i>	Business as Usual
<i>COP</i>	Conference of Parties
<i>FABLE</i>	Food, Agriculture, Biodiversity, Land Use and Energy
<i>FELD</i>	Food, Environment, Land and Development
<i>FLR</i>	Forest Landscape Restoration
<i>FOLU</i>	Food and Land Use Coalition
<i>GDP</i>	Gross Domestic Product
<i>GHG</i>	Greenhouse Gas
<i>INDC</i>	Intended Nationally Determined Contribution
<i>IPCC</i>	Intergovernmental Panel on Climate Change
<i>LULUCF</i>	Land Use, Land Use Change and Policy
<i>MRV</i>	Monitoring, Reporting and Verification
<i>NAP</i>	National Action Plan
<i>NDC</i>	Nationally Determined Contribution
<i>PA</i>	Paris Agreement
<i>REDD+</i>	Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
<i>UNEP</i>	UN Environment Programme
<i>UNFCCC</i>	United Nations Framework Convention on Climate Change

Chemical Formulae

<i>CH₄</i>	Methane
<i>CO₂</i>	Carbon Dioxide
<i>eq</i>	Equivalent
<i>N₂O</i>	Nitrous Oxide

Abstract

Climate change represents an urgent global challenge, disproportionately affecting vulnerable communities through extreme weather events and long-term environmental impacts. International agreements, such as the Paris Agreement (COP21), seek to promote equitable climate action, yet translating global climate goals into effective national policies remains a complex and divisive issue. To achieve meaningful climate mitigation and adaptation, it is crucial to evaluate the efficacy of current agreements and national efforts, particularly at the local level in complex sectors like the Land Sector. Land use is responsible for approximately a quarter of global GHG emissions annually, but it also holds significant mitigation potential and is intrinsically linked with other sectors. This research focuses on how the land sector is represented in the Nationally Determined Contributions (NDCs) under the Paris Agreement and the efforts made at the national level to meet these targets.

Addressing the emissions gap, particularly in high-emitting sectors like land use, is critical for preventing severe climate impacts. Decision support tools (DSTs), such as the International 2050 Climate Calculator, play a key role in facilitating this process by offering valuable data and analysis to guide policymakers. These climate calculators model the effects of various mitigation strategies, helping to balance emissions reduction with economic growth. This thesis explores the role of climate calculators in bridging the emissions gap within the land sector.

The research involves reviewing NDCs and assessing the effectiveness of climate calculators in modelling the land sector and calculating its contribution to climate change. It reveals inconsistencies in terminology and reporting across countries, which complicates the alignment of national strategies with global climate goals. The study emphasises the importance of integrating energy, land, and food systems into climate strategies, overcoming language barriers, and addressing cultural and implementation challenges to create more effective climate policies and achieve sustainable climate mitigation.

1. Introduction

Climate change is increasingly perceived as a pervasive and existential global challenge, presenting an ever-growing threat of extreme weather events and other long term-effects that often disproportionately impact the most vulnerable communities around the world. Whilst international agreements aim to make the shared responsibility of climate action as equitable as possible, negotiations still have to traverse complex social, political and economic domains to determine fair, effective and ambitious climate goals. Since the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, countries were required to report on their emissions and mitigation and adaptive climate measures. The most recent comprehensive international agreement, the Paris Agreement, participants are required to give binding Nationally Determined Contributions (NDCs) outlining their individual commitments to reducing GHG emissions and enhancing climate resilience. Despite the progress over the last few decades in improving climate awareness and measures at all levels of governance (local, national and international), an emissions gap has been identified between the designing of climate targets and the implementation of interventions to materially address them. As the threat of climate change becomes ever more pressing, urgent action is required across all scales. This is particularly true in large emitting sectors like the Land Sector, where misalignment of target and intervention setting can be exacerbated by the complex social, political, cultural and economic dynamics of the sector. There are several decision support tools that are designed to help bridge this planning and implementation gap between global emissions and national level targets, but no significant investigation has been carried out to understand their utility in helping facilitate reaching the significant mitigation potential that the land sector globally represents.

1.1. Climate Change

1.1.1 History

Climate change, referring to the human-driven long-term alteration of the Earth's climate patterns, is widely considered one of the most urgent global challenges in the 21st century (Gills and Morgan, 2020). Whilst long-term shifts in temperature and weather patterns may be attributed to natural causes, human activity has been the primary driver of climate change since the 1800s mostly due to the burning of fossil fuels (Crowley, 2000; Abergel *et al.*, 2010). Gases that are released through this burning process, such as carbon dioxide (CO₂), nitrous oxide (N₂O) and methane (CH₄), get trapped within the Earth's atmosphere and contribute to its warming known as the Greenhouse Gas (GHG) Effect (Abergel *et al.*, 2010). The GHG effect itself is a natural process that regulates the Earth's temperatures by absorbing and re-radiating infrared radiation emitted and reflected by the Earth's surface and from the sun and preventing it escaping back into space (Audi *et al.*, 2020). However human activities, especially since the 1800's, have enhanced the GHG effect and accelerated the rate of global warming beyond historic background levels (Audi *et al.*, 2020; Yoro and Daramola, 2020).

The Industrial Revolution is a milestone of the 1800s characterised by the widespread use of fossil fuels within industrial processes (Jones *et al.*, 2023). Industrialisation saw coal become the primary source of energy for manufacturing, transportation, and heating, which released large quantities of CO₂ into the atmosphere (Jones *et al.*, 2023). The expansion of these industrial activities, and urbanisation that followed in its stead to house the growing workforce, is preceded by widespread deforestation across Europe and North America to accommodate the demand for agricultural land, settlements and industrial development (Song *et al.*, 2018). Deforestation also directly fed into anthropogenic climate change as reduced forests meant a reduced capacity to sequester and store atmospheric CO₂ (Song *et al.*, 2018; Zhang *et al.*, 2019).

The conversion of lands, and the change in their use, additionally altered the composition of the Earth's land cover and surface albedo (reflectivity), affecting regional climate patterns (Zhang *et al.*, 2019; Varamesh *et al.*, 2022). In the same way that the release of GHGs into the atmosphere increased the rate of global warming by increasing the re-absorption of radiation off the Earth's surface, altering surface albedo changes the volume of radiation that is reflected out in the first place, and can increase the surface absorption of radiation, increasing local climatic temperatures, precipitation and other climatic variables (Varamesh *et al.*, 2022). This highlights the importance of land management to climate stability.

The innovation of the steam engine meant that not only was there land use change to accommodate industrial development, but that railways and steamships provided transportation links, furthering GHG emissions and land use change (Merchant, 2020). Overall, this mass shift towards combustion of fossil fuels marks the early stage of human-driven (anthropogenic) climate change, with studies evidencing that humans are responsible for the majority of global heating over the last 200 years, causing a rate of global heating which has not been seen in at least the last 2000 years (Jones *et al.*, 2023). Not only was 2022 the 11th year in a row where CO₂ has increased by more than 2ppm, it showcases the highest sustained rate of CO₂ increases since monitoring began 65 years prior, the next longest was three consecutive years of CO₂ growth (NOAA, 2023). Atmospheric CO₂ is now 50% higher than pre-industrial levels (NOAA, 2023).

Whilst there is a discourse that exists about the casual factors of climate change, a lack of consensus is most prevalent in countries with a strong demarcation between political parties, such as the US (Hartter *et al.*, 2018), and is heavily influenced by political, cultural and identity driven viewpoints. Ultimately, there is a far reaching scientific documentation of anthropogenic climate change, including reviews (IPCC, 2023; Melillo *et al.*, 2014), statements from leading scientists and science organisations, and published scientific reports. Additionally, whilst there might be disagreement on the causal factors behind climate change, the majority agree that the climate *is* changing and that without preventative measures the world will surpass a global temperature threshold that minimises the most damaging impacts of climate change.

Definitions

Deforestation: The clearing or removing of trees and forests, usually for agricultural, industrial or urban development purposes.

GHG: Greenhouse gas
e.g. Carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O)

Land Use Change: The alteration, or modification of how a land is utilised.

Surface Albedo: The measure of how much sunlight is reflected by a surface (e.g. ice, water, land). Lower reflectivity means greater absorption of light (and heat).

Urbanisation: The process of a population shifting from rural areas to cities and towns, leading to an expansion of urban areas.

1.1.2. Impacts

Anthropogenic climate change since the 19th century has significant implications for the Earth's ecosystems, societies and future generations. The years 2011-2020 have been the warmest on record, with each of the last four decades warmer than any other since 1850 (WMO, 2023). It has resulted in the average temperature of the Earth's surface to be ~1.1°C warmer than the years predating the industrial revolution, representing the warmest temperature experienced in the 100,000 years (Snyder, 2016). This increasing temperature has ripple effects on the global climate system including consequences such as increasing severe weather events, rising sea levels and declining biodiversity (Zhao *et al.*, 2022).

Heatwaves are increasingly prevalent due to the GHG effect and feedback mechanisms like the reduced albedo effect (Touchaei *et al.*, 2016). They directly affect human health, causing conditions such as heat exhaustion and heatstroke, particularly among vulnerable populations like the elderly and young children (Arbuthnott and Hajat, 2017; Margolis, 2020). This increases the strain on health infrastructure as heat-related medical incidents rise. Additionally, high temperatures disrupt infrastructure, causing power outages, transportation issues, and seasonal spikes in energy use, straining power grids (Staffell *et al.*, 2023). Heatwaves also damage crops, reduce yields, and threaten livestock, which disrupts food systems, elevates the cost of living, and results in economic losses as the expense of maintaining food supply is passed on to consumers (Zuo *et al.*, 2015; Nota *et al.*, 2024). Urban areas face exacerbated health impacts due to the urban heat island effect, while rural areas might suffer more from secondary impacts like drought (Arbuthnott and Hajat, 2017). Factors such as topography and proximity to water bodies influence heatwave intensity, with coastal areas experiencing milder temperatures compared to inland areas (Martinelli *et al.*, 2020). Despite the global nature of this issue, a lack of awareness or personal experience leads some to underestimate the threat of heatwaves, particularly in regions with well-adapted infrastructure or cultural preferences for hot weather (Rising *et al.*, 2022). This underestimation can hinder the development and implementation of effective land sector policies necessary to mitigate the diverse impacts of heatwaves.

Climate change also influences flooding and drought through various mechanisms that significantly impact the land sector. Whilst studies showing warmer air retains moisture better, leading to more intense precipitation and increased risks of flash floods, river flooding, and urban flooding (Wasko, 2021), these studies have not been done on a global scale, shifting global weather patterns and atmospheric circulation does contribute to extreme rainfall events and prolonged droughts (Liu *et al.*, 2020a). Increased evaporation due to higher temperatures exacerbates drought conditions, depleting soil moisture and compounding effects on agriculture, water supply, and ecosystems (Wasko, 2021). These changes pose severe challenges to human health, with floodwaters spreading waterborne pathogens and drought causing dehydration and food insecurity (Zhao *et al.*, 2022). Flooding and drought can devastate agriculture, causing crop failures, livestock loss, and reduced yields, especially in regions dependent on farming or already facing variable climates (Ward *et al.*, 2020; Guan *et al.*, 2021). The simultaneous occurrence of flooding and drought in different regions, or even within the same region, is increasing. However, some individuals underestimate the long-term impacts, viewing them as uncontrollable acts of nature (Mills, 2020). This perspective hinders effective land management and policy-making, crucial for mitigating the chronic impacts of climate change, which reduce land habitability and impede efficient resource use, including food production, a core component of the land sector.

Severe weather events pose significant challenges to societies, economies, and ecosystems, underscoring the urgency of mitigating climate change and adapting to its impacts. However, economic

interests tied to land development, resource extraction, and agriculture often inhibit motivations for change, favouring short-term gains over long-term sustainability (Gonzalez-Redin *et al.*, 2024). This is particularly impactful on the land sector, where these activities are deeply entrenched. Additionally, those in less affected areas may underestimate the consequences of climate change due to a lack of exposure, leading to an "inconvenience bias" that downplays the relevance of these issues (Johnson and Levin, 2009). Whilst this is not a topic that has been heavily studied, the unequal impact of climate change is evident, with regions more vulnerable to heatwaves, flooding, and drought facing more severe consequences and sometimes becoming trapped in a disaster-inequality cycle (Dietz *et al.*, 2020; Cappelli *et al.*, 2021; Ciple *et al.*, 2022).

Developing countries can be particularly susceptible to climate change impacts due to their reliance on climate-sensitive sectors such as tourism, agriculture, and fisheries (Thomas *et al.*, 2020; Le, 2020). Limited resources and infrastructure further exacerbate their vulnerability, as these nations struggle to mitigate or adapt to extreme weather events. The land sector in these regions faces significant challenges, including loss of crop yields, livestock, and economic stability. Sea-level rise threatens the existence of low-lying island nations, forcing communities to relocate and increasing the number of people displaced by weather-related events (Armstrong and Corbett, 2021). Despite contributing less to global GHG emissions, developing countries bear a disproportionately greater burden of climate change impacts, highlighting the deep inequality in global climate resilience (Cappelli *et al.*, 2021; Ciple *et al.*, 2022). Addressing these impacts requires recognising the diverse and far-reaching consequences of climate change on ecosystems and human societies, and the potential for exacerbating existing socio-economic inequalities. This is especially true in socially complex sectors such as Land, as it is a sector so heavily interlinked with the vulnerabilities these regions are facing.

Key takeaways:

The impacts of climate change are pervasive, disproportionately impacting both the land sector and vulnerable regions or countries

Authors Note

This author acknowledges the challenge of labelling countries as "developed" and "developing," noting that this oversimplification often fails to capture the diverse socio-economic realities within and across nations. Terms like "developed" typically refer to industrialised Western countries, while "developing" encompasses the rest, perpetuating power imbalances in international relations.

In recent years, there has been a shift towards using more neutral and specific terms such as "low-income countries," "middle-income countries," "high-income countries," "emerging economies," and "least developed countries" (LDCs), based on objective criteria like GDP per capita and human development indices. These terms are used by the UK's FCDO to define ODA in the DAC list, revised every three years, and play a crucial role in this research. While "developed" and "developing" will be used in this thesis for simplicity and historical context, the author recognises their limitations. Using these terms allows for comparative analysis with previous studies, however for more equitable representation, ODA distinctions within "developing country" when examining how demographics influence a country's land sector will be used.

1.1.3. Politics of Climate Change

The outlook on climate change is a significant force shaping the trajectory of efforts to address this global issue. Despite both climate change and its effects being well documented and scientifically agreed that it is being almost exclusively driven by human actions, the impact that climate change has on society, and the outlook that society has towards climate change, is influenced by multiple factors. Political ideologies and beliefs can affect attitudes towards climate change and have a direct impact on the prioritisation of environmental issues within government discussion and political agendas. Whilst in many countries the political party in power is influenced by the general public, the political leaning of the parties in power might limit or enable government intervention to address climate change (Lassa *et al.*, 2019; Victor *et al.*, 2022). A country's commitment has even been proposed as a necessary index to understand political drive to respond to climate risk and disaster (Lassa *et al.*, 2019). This is further influenced by the capacity for corporate interests to lobby or shape political decisions. Often, the loudest voices in this arena are fossil fuel companies and other industrial sectors with vested interests in activities that are typically high emitters of GHG emissions, such as the oil and gas industry (Graham *et al.*, 2024). These companies can lobby political parties to oppose regulations that could affect future profits that would be stemmed due to measures to reduce emissions and can have such sway that the argument has been made that American fossil fuel lobbyists have driven a spread of climate change denial (Balková, 2020).

Resistance to lower emissions pathways, such as renewable energy, often prioritises short-term economic growth through continued exploitation of non-renewable resources (Månsson, 2015). Transitioning to renewable energy requires significant investments in infrastructure, technology, and subsidies, risking short-term economic disruptions like job losses in traditional energy sectors and increased energy prices. However, global losses from natural disasters was projected to double every 10 years, implying the cost of climate change could hit 150 billion USD a year (Aitken, 2003). Despite this being published over two decades ago, more recent publications echo this sentiment (Coronese *et al.*, 2019), with other studies indicated the cost from natural disasters in the US alone is in the trillions of USD (Smith *et al.*, 2022; Bhola *et al.*, 2023). Politicians may deprioritise climate change if it necessitates unpopular policies, yet global attitudes and international agreements compel action to avoid reputational damage and fulfil obligations. For instance, Saudi Arabia, heavily invested in the fossil fuel industry, has taken minimal actions consistent with the 1.5°C global temperature limit (CAT, 2023a) and has lobbied for costly carbon capture and storage (CCS) technologies, including an 'energy penalty' that makes a CCS-equipped facility more expensive to operate (Zero Carbon Analytics, 2024).

Resistance to renewable energy stems from economic interests in maintaining fossil fuel investments is known as the 'resource curse' (Månsson, 2015). Resource-rich countries like Nigeria and Angola face economic volatility, governance challenges, and underinvestment in other sectors, stalling broader progress. Fossil fuel companies resist transitioning to renewables due to potential revenue losses, job displacement, and market competition (Månsson, 2015). Additionally, communities and individuals reliant on the fossil fuel industry for employment and livelihoods may fear the economic consequences of transitioning away from traditional energy sources (Månsson, 2015; Ebimobowei, 2022). This dependency creates significant barriers to policy shifts, as the short-term economic benefits of fossil fuels often outweigh the perceived long-term gains of renewable energy investments. This resistance is not merely about economic interests but deeper societal fears and uncertainties about economic interests but also encompasses deeper societal fears and uncertainties about economic stability, job security, and the feasibility of transitioning to a new energy paradigm.

Natural resource wealth, such as oil, gas, and minerals, often underpins national economies, particularly in low- and middle-income countries (LMICs) (Khan, 2022). In Nigeria, oil and gas account

for about 10% of GDP and 90% of export revenues (Ebimobowei, 2022). This heavy dependence on natural resources shapes economic policies and priorities. In many low-income countries (LICs), agriculture dominates the economy. For example, in Ethiopia, agriculture contributes nearly 34% of GDP and employs about 80% of the workforce (Wendimu, 2021). Maintaining agricultural productivity can overshadow efforts to preserve non-renewable resources or transition to renewable energy sources. Economic interests associated with natural resources influence policy decisions towards short-term gains rather than long-term sustainability (Khan, 2022). Countries reliant on fossil fuel industries may face resistance from companies and the public when transitioning to renewable energy sources.

Public awareness and attitudes can play a significant role in driving political action on climate change. Pressure from environmental groups and public demonstrations can compel policymakers to prioritise climate action, especially if public pressure reaches a point where politicians need to adopt more ambitious climate policy and leadership on environmental issues to retain their government positions (Wyatt *et al.*, 2024). However, the debate over loss and damage reveals significant challenges, particularly from the perspectives of low- and middle-income countries (LMICs) like India and Nigeria (Trotter *et al.*, 2022; Franczak, 2024). These nations often emphasise the need to keep the costs of energy access low to support their development goals, which typically means continued reliance on fossil fuels. They argue that equity demands their right to affordable energy, highlighting the tension between immediate developmental needs and long-term climate goals (Muttitt and Kartha, 2020; Filipović *et al.*, 2022). The loss and damage debate under-scores this tension, as LMICs call for more significant financial and technical support from developed nations to transition to cleaner energy sources without compromising their economic growth and energy access for their populations (Filipović *et al.*, 2022). This complexity adds another layer to the public influence on climate policy.

The land sector represents a critical intersection of political influences and climate action, making it one of the most pivotal sectors in the climate crisis discourse. Politically, land use policies are often subject to intense lobbying by various interest groups, including agriculture, forestry, and real estate sectors, which can sway political decisions to favour practices that may not align with climate mitigation goals (Swinnen, 2021; Graham *et al.*, 2023). Political will is crucial in determining the direction of land use policies; governments that prioritise environmental sustainability can implement measures that promote the conservation of forests, the restoration of degraded lands, and the adoption of climate-smart agricultural practices (Shi and Moser, 2021). Conversely, political resistance driven by powerful agribusiness and industrial lobbies can impede these efforts, perpetuating practices that exacerbate climate change (Swinnen, 2021). Moreover, the land sector's role in food security, biodiversity, and livelihoods in many regions underscores the need for a balanced approach that addresses both climate and socio-economic goals. Therefore, effective climate action in the land sector requires not only scientific and technical solutions but also strong political commitment and public support to navigate the complex web of interests and achieve sustainable outcomes.

Key takeaways:

Climate change efforts are significantly shaped by political ideologies and interests

Developing countries (LMICs) face a tension between developmental needs and global climate targets

Effective climate action in the land sector requires balancing environmental and socio-economic goals, with strong political commitment and public support.

1.1.4. Addressing Climate Change

Political interests, natural resources, and financial capacity are all factors affecting a country's willingness and ability to respond to climate impacts, shaping a country's response to ignore, adapt, or mitigate against climate change.

Climate Change [...]:

Adaptation:	process of adjusting to the impacts of climate change to reduce vulnerability.
Mitigation:	Efforts to prevent or reduce GHG emissions to lessen climate change impacts.
Reversal:	Efforts aimed at undoing the impacts of climate change.

Climate adaptation involves adjusting to changing climate conditions to minimise negative impacts by considering social, economic, and environmental factors (Wang *et al.*, 2023). This requires understanding climate risks, ensuring flexibility in adaptive strategies, and integrating these strategies into broader frameworks. Adaptation efforts can be proactive, such as Early Warning Systems (EWS) that alert communities to impending weather events, facilitating pre-emptive measures that save lives and protect livelihoods. Germany's EWS for floods, storms, and heatwaves have minimised damage since the 2002 European Floods, demonstrating their effectiveness (Petrow *et al.*, 2006). However, system effectiveness relies on dissemination and clear communication of flood warnings; 2021 saw high rates of residents not receiving warning, and 85% of those who did, did not expect severe flooding (Thieken *et al.*, 2023). Situational knowledge and previous flood experience had a greater link to more effective loss-reducing action (Thieken *et al.*, 2023). Other social factors such as low literacy, language barriers, and mistrust in EWS further inhibit their success. Effective land use and conservation strategies, with integration of different stakeholders, can mitigate climate impacts by providing "potential paying sides" (e.g. insurance) with more information (Petrow *et al.*, 2006).

Unlike adaptation, which focuses on reducing vulnerability, mitigation aims to abate the rate of climate change by reducing GHG emissions (Wang *et al.*, 2023). Measures such as renewable energy deployment and energy-efficient improvements lower emissions, reduce costs, and enhance productivity. Sweden's hydropower potential, forested areas for biomass, and financial capacity have facilitated these initiatives, illustrating how resource availability and financial capacity are crucial for deploying these measures (Renöfält *et al.*, 2010). Transportation and urban planning also offer significant mitigation opportunities, as demonstrated by Curitiba's Bus Rapid Transport (BRT) system (Kapetanakis *et al.*, 2023) and Copenhagen's focus on cycling (Raleigh, 2024), reducing congestion and improving public transport efficiency. These strategies highlight the importance of land use planning and urban development in creating sustainable and resilient communities. Addressing public acceptability, technological lock-in (where investments in high-carbon infrastructure constrain cleaner alternatives), and the integration of afforestation and reforestation efforts are essential for long-term GHG reduction and climate stabilisation (Brown *et al.*, 2008; Wong *et al.*, 2023).

Habitat-specific afforestation and reforestation projects are examples of integrating adaptive and mitigative strategies (Costa and Aubert, 2022). Afforestation and reforestation reduce atmospheric GHGs through natural processes, increasing carbon sequestration (CO₂ removal from the atmosphere, to be stored in natural reservoirs) and offering co-benefits like biodiversity, soil conservation, and water management. Techniques such as carbon dioxide removal (CDR) and carbon capture and storage (CCS) use artificial methods to achieve similar goals (Dods *et al.*, 2021). There are some studies that refer to increased soil carbon in agriculture, or pasturelands, as a form of carbon capture as well

(Chiaramonti *et al.*, 2024). However, many of these CDR and CCS efforts, particularly the artificial processes or the more analogous but still arguably artificial process of biochar, require long-term stewardship and face barriers such as limited natural, financial, and technological resources (Wong *et al.*, 2023). Many countries employ a combination of climate adaptation and mitigation. Integrating these strategies, such as habitat-specific projects, enhances effectiveness and co-benefits, with native species chosen for resilience to climate stresses (Costa and Aubert, 2022). Treating them separately leads to missed opportunities for synergies and trade-offs, resulting in suboptimal outcomes and lost co-benefits (Wang *et al.*, 2023). This holistic approach maximises co-benefits and enhances the effectiveness of climate interventions.

Limited resources may impede a country's capacity to fund climate efforts, leading many nations to prioritise adaptation over mitigation. National Action Plans (NAPs) are strategic documents addressing adaptation needs by integrating climate resilience into policies and investments, though the gap between planning and implementation poses a significant challenge (Woodruff and Regan, 2018). For example, Bangladesh faces barriers due to limited financial resources and technical capacity, highlighting structural issues best addressed through long-term mitigation efforts (Ayers *et al.*, 2016). Regional organisations and local governments also play crucial roles in climate adaptation and mitigation. Initiatives like the Asian Cities Climate Change Resilience Network (ACCCRN) and the African Union's Programme on Climate Change Adaptation facilitate knowledge exchange and collaboration on resilient infrastructure projects (Zougmore *et al.*, 2016; Kristanti *et al.*, 2021). However, misalignment at the national level can hinder global climate efforts. Understanding how individual countries' actions coexist is essential for grasping current global climate trajectories and identifying areas for improvement. With many countries committing to net-zero emissions by 2050, global emissions need to be halved by 2030 to avoid irreversible climate change impacts, requiring a significant reduction in the use of coal, oil, and gas, with over two-thirds of current fossil fuel reserves needing to remain untapped by 2050 (IPCC, 2023).

Addressing climate change demands concerted efforts at international, national, and local levels to mitigate emissions, adapt to impacts, and transition to a sustainable future. Immediate and ambitious international action is necessary, but adaptive capacity is unevenly distributed across countries, leading to disparities in GHG emissions (Wang *et al.*, 2023). Wealthier countries are often responsible for greater emissions, exacerbating climate change and raising issues of fairness and justice on the international stage. This inequity can undermine global cooperation, creating tensions over responsibility, burden-sharing, and financial assistance. Disagreements can hinder meaningful climate discussions and consensus on mitigation and adaptation measures. Aggregate national-level assessments often exacerbate these disagreements as they fail to account for per capita emissions, leading to perceptions of inequity. For instance, while China and India are major global emitters, their per capita emissions are relatively low, especially in India (Wang and Zhoi, 2020). This discrepancy highlights the need for international agreements to consider per capita emissions for fair and equitable climate action. Addressing climate change as a global problem requires a nuanced approach that recognises both aggregate and per capita emissions to foster cooperation and shared responsibility.

Key takeaways:

A country's capacity and commitment to address climate change is not globally uniform

Adaptive and mitigative efforts implemented at a national level still need global cooperation

Countries have access to differing geographic conditions, economic capacity, and local contexts, leading itself to different mitigative measures.

1.1.5. Adaptive Capacity and Resources

Adaptive capacity is the ability to adjust or respond effectively to changes in the environment, allowing to premeditatively anticipate or quickly recover from stresses that changes in the environment cause. Adaptation in anticipation of future climatic events (such as extreme weather conditions, or flooding) and limit the need for coping, or managing, the aftermath of said event, and future events (Lavell *et al.*, 2012) (see section 1.1.2.). Adaptation capacity is determined by several factors and is linked to both climate vulnerability and risk; adaptive capacity heavily influences regional susceptibility to the impacts of climate change. Effective governance is considered a key component for a country to be better equipped to face climate change challenges (Camacho, 2009). However, this is not the only, or arguably even the most influential, causal factor of adaptive capacity. The distribution of resources, both natural and financial, plays a critical role in shaping a region's ability to adapt (Tompkins and Adger, 2004). Regions with abundant resources and wealth can invest in advanced infrastructure, technology, and social systems that enhance resilience against climate impacts (Bleischwiz, 2020; Lemos *et al.*, 2013). In contrast, areas with limited resources often struggle to implement effective adaptation strategies, leaving them more vulnerable (Lemos *et al.*, 2013). This disparity in resource distribution exacerbates the inequities in climate change impacts, as wealthier nations can mitigate and adapt more effectively than poorer regions. Therefore, understanding adaptive capacity requires a holistic view that considers governance alongside the availability and equitable distribution of resources, highlighting the complex interplay between socio-economic factors and environmental resilience.

A country's infrastructure quality greatly impacts its climate change adaptation, particularly in the land sector (Shobande *et al.*, 2024; Ojo, 2024). Resilient infrastructure, such as robust transportation, water, and sanitation systems, can better withstand climate events, ensuring continued service and reducing extreme weather risks (Andersson *et al.*, 2022; Ojo, 2024). Integrating climate considerations into infrastructure design boosts resilience and reduces vulnerability (Ojo, 2024). Despite global movement towards climate-resilient infrastructure and disaster preparedness, countries like Bangladesh remain vulnerable due to geographic susceptibility and limited resources (Hoque *et al.*, 2020; Hossain *et al.*, 2020). Bangladesh's land sector, including agriculture, water management, and urban development, faces compounded challenges from competing priorities such as economic growth and poverty alleviation (Hoque *et al.*, 2020), with marginal impacts not uniformly distributed across farmland, impeding effective mitigation (Hossain *et al.*, 2020). Developing countries often struggle with inadequate or outdated infrastructure, hindering resilience efforts, while wealthier regions can invest in sustainable technologies and diversify their economies to buffer against climate shocks (Maxim *et al.*, 2022). Developing nations can lack the resources for effective mitigation, creating disparities in climate adaptability. That said, financial stability alone doesn't ensure climate-positive policies; access to advanced technology, expertise, and public support is crucial for effective climate adaptation (Shobande *et al.*, 2024), necessitating a multifaceted approach in sectors like land.

Land is a crucial sector to consider for adaptive capacity and resource distribution, as access to natural resources influences climate resilience in various ways, intersecting with political will, finance, and public opinion. Essential resources like water and land are vital for agriculture, industry, and human consumption, and their resilience is critical as climate-induced events increase the risk of food and water scarcity (Lavorel *et al.*, 2020; Leal Filho *et al.*, 2021). Countries with ample arable land can ensure agricultural resilience through sustainable land management practices that enhance food security, biodiversity, and ecosystem services, but these practices must be integrated to maintain these benefits amidst growing climate pressures (Lavorel *et al.*, 2020). Similarly, countries with abundant renewable energy resources, such as solar, hydro, and geothermal energy, have greater opportunities

to diversify their energy sources, enhancing energy security and reducing GHG emissions. Leveraging clean energy helps countries transition to lower GHG emission pathways and economies, mitigating climate risks associated with fossil fuel dependency (Murshed *et al.*, 2021). Fossil fuel extraction, while economically beneficial, poses environmental risks and significantly contributes to GHG emissions. Renewable energy sources offer more geopolitical and market stability compared to internationally traded fossil fuels due to being domestic, abundant, and inexhaustible (Paravantis and Kontoulis, 2020). Sustainable management of natural resources and diversification of energy supply reduce a country's dependency on oil and gas, thereby increasing its climate adaptive capacity.

Global inequitable distribution of resources and the nexus between these resources, from financial to natural, have far-reaching implications for national-level capacity to address issues presented by climate change. Whilst there is a general global consensus that climate change is an issue that needs addressing, a country's outlook on climate change is heavily influenced by these factors, which can act as both motivators and inhibitors to prioritising climate change within their national policies and interventions.

Definitions

Interventions: Any policies, regulations, management, monitoring or other programmes placed by Governments for climate mitigation or adaptation.

Key takeaway:

The unequal distribution of resources globally affects national capacities to address climate change.

Adaptive capacity, or the ability to respond to environmental changes, is influenced by governance, resource distribution, and infrastructure quality.

1.1.6. International Agreements

Global cooperation is essential for effectively addressing climate change, as individual country action alone cannot ensure fair, equitable, and effective global efforts (Bowen *et al.*, 2017; York *et al.*, 2021). Societal attitudes towards climate change influence diplomatic efforts, international agreements, and cooperation on climate-related initiatives. When climate change is perceived as a shared challenge requiring collective action, collaboration and negotiation agreements to reduce emissions and support vulnerable nations improve (Carattini *et al.*, 2024). Several initiatives have emerged to support countries in enhancing their climate adaptability and addressing the uneven distribution of resources and vulnerabilities. Global climate finance mobilises international support for both adaptation and mitigation measures through financial aid from international organisations, multilateral development banks, and climate funds (Watson and Schalatek, 2021). This concept gained significant momentum with the 1997 Kyoto Protocol, which implemented mechanisms like the Clean Development Mechanism (CDM) to facilitate fund transfers from developed to developing countries (Kyoto Protocol, 1997). Another key initiative is the Reducing Emissions from Deforestation and Forest Degradation (REDD+) program, which incentivises developing countries to reduce emissions from deforestation and invest in low-carbon development, promote forest conservation, and enhance forest carbon stocks (Alusiola *et al.*, 2021). REDD+ is not an independent agreement but a global mechanism operating at multiple levels, requiring a multilevel approach for national and sub national coordination and cooperation. REDD+ and CDM are mechanisms that help countries reach the specific objectives of an agreement, aiming to address climate change equitably through global cooperation (Alusiola *et al.*, 2021; Watson and Schalatek, 2021).

Multilateral agreements, negotiated through international organisations like the UNFCCC, involve cooperation among multiple countries to address global or regional issues and require broad participation (York *et al.*, 2021). Bilateral agreements, tailored to the priorities of participating countries, are negotiated between two parties to address specific issues (Barrett and Stavins, 2003). Global agreements incorporate all, or a majority, of countries and aim to address global challenges and areas for concern. These agreements ideally involve the entire international community and communicated through international organisations like the United Nations (UN) (Barrett and Stavins, 2003; Carattini *et al.*, 2024). The Sustainability Development Goals (SDGs) is an example of a global agreement (Bowen *et al.*, 2017). Multilevel governance, involving coordination between national, regional, and local governments as well as non-state actors, is crucial in climate change action, emphasising the need for cooperation across various governance levels (Bodin, 2017). Multilateral agreements involve cooperation among multiple countries, providing a platform for nations to collectively address global challenges like climate change. These agreements acknowledge the principle of common but differentiated responsibilities, ensuring that while all countries share the responsibility to combat climate change, the allocation of responsibility and resources is not uniform (Rajamani, 2000; Anderson *et al.*, 2020). However, these agreements can face limitations if they are overly prescriptive, focusing solely on intergovernmental interaction without acknowledging the role of each governance level, leading to misalignment of national climate policies with regional and local ones (York *et al.*, 2021). Additionally, differing interests and priorities among countries can complicate negotiations and hinder progress, highlighting the importance of the role that methods and tools used to make this process easier hold. This is especially true as participation in multilateral climate agreements often facilitates greater ambition within a country towards climate change interventions, with the shared commitment being a significant motivator.

However, ambition does not guarantee that a country will fulfil its pledge or maintain its inclusion in an agreement. Implementation gaps and compliance issues often arise, as some countries struggle

due to domestic constraints, limited resources, or political and economic reasons (Bodin, 2017). Transparency and reporting mechanisms help reinforce a country's commitment by promoting accountability and trust among participating nations (Raiser *et al.*, 2022). Publicly disclosing emission reduction targets, adaptation measures, and financial contributions holds countries accountable and motivates timely fulfilment of obligations. This mutual accountability builds trust and compliance over time. The Copenhagen Climate Summit in 2009 (COP15) elicited explicit emissions pledges from all major economies, including China and other major developing countries, but did not establish binding commitments (C2ES, 2009). A legally binding agreement ensures fairness and effective implementation, as it compels all parties to act. Multilateralism should recognise the contributions of smaller groups based on representation, with decision-making enhanced through a mix of well-established UN processes and innovative ideas from other multilateral environmental agreements can increase effectiveness (Winkler and Beaumont, 2011). Many of these concerns were addressed by the landmark Paris Agreement in 2015, which managed to overcome many stereotypes of multilateral agreements and avoided these issues.

Paris Agreement

The Paris Agreement (PA), adopted in 2015 and ratified by 197 countries, represents an historic moment of global cooperation to combat climate change. It sets ambitious long-term goals to limit global warming well below 2°C above pre-industrial levels, with efforts to cap the increase at 1.5°C (UNFCCC, 2015). The agreement uses a bottom-up approach, allowing each country to set its own emissions reductions through nationally determined contributions (NDCs) based on their circumstances and capabilities, fostering broad participation and a sense of shared responsibility. However, whilst legally binding, a lack of strong enforcement mechanisms and variability in emissions reporting can undermine its effectiveness, as there is no way to confirm the completeness or accuracy of a country's emissions data (Raiser *et al.*, 2017). Many NDCs are not ambitious enough to keep global warming below the desired thresholds, with countries often setting conservative targets due to political, economic, or social reasons (see section 1.1.3, 1.1.4. and 1.1.5.). Political cycles and economic pressures often take precedence over long-term climate goals, leading to NDCs that prioritise economic development over ambitious emissions reductions (Underal, 2010; Falduto and Rocha, 2020). Additionally, countries with significant historic contributions to global GHG emissions, or with substantial economic capacity, may set disproportionately low targets relative to their responsibilities and capabilities. For instance, India aims to reduce GHG emission intensity relative to its GDP by 33-35% by 2030 compared to 2005 levels, a target that focuses on emissions intensity rather than absolute reduction (Akash *et al.*, 2017). While India's per capita emissions are lower than those of developed countries, its rapid industrialisation and reliance on coal power make it a significant GHG emitter in absolute terms (Akash *et al.*, 2017). This highlights the need for developed countries, with their longer histories of industrialisation and greater economic capacity, to take on more substantial targets to address global socio-economic disparities and support developing nations in achieving sustainable development.

The principle of common but differentiated responsibilities, a core component of the UNFCCC, acknowledges that while all states must address climate change, their capabilities and responsibilities vary (Oberthür and Groen, 2020). This principle ensures fairness in climate action, allowing developing countries more leniency compared to developed nations, aiming for fair and contextually sensitive discussions whilst recognising that insufficiently ambitious targets undermine the collective efforts needed to limit global warming. The PA's five-year framework, including a global stocktake to review progress and update NDCs, promotes continuous improvement and accountability, although its success relies on countries' willingness to enhance their commitments (Oberthür and Groen, 2020). The PA, adopted at COP21, provides a flexible and inclusive framework for global cooperation. Since

the first COP (Conference of Parties) in 1995, these annual meetings have become crucial forums for advancing global climate action and shaping the climate agenda. The PA introduced significant changes to the global climate framework, making it more flexible and inclusive than the Kyoto Protocol by acknowledging the role of non-state actors and fostering a multilevel approach to governance (Savaresi, 2015). On the other hand, Kyoto had mandatory targets (top down) for developed countries, whereas NDCs are proposed by the countries themselves (bottom up) which was important to reach consensus on a new agreement such as the PA, but it gives the possibility of having unbalanced NDCs (CAT, 2024). Despite this, the PA still evidences the importance of the role that cities, universities, and businesses play in implementing the PA by promoting clean energy and sustainable practices at local levels, supporting national efforts to reduce emissions. Such movements show that more localised levels of government can support national efforts to reduce emissions. This local and non-state actor involvement distinguishes the PA from conventional agreements, enabling near-universal participation and advancing ambitious goals to limit global warming to 1.5°C. Whilst not explicitly stated during the PA, the route to achieving these temperature targets effectively requires net-zero emissions by 2050 (Sun *et al.*, 2021). This is outlined further in various scientific assessments, including those published by the Intergovernmental Panel on Climate Change (IPCC).

The International Panel on Climate Change (IPCC)

The concept of "net zero emissions" gained momentum with the 2018 IPCC Special Report on Global Warming of 1.5°C, which highlighted the need to achieve net zero by 2050 to limit warming to 1.5°C (IPCC, 2018). Following this, countries, regions and businesses adopted the net zero emissions target, integrating it into their climate strategies. The UK became one of the first major economies to legally commit to achieving net zero by 2050 in 2019 (Sasse *et al.*, 2020), with the EU, China, and the US announcing similar commitments. The IPCC, established in 1988, has significantly influenced global climate policies through regular assessments that synthesise scientific information for policymakers. Through collaboration with thousands of scientists and experts, the IPCC produces comprehensive Assessment Reports every 6-7 years, serving as key references for various stakeholders. These reports have progressively highlighted human influence on climate and the urgent need for mitigation. The First Assessment Report (FAR), released in 1990, concluded that human activities substantially increase GHG concentrations (IPCC First Assessment Report (FAR), 1990). The Second (SAR) and Third (TAR) reports, released in 1995 and 2001, built on these findings with enhanced regional assessments and future climate projections (Kwon *et al.*, 2007). The Fourth Assessment Report (AR4) in 2007 provided unequivocal evidence of human impact, while the Fifth Report (AR5) in 2014 used Representative Concentration Pathways (RCPs) to model future scenarios, stressing the need for ambitious efforts to achieve net zero emissions (Kwon *et al.*, 2007; Meehl, 2023). These RCPs, developed through global scientific collaboration, provide a range of GHG concentration trajectories and radiative forcing levels for climate models, allowing for detailed exploration of potential future scenarios. This integration of the RCPs into the AR5 contributed heavily to the understanding of potential consequences of the different trajectories, further highlighting the critical need for ambitious and coordinated global efforts to achieve net zero emissions and stabilise the climate (Meehl, 2023). The ongoing Sixth Assessment Report (AR6), initiated in 2021, continues to build on this legacy, reinforcing the importance of immediate and sustained climate action.

RCP Projections

The development of RCP projections involves extensive steps to ensure robustness, incorporating the latest scientific research on socioeconomic and policy factors affecting GHG emissions (Meehl, 2023). These scenarios, based on assumptions about population growth, energy use, land use, and economic activity, undergo rigorous validation and review by IPCC member states. This meticulous process builds consensus among scientists and policymakers, fostering international cooperation. However, the need for broad agreement often results in conservative language, potentially diluting the urgency of the climate crisis (Gills and Morgan, 2022). So, whilst the underlying science is robust, data presentation might not fully convey the immediacy and scale of climate change threats, risking to less aggressive policy responses than might be warranted (Gills and Morgan, 2022). Despite inherent uncertainties surrounding human behaviour and policy decision, RCP projections offer invaluable insights into the potential future impacts of climate change, aiding policymakers in understanding possible outcomes. The RCPs chosen to represent the spectrum of future emissions trajectories are what are used in climate modelling experiments to assess their future climate change implications (Figure 1). These RCPs guide climate modelling experiments and are linked to mechanisms like the GCF, which uses AR5 projections to prioritise investments in climate mitigation projects, especially in developing countries (Photiadou *et al.*, 2021). The GCF works under the principle of country ownership; the recipient countries design and implement the projects based on their specific needs and circumstances (Zamarioli *et al.*, 2020). While the GCF mobilises climate finance and supports low-emission project development, accessing funds can be challenging due to bureaucratic hurdles, particularly for countries with limited institutional capacity (Peterson and Skovgaard, 2019). The RCPs can be linked to several other agreements and mechanisms aimed to help tackle climate change on a global scale (Figure 2).

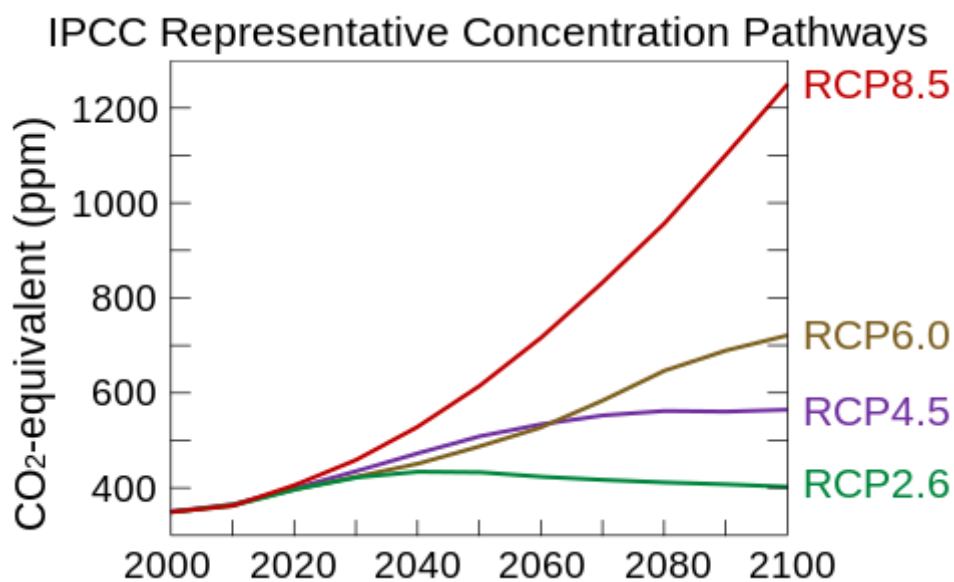


Figure 1. Different RCP scenarios result in different predicted GHG concentrations in the atmosphere. RCP 8.5 essentially representing a 'Business as Usual' trajectory, resulting in the highest GHG concentration (measured in CO₂ equivalents) (Collier *et al.*, 2011).

Definitions

AFOLU:	Agriculture, Forestry and Other Land Uses. A commonly used terminology for the 'Land Sector'.
Agriculture:	The cultivation of crops and rearing of animals for food and other uses
Baselines:	Refers to a reference point by which progress is measured, often representing the initial state of the parameter, such as atmospheric GHG emissions.
CO ₂ equivalents:	A method of expressing the global warming potential of various GHGs in terms of CO ₂ emissions.
Decarbonisation:	Human actions to reduce carbon dioxide emissions from human activities (IPCC, 2022).
Emissions Gap:	The difference between GHG emissions projected under current national commitments (e.g. NDCs) and the levels required to meet global climate
Forestry:	The science, practice, and management of forests, woodlands, and other areas with significant tree coverage.
Global Warming Potential:	measure of how much heat a GHG traps in the atmosphere over a specific time period (100 years), compared to CO ₂ .
Land Use Change:	Is this transition from one land type to another.
Net Zero:	Condition in which anthropogenic carbon dioxide (CO ₂) emissions are balanced by anthropogenic CO ₂ removals over a specified period (IPCC, 2022).
Radiative forcing:	Radiative forcing is a measure of how certain factors, like greenhouse gases, affect Earth's energy balance by either trapping heat or allowing it to escape. Positive radiative forcing implies a warming effect on the climate system, while negative radiative forcing indicates a cooling effect.
Stakeholder:	Stakeholders are any individuals or groups that impact, or are impacted by, a project, event, or situation (Reed, 2008; Hoare <i>et al.</i> , 2023).

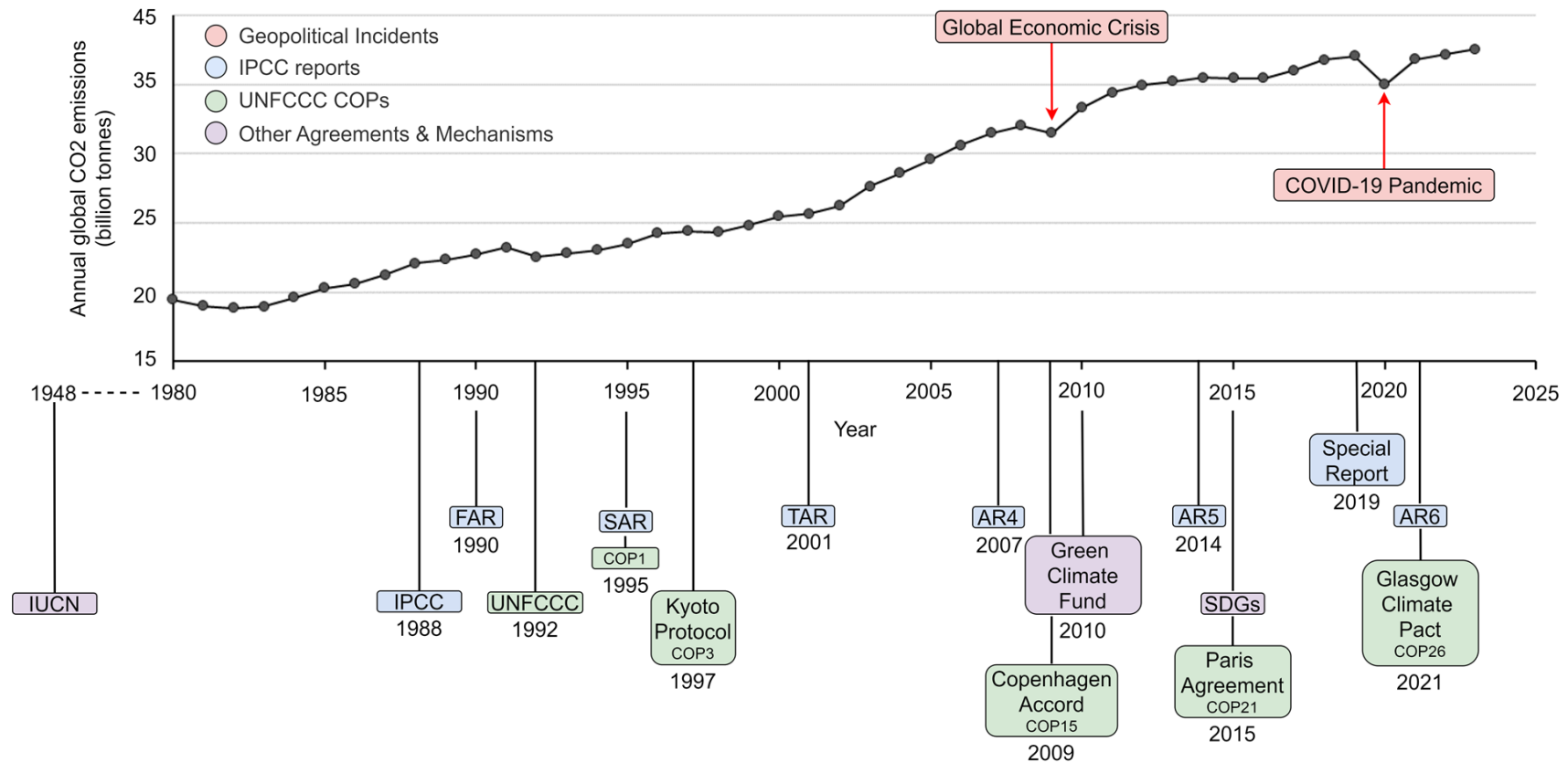


Figure 2. Seminal climate agreements, mechanisms and incidents in recent history against annual global GHG emissions.

Annual global CO₂ emissions data was taken from Friedlingstein *et al* (2021).

Success of these agreements

International climate agreements vary in success, needing to overcome several hurdles to raise awareness and ensure cooperation. Successful agreements typically have ambitious goals for reducing GHG emissions, broad and inclusive participation, and binding commitments for accountability, aiming to mobilise action and deliver tangible outcomes. The PA exemplifies these traits, yet GHG emissions continue to rise (Hewitt *et al.*, 2020). Emissions dips in 2008 and 2020 (Figure 2), generally acknowledged to be due to the Financial Crisis and COVID-19 pandemic respectively, highlight that reductions were linked to economic slowdowns rather than deliberate climate policies. The 2008 financial crash reduced consumer spending, industrial output, and energy demand, while the pandemic's lockdown measures restricted travel and industrial activity (Zhang *et al.*, 2023). Whilst during the COVID-19 pandemic some governments seized this moment to implement low-carbon initiatives, and both events saw reduced global emissions, the emissions reduction was due economic recession rather than deliberate climate policies, as evidenced by the rise in emissions during economic recovery (Zhang *et al.*, 2023). Despite these temporary reductions, both the financial crash and the COVID-19 pandemic highlight the need for sustained, systematic efforts and long-term policies to address climate change and promote clean energy and sustainable development.

While international agreements have slowed the rate of GHG emissions increase, no recent events have reduced global emissions like the 2008 financial crisis and COVID-19 pandemic. Despite the PA's high regard, NDCs are insufficient to limit global warming to 2°C, let alone 1.5°C, as highlighted by several studies, as well as the UNEP Emissions Gap Report (Anderson *et al.*, 2020; UNEP, 2017). Although there are positive trends in renewable energy uptake, few countries are on track with their NDC commitments. For instance, the UK has reduced emissions by phasing out coal-fired power plants and improving energy efficiency but has fallen short in transportation and managing carbon leakage from imported electricity. The UK's Net-Zero Strategy lacks detail on implementation and financing, making it unclear how it will achieve its net-zero emissions target by 2050 (CAT, 2023b).

The status of NDC implementation varies due to differences in policy ambition, resource availability, climate adaptive capacity, and institutional capacity. Bhutan, for example, is carbon negative, absorbing more CO₂ than it emits (Kamei *et al.*, 2021). Bhutan's NDCs focus on forest cover maintenance and sustainable agriculture; extensive natural forest resources, which support both economic development and environmental conservation, is one of the reasons behind the country's success (Third National Communication to the UNFCCC, 2020). However, such natural resources are not uniformly available globally, creating variability in the barriers countries face regarding NDC implementation. Implementation ease also varies across economic sectors, which refer to distinct areas within an economy that contribute to economic activity and can either emit or sequester carbon, representing unique interactions with climate change. The IPCC Working Group III (WG3) characterises global GHG emission sources into five broad economic sectors: energy systems, industry, buildings, transport, and AFOLU (agriculture, forestry, and other land uses) (IPCC working groups, 2024). Each sector plays a crucial role in international climate agreements as they represent different proportions of a country's GHG emissions profile. Understanding the emission sources for each country and how they are split across sectors is vital, as the sectors vary in their potential for GHG emission reduction, carbon removals, and speed of transitioning to low-carbon practices.

Energy and transport sectors offer significant potential for transformation to greener practices and renewable energy sources, while sectors like land use present opportunities for increased carbon sequestration through reforestation and agricultural changes (Teske *et al.*, 2021). The primary sources of a country's emissions indicate where interventions could be most effective, but these sectors face unique challenges based on each country's capacities. For instance, Indonesia's reliance on coal for

electricity generation complicates its transition to cleaner energy (Fünfgeld, 2020). International climate agreements often provide mechanisms like funding and capacity-building to address these challenges, but economic sectors have varying vulnerabilities to climate impacts. The diversification of the global energy grid is crucial for resilience, as shown by the 2008 financial crash and the COVID-19 pandemic. AFOLU, particularly agriculture, is highly sensitive to climate variations, impacting crop yields, livestock productivity and food security (Nabuurs *et al.*, 2022). Despite international efforts to enhance adaptation and resilience, vulnerable regions with limited adaptive capacity remain at risk; economic sectors are central to implementing climate agreements as analysis from the Climate Action Tracker indicates that emissions from new gas capacity threaten the 1.5°C global warming limit (CAT, 2022).

Electricity and heat production and AFOLU are the highest-emitting sectors, each responsible for about 25% of global emissions (Teske *et al.*, 2023). The AFOLU sector, comprising agriculture and deforestation, accounts for about 23% of global emissions and has seen a gradual upward trend since the millennium, at a rate of 0.8%/yr⁵ (Nabuurs *et al.*, 2022). The emissions within the AFOLU sector are mainly due to agriculture and deforestation in the forestry sector, responsible for around 11% and around 12% of global emissions, respectively (Nabuurs *et al.*, 2022). The interconnectedness of economic sectors means that climate impacts in one can affect others, exacerbating socio-economic challenges. Ultimately, whilst the difficulties that each country faces in its own right whilst tackling climate change is only compounded by the global interconnectedness of all the economic sectors, in order to prevent catastrophic consequences of climate change, the current global emissions gap has to be addressed. This means taking a critical look at some of the largest emitting economic sectors globally and understanding which sector is the most pertinent to evaluate the efficacy of current measures and processes in place currently to help reduce, and hopefully bridge, the emissions gap.

Key takeaways:

Multilateral Agreements are representative of historic and modern efforts for global collaboration, and provide several bench marks in tackling climate change including the figure of 1.5°C temperature cap and net zero emissions by 2050.

There is evidence of planning and implementation gaps from national (NAPs) to international (PA) scales.

However, more needs to be done to understand how to bridge the two-way gap between global mitigation efforts and national scale intervention that is evident within modern multilateral agreements, such as the Paris Agreement.

1.2. The Land Sector

1.2.1 Sectors with Significant GHG Emissions

Efforts to tackle GHG emissions have focused on all emitting economic sectors, but held strong focus on the energy sector; the Kyoto Protocol did include land use, land-use change and forestry (LULUCF), but in a selective capacity (Schlamadinger and Marland, 2000). Governments and organisations worldwide have concentrated on transitioning from coal, oil, and natural gas to renewable energy sources such as wind, solar, and hydroelectric power. Policies promoting energy efficiency and cleaner technologies have been at the forefront of international climate agreements like the Kyoto Protocol and the Paris Agreement (Falkner, 2016). In contrast, the land sector, despite its significant contribution to global emissions, has received relatively less attention. This disparity arises because emissions from land use, particularly deforestation and agriculture, are more diffuse and harder to quantify and regulate than those from energy production. Furthermore, land-related emissions involve complex socio-economic factors, making policy interventions more challenging to design and implement (Sanz *et al.*, 2017). However, there has been a growing recognition of the importance of sustainable land management and reforestation efforts, as evidenced by initiatives like the REDD+ program and increased investment in sustainable agriculture practices. As awareness of the interconnectedness of energy, land, and food systems grows, more integrated approaches are being developed to address emissions across these sectors comprehensively.

The food system, responsible for approximately 30% of global GHG emissions, is intricately linked to both the energy and land sectors (Crippa *et al.*, 2021). Agricultural activities, such as livestock production and crop cultivation, contribute significantly to emissions of CH₄ and N₂O, potent GHGs (Giamouri *et al.*, 2022). These activities often necessitate deforestation and land conversion, directly tying the food system to land-use changes. Additionally, the food system relies heavily on the energy sector for powering agricultural machinery, irrigation systems, food processing facilities, and transportation networks, this reliance highlights the embedded energy costs within every stage of the food supply chain, from farm to table (Li *et al.*, 2022). As renewable energy technologies advance and become more widely adopted, reducing emissions from the energy sector, attention is turning to how land is used and managed.

Due to the progress made with non-land-based energy sources, such as wind, solar, and hydropower, the focus on land as a critical component of climate mitigation has become increasingly compelling. Land is crucial not only for its potential for carbon sequestration through reforestation and soil management but also for its pivotal role in supporting the food system (Crippa *et al.*, 2017). The way land is utilised for agriculture, forestry, and urban development has profound implications for climate change, biodiversity, and ecosystem services. There is a strong argument that food production is a major driver of land use within the land sector (Ramankutty *et al.*, 2018). Agriculture requires vast tracts of land for growing crops and raising livestock, leading to deforestation, habitat destruction, and soil degradation (Ramankutty *et al.*, 2018). This demand for land is expected to increase as the global population grows and dietary patterns shift towards more resource-intensive foods like meat and dairy (Rizvi *et al.*, 2018).

Consequently, the food system's impact on land use not only contributes significantly to GHG emissions but also exacerbates other environmental issues such as water scarcity and biodiversity loss (Ramankutty *et al.*, 2018; Rizvi *et al.*, 2018). Addressing this challenge involves rethinking agricultural practices, promoting sustainable land management, and exploring innovative solutions like agroforestry, regenerative agriculture, and vertical farming (Sobhani *et al.*, 2021). By aligning food production with sustainable land use, it is possible to mitigate climate impacts while ensuring food security and preserving vital ecosystems. Given the complexity of land management and the recent

surge in policies aimed at better land use practices, it is essential to delve into how land has been approached in the climate mitigation and adaptation landscape.

By examining the historical and current strategies, policies, and practices surrounding land use, we can gain insights into the shortcomings that have hindered progress toward meeting climate targets. Understanding these factors is essential to identify the gaps and challenges that have prevented us from achieving our climate goals and to develop more effective and integrated solutions. Focusing on land use offers a compelling pathway to address climate change comprehensively, leveraging the interconnectedness of land, energy, and food sectors to drive meaningful improvements moving forward. Ultimately, while the energy sector has made significant strides, it is the land sector that holds untapped potential for substantial climate mitigation, making it a critical area of focus for future climate strategies.

1.2.2. The Land Sector

The land sector plays a significant role in climate change, encompassing agriculture, forestry, and conservation. It supports human livelihood, biodiversity, climate regulation, and ecosystem services. Many countries included land-sector mitigation in their NDCs, with 10-30% of planned emissions reductions falling within this sector (Roe *et al.*, 2019; Forsell *et al.*, 2016; Grassi *et al.*, 2017). Unique in its dual role as both a source and sink of GHGs (Nabuurs *et al.*, 2022), the land sector's emissions stem primarily from deforestation and land use change, which release stored carbon into the atmosphere (Forsell *et al.*, 2016; Grassi *et al.*, 2017). Additionally, agricultural activities contribute significantly to GHG emissions, particularly CH₄, N₂O and CO₂ (Nabuurs *et al.*, 2022). Livestock, specifically ruminants, produce CH₄ during digestion, which is released through eructation and flatulence; cows are the largest of the methane emitters due to their unique digestive system (Giamouri *et al.*, 2022). CH₄ is also released during the anaerobic decomposition of organic matter in flooded rice paddies, when the environment is oxygen starved (Gerber *et al.*, 2013). Whilst the proportion of global agriculture that is attributed to rice cultivation fluctuates, rice is one of the most widely cultivated crops globally, representing millions of hectares of agricultural land (Bin Rahman and Zhang, 2016). N₂O, whilst released primarily as a by-product through microbial processes in soil, is a by-product of the use of nitrogen in agricultural fertilisers (Bin Rahman and Zhang, 2016; Shi *et al.*, 2023). As it has a high global warming potential (GWP), approximately 298 times that of CO₂ over the course of 100 years, the importance of N₂O as a GHG, whilst not as recognised as CO₂, should not be overlooked-especially in the land sector (IPCC, 2001).

Natural ecosystems, particularly forests and healthy soils, act as carbon sinks by sequestering CO₂ from the atmosphere (Nabuurs *et al.*, 2022). Forests absorb CO₂ through photosynthesis and store carbon within their biomass, with old-growth forests storing significant amounts over long periods (Teske *et al.*, 2021). Together with oceans, they globally absorb around 30% of anthropogenic CO₂ emissions annually (Shadwick *et al.*, 2023). However, sequestration capacity varies, and events like deforestation and ocean acidification, which harms marine life, can reduce their effectiveness. Certain habitats, such as peatlands, store 30% of the world's soil organic carbon (SOC) but cover only 3% of the Earth's surface, highlighting further the unequal distribution of land, resources and protection focus (Harenda *et al.*, 2018). However, human activities can degrade these natural sinks, reducing their capacity and increasing atmospheric GHGs and raising concerns about long-term effectiveness, potential disruptions due to feedback loops and tipping points. It is this dual role that also feeds into the land sector having complex interactions with the climate system. Deforestation releases stored carbon, reduces that land's capacity to absorb future carbon, and impacts local and regional climates, presenting the potential for trans-national consequences (Perz *et al.*, 2013). Moreover, reforestation and sustainable agricultural practices can enhance carbon sequestration. However, the

implementation of these practices requires careful consideration of socio-economic factors and local ecosystems to ensure they are both effective and equitable. The Amazon rainforest exemplifies the need for careful consideration in land management (Perz *et al.*, 2013). While its development can stimulate economic growth, it raises environmental and social concerns, particularly for indigenous communities.

The Amazon rainforest exemplifies the need for careful consideration in land management. As a resource-rich region with significant economic potential for agriculture, mining, and logging, its development can stimulate economic growth, generate jobs, and provide revenue for local governments and businesses (Massaro *et al.*, 2022). However, the deforestation and degradation associated with these activities raise concerns about environmental and social impacts. The rainforest is vital to the livelihoods and cultural identities of many communities, particularly indigenous peoples who possess unique traditional knowledge and sustainable practices that have preserved the ecological integrity of the habitat (Massaro *et al.*, 2022; Haddad *et al.*, 2024). The activities that might stimulate economic growth, generate jobs and revenue for the local government and businesses, threaten indigenous rights through habitat degradation, land grabbing, and extractive industries (Haddad *et al.*, 2024). These activities also threaten the rainforest's biodiversity; habitat destruction puts unparalleled plant, animal, and microorganism diversity at risk. Conservation efforts are essential to protecting this biodiversity and preserving ecosystem services like pollination, water regulation, and nutrient cycling, which extend beyond local levels. The Amazon plays a critical role in regulating the global climate, often referred to as the "lungs of the planet" due to its significant contribution to atmospheric moisture and rainfall, affecting global weather patterns (Wilson, 2020). Whilst this is a controversial concept now disproved (the primary providers of O₂ is now considered to be phytoplankton), the concept is still of importance to note because preservation and sustainable management of the Amazon is still crucial for mitigating the broader environmental and socio-economic risks that affect local and global communities. This interconnectedness highlights the land sector's value and the diverse stakeholders and governance challenges, emphasizing the global implications of its management.

Balancing competing land uses while addressing environmental, social, and economic objectives requires significant discussion and frequent trade-offs. In the Amazon rainforest, stakeholders' priorities often clash, reflecting tensions between climate change mitigation, indigenous rights, and sustainable development (Massaro *et al.*, 2022; Haddad *et al.*, 2024). These challenges are shaped by the unique biodiversity, ecological characteristics, landforms, and socioeconomic contexts of each region. Consequently, land use planning and management must balance economic development with environmental goals and social equity, making land management a contentious issue at local, national, and international levels. Furthermore, co-ordination between these levels can be challenging; the way land is managed often reflects back the tensions between relevant stakeholder groups (Barletti *et al.*, 2020). This difficulty changes shape depending on the specifics; landscape heterogeneity in terms of biodiversity, ecological characteristics, landform and socioeconomic contexts often combine to make the environmental challenges the land sector faces unique to the region and specific location (Barletti *et al.*, 2020). This nexus necessitates the tailoring of land use planning and management approaches, with decision processes needing to balance economic development objectives with environmental goals and social equity concerns.

The interconnection of the land sector with other sectors, such as water resources, energy, transportation, and waste management, can only intensify this contention, as actions in one has causal consequences in others (Liu *et al.*, 2020b). Development can fragment natural habitats, disrupt wildlife corridors, and reduce genetic diversity, increasing extinction risks for vulnerable species. Agriculture,

a key land sector component, can also cause habitat fragmentation and biodiversity loss, with practices like monocropping leading to reduced ecosystem resilience (Tan *et al.*, 2023). As a finite resource essential for economic activities, livelihoods, and ecosystems, land management is politically complex, with different interest groups influencing policies through lobbying and advocacy. International cooperation, negotiation, and multilateral agreements are often required, making it challenging to include every stakeholder. The political complexity of the land sector stems from intersecting power dynamics and policy dilemmas inherently linked with balancing socio-economic and environmental objectives (Liu *et al.*, 2020b; Tan *et al.*, 2023; Haddad *et al.*, 2024).

The political complexity and differing objectives in the land sector have led to various terminologies in international agreements and policies. The UNFCCC uses “AFOLU” (agriculture, forestry, and other land uses) and “LULUCF” (land use, land use change, and forestry) to categorise land-related activities. “AFOLU” became prominent in the 2006 IPCC guidelines, integrating agriculture and LULUCF, which were previously separate (Paustian *et al.*, 2006). The variability in definitions, data recordings, and monitoring of GHG emissions affects how these emissions are grouped and assessed. AFOLU is uniquely positioned as a sector viable for emissions reduction, removal of atmospheric carbon and as provision of raw materials to enable mitigation in other sectors (Nabuurs *et al.*, 2022). AFOLU encompasses farming, recreational use, areas of conservation as well as land cover change. Before AFOLU entered main stream use, GHG emissions from agriculture were often omitted from the land sector and commitments to GHG removals. Historically, agricultural emissions were often omitted from land sector commitments due to challenges in quantifying diverse sources like livestock fermentation, rice cultivation and management practices (Paustian *et al.*, 2006; Nabuurs *et al.*, 2022). This complexity makes standardising emissions accounting difficult. Historically, discussions on land use have focused on deforestation, particularly in tropical regions. Recognition of deforestation as a major driver of carbon emissions gained traction in the late 20th century and has since dominated conversations around land-based carbon emissions, overshadowing other sources, such as agricultural emissions. This omission has led to less robust data compared to other sectors, complicating efforts to address agricultural emissions (Herold and Böttcher, 2018). This lack of robust data complicates understanding and addressing agricultural emissions, which don't fit neatly into existing economic sectors and frameworks for climate change mitigation. Unlike other sectors where emissions can be regulated through carbon pricing, agricultural emissions require tailored approaches considering the land sector's unique characteristics and diverse agricultural systems (Kamyab *et al.* 2024).

The inclusion of agriculture into land-terminology and discussions has highlighted the sector's diversity. Encompassing food, diet, and land tenure presents a more holistic image of the sector as both carbon sources and sinks (Paustian *et al.*, 2006; Nabuurs *et al.*, 2022). This broader perspective allows countries to design tailored land sector mitigation, adaptation, and reduction measures. However, this diversity also increases the risk of erroneous or misleading reporting, as some may understate carbon sinks or inflate baselines. Accurate reporting of emissions within the land sector is crucial because the land sector's mitigation potential and the complexity of its emissions pathways are vital for effective climate change management.

1.2.3. Emissions Within the Land Sector

Generally, AFOLU, or more broadly the managed land sector, accounted for 13-21% of global GHG emissions between 2010-2019, and currently responsible for ~25% of net anthropogenic GHG emissions (10-20GtCO₂), with around half of this allocable to agriculture, and half to LULUCF (Le Quéré *et al.*, 2018). LULUCF represents the net balance between emissions between other land uses (including forest and habitat management techniques) and land use change, and carbon sequestration (Le Quéré *et al.*, 2018). Whilst the land sector, especially when considering AFOLU and all managed

land, generates considerable emissions, global terrestrial sinks currently sequester ~30% of annual global anthropogenic GHG emissions, making land management vitally important to promote the generation of 'negative emissions' (Shadwick *et al.*, 2023).

Ten countries—Brazil, China, Indonesia, the European Union, India, Russia, Mexico, the United States, Australia, and Colombia—representing 54% of global AFOLU emissions, also have the highest mitigation potential within the land sector (Tubiello *et al.*, 2013). This potential is highest in tropical countries through carbon removals such as reforestation and afforestation, and reduced land-use changes (Mackey *et al.*, 2020). Large emerging countries like China, India, and Russia, as well as developed countries in the EU and the US, have significant mitigation potential due to their vast forested landscapes (Zomer *et al.*, 2008). China's large-scale afforestation programs, like the Grain for Green Program, exemplify this potential (Deng and Shangguan, 2013). Agricultural measures like better livestock feed and improved rice cultivation offer the largest potential for non-CO₂ GHG emissions reductions, with CH₄ reductions of up to 1.2 and 0.9 GtCO₂e respectively (Wollenberg *et al.*, 2016). Agriculture is responsible for 56% of CH₄ and 27% of potent short-lived gases, so reducing CH₄ emissions from livestock and rice cultivation could significantly expedite global warming mitigation efforts (Montzka *et al.*, 2011). Enteric fermentation in Brazil and India and rice cultivation in China are significant sources of methane emissions, however mitigating these emissions requires shifts in traditional farming practices and consumer preferences. On the demand side, shifting diets and reducing food waste can mitigate up to 8 GtCO₂e and 4.5 GtCO₂e respectively, with a 50% reduction in food waste by 2050 potentially reducing emissions by 2.4 GtCO₂e annually (Hawken, 2017).

The mitigation potential in emerging and developed economies is notable, but AFOLU contributes more significantly to GHG emissions in developing regions, where it accounts for 75% of AFOLU emissions (Enerdata, 2021). Developing countries possess about 85% of the global cost-effective mitigation potential for sustainable high-carbon ecosystem management, though they face major implementation barriers. In Africa, Latin America, and Southeast Asia, CO₂ emissions from land use and management dominate, with AFOLU responsible for over 50% of GHG emissions (Lamb *et al.*, 2021). These regions' forests are heavily pressured by agricultural expansion, replacing critical CO₂ sinks. In contrast, developed countries in Asia Pacific, Europe, and North America have higher GHG emissions from sectors like energy, industry, and transport, with lower AFOLU shares. In both Europe and North America, agricultural and land encroachment happened before the 20th century meaning that legacy land use CO₂ emissions are arguably negligible (Amos *et al.*, 2013). Europe, for example, has seen forest regrowth on former agricultural lands, increasing carbon stocks and CO₂ removals since 2010, while agricultural N₂O and CH₄ are the primary AFOLU emissions sources in such regions. In 2019, AFOLU accounted for 10% of GHG emissions in the UK (BEIS, 2019), and agriculture alone for nearly 11% of US GHG emissions (Stands, 2024).

Global efforts are essential to fully realise the land sector's mitigation potential, which could contribute up to 30% (15 billion tonnes of CO₂e per year) of the annual global mitigation needed by 2050 to achieve the 1.5°C temperature cap (Nabuurs *et al.*, 2022). Focusing on land use change (LUC), which drives fluctuations in AFOLU CO₂ emissions and accounts for ~50% of total net AFOLU emissions, is crucial (Nabuurs *et al.*, 2022). Land use change (LUC) specifically is the transition between two uses (e.g. agricultural land to woodland) or within a use (e.g. arable farming to pastoral farming) (IPCC, 2018). Changes in land use and AFOLU practices affect SOC stocks, yet the inherent heterogeneity of these landscapes in soil type, climate, and land-use history makes predicting the impact changes will have on SOC stocks complex. This leads to a risk associated with carbon sequestration management, as carbon storage flux is likely.

From 1990-2010, land use and LUC accounted for about 12.5% of anthropogenic carbon emissions (Haughton, 2012). Reducing land-use change, such as deforestation and degradation, offers significant mitigation potential, around 8 GtCO₂e per year, and preserves ecosystem services (Frank *et al.*, 2021). However, while many countries' commitments include LUC and afforestation/reforestation, few address soil carbon sequestration or agricultural emissions, and none focus on demand-side shifts. Updating NDCs presents opportunities to enhance land sector strategies (Roe *et al.*, 2019), but poor land management can lead to risks like environmental degradation and biodiversity loss. Integrated responses acknowledging mitigation, adaptation, and other land challenges are more likely to succeed.

Despite decades of understanding AFOLU interventions, global deployment remains slow, contributing only 0.65 GtCO₂eq per year (1.4%) of mitigated emissions from 2010-2019 (Nabuur *et al.*, 2022). This gap is evident as the Climate Action Tracker (CAT) indicates that no countries are currently 1.5°C PA compatible, reflecting insufficient progress in emissions reductions, renewable energy, efficiency measures, and land-use policies (CAT, 2024). Current efforts are inadequate to meet Paris Agreement targets, including those in the land sector. Implementation of land-based measures is often hindered by lack of institutional support and uncertainty about long-term effects and trade-offs. Despite these challenges, AFOLU mitigation options are effective and, with appropriate support, can enable rapid emission reductions. This raises the question of why, despite the known potential and theoretical feasibility of these measures, institutions like CAT and recent NDC reviews indicate that current efforts are off track. Reported limitations in translating commitments into effective interventions, such as missed interim targets for the Paris Agreement at Glasgow (Cutts, 2022), reflect ongoing barriers like weak or conflicting policies, complex land tenure systems, insufficient finance, and growing demand for commodities driving deforestation (van de Ven *et al.*, 2023). The gap between land-based climate targets and successful interventions is concerning, as system and behavioural changes within the land sector are crucial for achieving global climate mitigation goals (Hewitt *et al.*, 2020).

Overall, the complexity of the land sector arises from its multifaceted nature, involving diverse stakeholders, land uses, spatial contexts, interconnected systems, global interdependencies, dynamic processes, and policy challenges. This makes investigating the emissions gap through the land-sector an important avenue of research as the land sector embodies the complex human, political and resource interactions of climate change.

Key takeaways:

The emissions gap is prevalent in all sectors, but concerningly so within the land sector.

Investigating the emissions gap and how to bridge it through a land sector lens acknowledges that the land sector embodies complex human, political and resource interactions of climate change.

2. Thesis and Contextual Framework

2.1. Thesis Framework

Land and agricultural emissions can be considered to have fallen into a policy or governance gap, as it is difficult to align them neatly into existing economic sectors and frameworks for climate change mitigation and land-use planning. Unlike other sectors where emissions can be more easily regulated through carbon pricing mechanisms, addressing agricultural and land-based emissions requires tailored approaches that consider the unique characteristics of both the land sector, the diversity of agricultural systems and the dynamic socioeconomic contexts in which they operate. This complexity necessitates innovative tools and strategies to effectively address the emissions gap. In this context, the exploration of Climate Calculators emerges as a promising avenue. These tools can serve as vital climate policy decision support systems, potentially bridging the global land sector emissions gap.

This leads to the two research aims and four objectives of this thesis (Table 1): ‘The utility of Climate Calculators as climate policy decision support tools in bridging the global land sector emissions gap’.

Table 1. The two primary aims for this research and the objectives designed to achieve them

Aims	Objectives
A.1. Investigate the success of the Paris Agreement in addressing the translation of global needs to national land sector targets	O.1.1. Contextualise the land sector on a global scale by determining historic land-based commitments and countries’ intended land-based actions O.1. 2. Catalogue direct action taken within the land sector since the Paris Agreement to evaluate intervention successes
A.2. Understand the role of climate calculators in reconciling the gaps in the current system	O.2.1. Determine the accuracy of the current climate calculator structure in modelling the current land sector. O.2.2. Develop an understanding of the influence calculators <i>have</i> had and <i>could</i> have on policy development

2.1.1. Aims and Objectives

Aim 1 (Table 1)

Contextualising the role the land sector has on a global scale is important to understand the different ways in which the land sector has been approached, both in terms of commitments and interventions. Isolating the different policies, managements and monitoring techniques which have occurred in response to various variables, for example through the NDCs submitted during the Paris Agreements, allows us to understand how effective land policy to action in the land sector is. Understanding the direct actions, and the perceived successes and failures, of various countries since these commitments were made, specifically within the land sector, is an important step in understanding the way in which the world views and acts upon the land sector.

Sub-Research Questions:

1. Which countries have included the Land Sector within their NDCs and in what capacity (e.g. AFOLU vs LULUCF)?
2. What interventions (management, monitoring and mitigation schemes and initiatives) have occurred, and where, due to the Paris Agreement and the NDCs?

Aim 2 (Table 2)

Understanding the way climate calculators have been used as a DST, will help inform future decisions on how they are made, introduced and used. This aim can also be used to help further the current understanding of the nexus between a country, the land sector and climate calculators, critically evaluating the dynamic between the three. This will be the aim that most directly evaluates the utility of the climate calculator with specific concern for the land sector and how this utility may differ e.g. from country to country, between regions etc.

Sub-Research Questions:

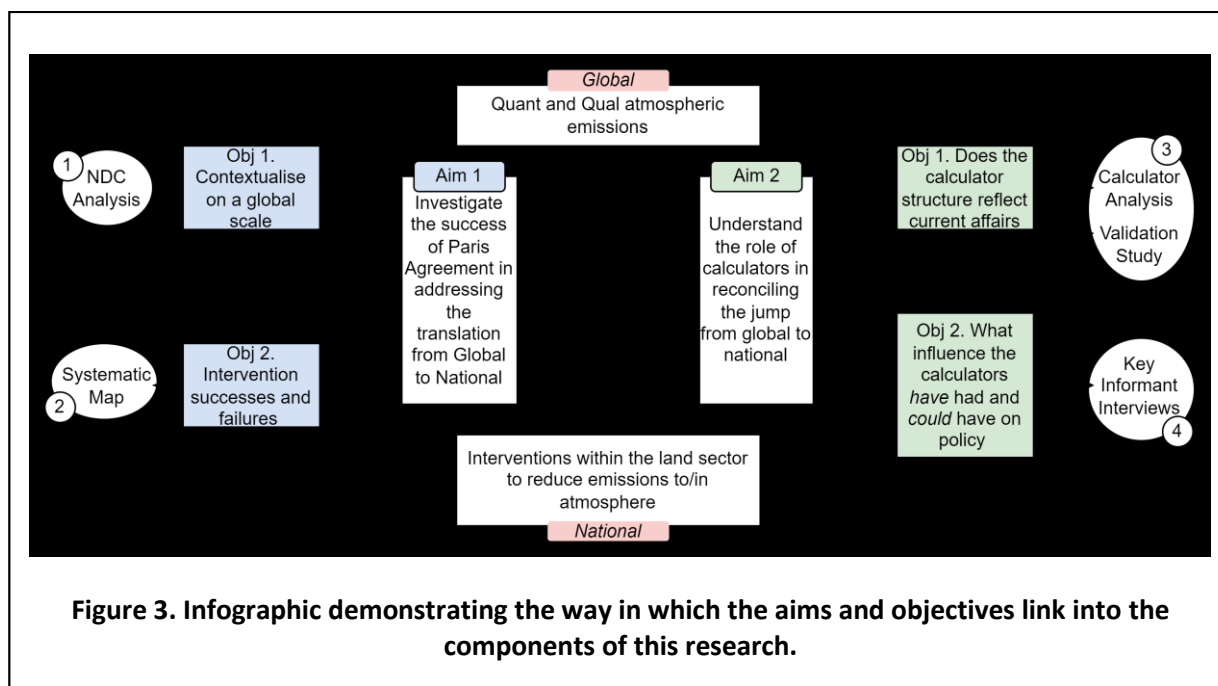
1. How do calculators contribute to, or clarify, uncertainty around AFOLU?
2. What are stakeholder attitudes (both users and creators) of the land sector and climate calculators, both in regard to the themes elicited from the literature analyses and regarding O.2.1 and O.2.2?
3. What are the limitations calculators place on AFOLU management and the potential for future adaptations for management of the sector?

2.1.2. How this Study was Conducted

The two aims of this study are met through four objectives with each objective assessed through a unique research component and method:

1. An analysis of the NDCs submitted as part of COP21
2. A systematic map of the actions taken since COP21, and because of COP21
3. An analysis of the way in which the land sector has been included in different countries' calculators
4. Stakeholder engagement to investigate the results and themes brought to light by points 1-3, as well as discuss the overall relationship and utility of climate calculators as DSTs.

This thesis is structured to understand what the role of the Paris Agreement has been in translating quantitative and qualitative global atmospheric emissions down to land sector interventions to reduce atmospheric emissions on a national scale. The study has been split into two parts, aim 1 and aim 2 with each aim being assessed by two objectives. Objective 1.1 is being answered through an analysis of NDC documents (Chapter 4), and objective 1.2 through a systematic map (Chapter 5). Objective 2.1. and 2.2. are being approached by analysing the climate calculators and key informant interviews respectively. A validation study was carried out to test the findings from the calculator analysis (Chapter 6), which also helped in answering if both objectives for aim 2 were met.



NDC Analysis (1)

Assessing the NDCs submitted during the Paris Agreement provides an avenue to explore how land and its management is perceived as a sector that presents options for emissions reductions and climate mitigation by policy makers around the world, and to garner an understanding of the components of the land sector, if any, that are most commonly focused upon. This is imperative to the first aim of this thesis, as inclusion or exclusion of AFOLU from the NDC indicates the relative weight each country's policy makers assign to current and future land use emissions and their perceived ability to alter the course of those emissions. In addition, if AFOLU is included, the way in which it is included can alter the interpretation of GHG emissions and reduction targets (den Elzen *et al*, 2013). Inclusion of land and whether there is a focus on the trade-offs and synergies associated with land-based climate policies, is a good primary indicator of the relationship that country has with the land sector, especially if land plays a central role in the decision-making space, but the associated synergies do not. This analysis will provide the data to answer the first sub-research question "*Which countries have included the land sector (AFOLU, agriculture and LULUCF) within their NDCs and in what capacity?*" of aim 1.

A systemised approach similar to that of Fyson and Jeffrey (2019), where inclusion of LULUCF in the COP21 NDCs was categorised and the type of data extracted was primarily binary (yes/no) with some areas for explanation. Rather than doing all of the countries that ratified their COP21 NDCs, this study looks specifically at those which are associated with the climate calculator programme, as well as the top 8 global emitters. The data collected ranged from whether land (broadly) was included, whether it was referred to as AFOLU or LULUCF, whether it was conditional or unconditional and the manner of the pledge.

The countries this study extracted data from were chosen because they are, in some manner, involved with the 2050 climate calculator programme (has created, is creating or may create their national climate calculator), or one of the top 8 global GHG emitters. This boundary was put in place to keep the research within an accomplishable time frame (there are just over 30 countries participating within the climate calculator programme, whilst 197 countries ratified their NDCs at the Paris

Agreement). Secondly, bounding the list of countries primarily to those that are associated with the climate calculator ensures that when land is investigated within climate calculators it can be directly compared to the countries' land sector commitments analysed in their NDCs. This is important as, just like with the NDCs, the way land is included within the climate calculator is determined by the country itself. Specifically, the dataset extracted has been designed so that can be directly compared to the dataset from the systematic map. This makes understanding the difference between the COP21 NDCs and the subsequent actions much easier.

Systematic Map (2)

This research will address the second sub-research question for aim 1 (Table 1) providing an understanding of the current processes and responses different countries currently take to create policy and action to reach a target, both with respect to the NDCs and in general. Undertaking this research following the PA is crucial for two reasons. First, the PA marks a key historical moment for climate change mitigation, elevating climate measures onto a global platform and integrating them into policy creation processes (Savaresi, 2015). Second, it provides a method to hold participating countries accountable through their NDCs, offering a consistent way to evaluate and compare these countries. The NDCs are vital because land plays a significant role in GHG emission reduction and carbon sequestration. Understanding the actions taken since these commitments, specifically within the land sector is currently lacking, yet is essential to gauge the global response to the climate crisis and the effectiveness of the PA in instigating tangible actions.

This research addresses the response of different countries towards the land sector as a direct result of the PA, focusing on actions proceeding COP21. Using a systematic map approach aims to create a comprehensive review of global actions taken to fulfil NDC commitments. Whilst a systematic map does take time, from developing the protocol, conducting the search and screening of the papers all the way to analysing the metadata, it is an appropriate technique to collate known information on a topic and highlight any research gaps or unknowns (James *et al.*, 2016). This method highlights the quantity and quality of available evidence, research gaps, and trends within the literature over the past five years (Haddaway *et al.*, 2016). Understanding how land-based actions, including policies, management, and monitoring techniques, have evolved since the PA help contextualise land on a global scale and clarify how climate goals are transcribed into climate actions, thereby addressing the research question concerning climate-effective land management.

Calculator Analysis (3)

The next step in investigating the land sector in climate calculators is to address aim 2, objective 1 (Table 1), to evaluate the influence of climate calculators. This involves analysing how land terminologies are used, comparing the data to COP21 NDCs and the systematic map, and informing the next stage of stakeholder engagement. Reviewing countries with fully developed and published climate calculators, as well as those still in development, allows for systematic analysis regarding the inclusion of the land sector. The results can then be compared to the NDC analysis and the systematic map, helping build an understanding of the relationship between a country, the land sector, and its climate calculator. This will inform the themes and key questions for stakeholder engagement.

This research explores the connection between land and a country as reflected in its climate calculator, addressing questions such as whether the calculator influences the success of land sector actions, and if there is a relationship between a country's land sector ambitions and their inclusion in the calculator. Climate calculators help establish pathways to policy goals, offering users actionable routes through their warning and 4-level lever system (Figure 4). Achieving climate targets requires commitment beyond COP participation and NDC submissions; it involves translating promises into actionable interventions. It is this role of helping bridge complex gap that the climate calculators should have.

Document analysis is a qualitative research method involving the coding and interpretation of document content to develop empirical knowledge (Corbin and Strauss, 2008). Often used alongside other qualitative methods, it helps mitigate the risk of documents lacking detail, as they are produced independently of research agendas. Document analysis aids in triangulating data, identifying convergence, and corroborating evidence across different research methods. It is minimally time-consuming, requiring data selection rather than collection, and is non-reactive, meaning the presence of the researcher does not alter the study material (Merriam, 1988). This iterative process incorporates both content analysis, which categorises information related to the central research question, and thematic analysis, which identifies emerging patterns in the data (Fereday and Muir-Cochrane, 2006).

Validation Study (3)

After completing the first two results chapters, several concepts were brought into the third results chapter. It became clear that analysing climate calculators would help understand their theoretical role in reconciling the target-to-policy gap, but not necessarily their practical utility. There are assumptions that the calculator analysis is rooted in around the rationale of how the tool *logically* would be most effective, but that do not reflect the *actual* utility of the tool in practice. The validation study would help understand the nuances that can come from the human-side of tool use that the documents alone cannot provide. The validation study would increase the robustness of final recommendations for the tool and more specified, rather than broad strokes recommendations and conclusions.

The Kenyan Calculator team was chosen for this validation study because Kenya is a DAC ODA recipient with conditional and unconditional targets and interchangeable land terminology (as suggested from chapter 4 and 5), making it a good test case for the calculator's utility. Additionally, Kenya's climate vulnerability and land-based mitigation potential could inform impactful recommendations. This would provide a more nuanced understanding of the interaction of the calculator within policy creation, facilitating the development of greater-impact recommendations (chapter 8). KCERT (Kenya Carbon Emission Reduction Tool), being a recent development, represents refined and optimal standard practice of calculator development. So, whilst the calculator is young compared to others in the programme, the established nature of the programme at the time of development reduces the risk of study limitations that could be present in older calculators that do not have the benefit of 'lessons learnt' that come from experience that has been developed across the lifetime of the programme.

The feasibility of stakeholder engagement depends on the number of participants. Due to time limitations, in-depth key informant interviews were not viable, so the validation study focused on answering specific questions rather than being exploratory. Conducting stakeholder interactions in a limited timeframe increases the risk of biases, including over-representation or exclusion of certain groups. Historically it can be seen that certain stakeholder groups may be excluded from management decisions, or projects may have an over-representation of stakeholders in their interactions (Daniels and Walker, 2001). Additionally, less time inherently means less time to identify stakeholder groups that may be harder to identify or get involvement from. Whilst the validation study will have a limited number of participants, participatory processes often tend to focus on small groups for in-depth deliberation and reflection (Stringer *et al.*, 2006). While the validation study involved a small number of participants, the diverse range of individuals from the Kenyan calculator team provided valuable insights into the climate calculator's utility. Due to the recentness of the project, these individuals are accessible and able to talk about the calculator and its utility in real-time.

A purposive sampling process was used, a nonprobability technique suitable when time and resources are limited, to select key stakeholder groups (Etikan et al., 2016). Following the appropriate steps in purposive sampling allows for the type of information that is needed prior to engagement, and then to define the qualities that the informant should possess to answer these questions (Tongco, 2007). This pairs well with the parameters of the validation study. To accommodate the short timeframe and maximise responses, a brief survey with multiple-choice and optional open-ended questions was chosen as the most appropriate form of stakeholder interaction. Previous research indicates a negative correlation between survey length and response rate (Sahlqvist *et al.*, 2011), so the survey was capped at 10 minutes to align with the study's time constraints (see section 6.2.1.).

Key Informant Interviews (4)

Collecting data based on expert knowledge is a common technique in global analyses (Mezei and Sarlin, 2016; Colson and Cooke, 2018), especially when field data is lacking (Burgman, 2014). Expert opinions on the global land sector and its integration into climate calculators are essential due to the scarcity of empirical data on post-Paris Agreement interventions in the land sector. In these circumstances where empirical knowledge is lacking, expert opinion is often considered the most appropriate form of data gathering (Sutherland, 2006) despite concerns around the qualitative nature (Hocking, 2013) and robustness of expert knowledge and its inherent subjective nature.

Stakeholder analysis is a policy research or strategic tool which highlights the importance of certain actors and interest groups in the policy making process (Brugha and Varvasovsky, 2000) and can be used to generate knowledge about the stakeholders in order to comprehend their behaviour, intentions and influences that they bring into the situation (Brugha and Varvasovsky, 2000), whilst addressing the need to fairly represent the diversity of interests (Prell *et al.*, 2009). Stakeholder analysis has the capacity to address core issues within natural resource problems and for understanding the conflicts of interests that can impede the research process (Grimble and Chan, 1995) and is used as a complementary tool to other quantitative methods, such as those used within this research (Grimble and Chan, 1995).

The goal is to understand the role of the land sector within climate calculators and assess the tools' effectiveness in policy development. Content and thematic analysis will highlight the sector's perceived importance. By the nature of this purpose, there is intrinsic value towards the stakeholders' interests and their subjective opinions within the sector, making this a normative stakeholder analysis (Barry *et al.*, 2013). Narrative interviews, combining open and closed questions (Bernard, 2017), are beneficial as people often prefer talking over writing, and face-to-face interviews yield better quality information (Narayanasamy, 2009). Additionally, the benefit of face-to-face, or live, interviews is that they often generate better quality information as participants have the scope to provide more of their personal time and opinions, versus other interview formats (Holbrook *et al.*, 2003). Semi-structured interviews provide the scope to explore perceptions and opinions of the participants, enabling the clarification of replies and questions that may arise (Barriball and White, 1994), with conversational interviewing having been shown to produce more accurate data (Schober and Conrad, 1997). Whilst many of the studies supporting the methodologies for this research is older (1999 and earlier), these are studies that produced foundational theories and concepts in stakeholder engagement, interviewing techniques, and data analysis. These established methodologies have been built upon over time and are still used, evidencing the progression of knowledge and situating this research within the broader academic discourse.

2.2. Contextual Framing

Iteration is central to studying complex systems, where dynamic interactions among multiple components lead to emergent behaviours and patterns (Argyros, 2022). Researchers refine their models and simulations iteratively based on empirical data and theoretical insights. Both the Climate Calculator Programme and many of the concepts and machinations of COP21 utilise iterative processes in a deliberate and designed manner. The Climate Calculator Programme has defined development stages, with each step incorporating new knowledge to justify decisions or inform next steps (Strapasson *et al.*, 2020). It involves three iterative cycles driven by internal, expert, and external parties. The PA represents a give-and-take between scientific and policymaking communities, using a bottom-up approach with continuous goal evaluation, exemplified by the review of NDCs originally scheduled for COP26 in 2020.

This thesis uses the PA, NDCs, and the 2050 Climate Calculator Programme as its research components. These elements are interlinked yet capable of independent study, providing clear objectives and accountability in policy creation. As a collective, these are all interlinked; DECC's (a previous Govt. department) programme was designed to support the development of net zero pathways internationally, and the Global Calculators was launched ahead of COP21. NDCs are outputs from 197 countries that ratified the Agreement, with five-year checkpoints for reassessment. Both the Climate Calculator Programme and COP21 encompass diverse countries demographically, geographically, politically, and developmentally. The calculator programme has a rich history stemming from the original UK 2050 calculator, whilst COP21 is a well-documented, globally renowned historical moment that, for many, represented the start of an era of climate-focused change. The NDCs that were output from COP21 are representations of recent historical goals and can, theoretically, be identifiable as successful or not.

2.2.1. Paris Agreement

Global initiatives have set ambitious goals for environmental, economic, and social progress. Most land management research is localised (Solecka, 2019), making it crucial to understand different countries' interactions with the land sector to build a comprehensive overview of AFOLU globally. A clear way to examine the land sector's development and history is through countries' commitments to its protection, management, and use as a carbon sink. The Paris Agreement, one of the most globally subscribed climate change mitigation efforts, provides ideal study material through the NDCs submitted by participating countries. Preparing these NDCs involved significant national consultations and debates, with some countries creating special institutional arrangements for implementation (Gomez-Echeverri, 2018). Whether these arrangements are ambitious and sufficient for effective climate mitigation remains a critical question, which can be explored by analysing the Paris Agreement's outcomes since its inception.

Climate mitigation targets, particularly those in the COP21 NDCs, are interconnected and heavily impact each other. Actions in the land sector, such as carbon sequestration through reforestation and improved forest management (Baumgartner, 2019) or reducing GHG emissions through better agricultural practices (Seymour and Busch, 2016), have complex effects, both positive and negative. Markkanen and Anger-Kraavi (2019) emphasise the importance of inclusive design to identify adverse side effects and co-benefits of COP21 NDC mitigation actions. Mitigation policies often have indirect and complex social impacts, especially in the large and complex land sector, which contributes around 25% of global GHG emissions (Nabuurs, 2022). Understanding the direct actions and perceived successes and failures of various countries since the Paris Agreement, particularly in AFOLU, is vital.

With 197 countries ratifying the Agreement, this thesis can explore a diverse range of nations with varying GDPs, geographies, politics, and emission histories, contextualising AFOLU's complicated global role and examining how COP21 NDCs set both short- and long-term goals.

With land management, playing such critical roles towards climate change mitigation (Aryal *et al*, 2020), and with variable results when it comes to actions taken, it is important to understand the disparity between the intended, the perceived and the actual actions that have occurred directly due to the Paris Agreement within the land sector. There is a disconnect between the overarching goal of the COP21 NDCs (to reduce GHG emissions to a sufficient level as to cap the global temperature increase to a maximum of 2°C), and the way in which those goals are created. These goals not only need to be substantiated by actionable policies but must be both independently climate-effective land management methods, as well as an effective part of a global effort to reduce climate change. In exploring this, it establishes the role that the land sector plays on a global scale and the role that decision-making tools currently, and may have, in bridging the disconnect between establishing and setting national climate mitigation targets.

2.3. Research Significance

This research will seek to understand the current dynamic between a country, its national climate calculator and the land sector. This is important because currently there is a disconnect between what countries have said they will do and their plans in the real world (CAT, 2020). For example, the UK has set a legally binding target to achieve net-zero greenhouse gas emissions by 2050 (Sasse *et al.*, 2020). To meet this ambitious goal, the UK government has introduced various policies and initiatives, such as the Ten Point Plan for a Green Industrial Revolution (UK Govt., 2020), which outlines steps to advance offshore wind, hydrogen production, and electric vehicles, among others. Achieving these targets requires substantial collaboration between the public and private sectors. The government must provide regulatory support and incentives, while private companies need to innovate and invest in green technologies. Additionally, engaging local communities and industries is crucial for transitioning to sustainable practices, particularly in the land sector (Durán-Díaz, 2023). This coordinated effort is essential to bridge the gap between national climate commitments and practical implementation, ensuring that the targets are not only aspirational but also achievable.

This research seeks to understand the planned and actual effectiveness of country-level land-based policy creation and implementation since the PA, and the role that climate calculators have played. Whilst there are other models that can help address the land use dynamics within this context, such as GTAP (GTAP, 2024), they have a different approach and aim. In general, the 2050 calculators are normally built by local experts in supporting their national governments (they are a bottom-up initiative), rather than as consultancy work carried out by external bodies that risk a lack of deeper understanding for the country. Moreover, the calculators are usually not-for-profit and available fully open access. As such, the data gathered for this research will be explored through stakeholder engagement, discussing the reasonings behind results elicited through literature analysis. This will help further current understanding of the relationship between the land sector, the national climate calculator and climate mitigation policy implementation in a country, critically analysing any differences between countries highlighted. The stakeholder engagement results are used to identify what may be the cause of the differing relationships highlighted in the literature analyses and how, in the future, these might change in order to understand the utility of climate calculators for land-based policy decision making support.

Ensuring that the disconnect between current knowledge and political achievement in putting in place binding targets and agreed decarbonisation mechanisms is bridged requires monitoring and reflection (Barry *et al.*, 2013). Understanding what has occurred since the PA provides a level of accountability, evidencing areas of success and highlighting unsuccessful, mechanisms for policy implementation in the land sector. The land sector encompasses a wide range of essential services that support human life and well-being. It provides food through agriculture, fibre for textiles and other materials, fuel for energy, and amenities such as recreational spaces and scenic landscapes. Additionally, the land holds significant spiritual and cultural value for many communities, offering places for religious practices, cultural heritage sites, and a sense of connection to nature. When new demands, such as climate mitigation efforts, are introduced into the land sector, they can create trade-offs that affect the existing services provided by the land (See Chapter 1.2). To develop climate policies that are both sustainable and effective, it is essential to carefully balance the trade-offs associated with different land uses. This requires a holistic approach that integrates environmental, economic, and social considerations, aiming to achieve a harmonious balance between climate action and the preservation of essential land-based services. Defining the relationship that the world has with, and the way people

make decisions regarding, the land sector will ensure that future commitments are well-informed and reasonable. Highlighting both the utility and limitations of the climate calculator will ensure that it is one of the best tools being used and used to maximum efficiency. Senior decision makers often occlude systemic action, especially when functioning within a closed circuit of existing, complicated systems, such as the land sector (Rickards et al, 2014), so determining the utility of climate calculators as DSTs for the land sector will help inform the best multi-faceted approach to take when seeking effective mitigation (Rickards et al, 2014).

Problem Statement

“Uncertainty around the utility of climate calculators for land sector decision-making, leaves a disconnect between establishment of national climate mitigation targets and the mechanisms by which they are achieved.”

Sub Research Questions

Are climate calculators an effective decision support tool for facilitating the creation of climate-effective land management?

Is the tool used to create and inform effective policy making?

3. Decision Support Tools and the Climate Calculator Programme

The emissions gap is the disparity between current greenhouse gas (GHG) emissions pathways and the trajectory needed to limit global warming to below 2°C, as per the Paris Agreement (UNEP, 2017). Closing this gap is crucial, particularly in high-emitting sectors like the land sector, to avoid severe climate impacts (UNEP, 2017; Nabuur *et al.*, 2022). Countries are adopting more ambitious emissions reduction targets and sustainable practices and promoting behavioural changes towards sustainability to make adoption of such practices more feasible on the supply side. However, challenges such as delays in policy implementation, consensus among diverse stakeholders, and legal hurdles hinder progress (Oduro *et al.*, 2024). Additionally, varying levels of climate ambition and entrenched carbon-intensive practices pose systemic barriers to change.

Effective policy design can help optimise uptake and emissions reduction. Monitoring, Reporting, and Verification (MRV) mechanisms are crucial for tracking progress towards emissions targets and ensuring transparency (Singh *et al.*, 2016). They provide essential data to assess policy effectiveness, with many countries maintaining national GHG inventories that quantify emissions from various sectors, including energy, transport, land, and industry (Singh *et al.*, 2016). Well-designed MRV systems with clear scopes and standardised reporting can drive innovation and credibility in emissions reductions across sectors (Mercer and Burke, 2023). However, the current inconsistent patchwork of MRV mechanisms creates a complex information system that complicates navigation and comparison (Mercer and Burke, 2023). While MRVs are essential for tracking purposes, they do not necessarily help minimise the emissions gap by improving policy design and implementation. These systems are typically standalone processes rather than integrated into broader policy-making, causing a disconnect between the information generated and the needs of policymakers (Singh *et al.*, 2016; Mercer and Burke, 2023). Enhanced communication channels and knowledge exchange mechanisms between technical experts and policymakers are essential to ensure MRV information informs policy decisions effectively.

The current systems that are in place, including policy frameworks and MRVs, need to be able to continue increasing climate ambition whilst still being accessible to all stakeholders, especially policymakers. Integrating MRVs into emissions models and decision support tools (DSTs) could present an increased capacity of policy makers to address complex environmental challenges. By integrating MRV data into models, or DST, policy makers gain access to high-quality information that can inform evidence-based decision-making processes. Incorporating real-world data collected through standardised methodologies and in line with policy frameworks enhances the reliability of modelling efforts, whilst preserving the case-specificity that can be built into the design of the model, or DST.

3.1. Decision Support Tools

3.1.1 Purpose

Decision support tools (DSTs) can enhance efforts to bridge the emissions gap and achieve climate goals by providing valuable information, analysis, and guidance to policymakers and stakeholders (Rose *et al.*, 2016; Wong-Parodi *et al.*, 2020). These tools, often in the form of software, help users make informed decisions by packaging and analysing large data sets to present ideal options and scenarios. Designed to assist in complex decision-making processes, DSTs help non-experts understand and manage information that would otherwise be difficult and time-consuming to process. By utilising data analysis and modelling techniques, DSTs interpret the impacts of various scenarios on emissions reductions and socio-economic outcomes, allowing decision-makers to prioritise strategies that maximise benefits and minimise drawbacks (Wong-Parodi *et al.*, 2020).

Integrating diverse data sources and employing various analytical techniques, DSTs facilitate understanding and interpretation of complex data sets. Scenario planning through DSTs helps develop robust and flexible climate policies resilient to future uncertainties (Cobb and Thompson, 2012). Additionally, DSTs build technical expertise, institutional capacity, and climate awareness, promoting informed decision-making and stakeholder engagement at multiple governance levels (Rose *et al.*, 2016). By promoting a culture of learning and improvement, DSTs help build resilience in climate implementation, often facilitating stakeholder engagement and participation in the process.

3.1.2. Type of DSTs

DSTs range from spreadsheet-based models to advanced software integrated with AI, machine learning, and predictive analytics. Model-driven DSTs use data and pre-set parameters for decision-making, supporting physical, ecological, and economic simulations to analyse trade-offs and identify optimal decision pathways (Rose *et al.*, 2016). Document-driven DSTs manage and extrapolate data from unstructured sources, integrating local and expert knowledge for comprehensive decision support. These types of DSTs are relatively new to the area of decision support and have been developed alongside innovations in technologies, allowing for the collation of information from a wide variety of sources. The successful application of these emerging technologies within the business arena suggests that multiple inputs, or points of view, can be beneficial to the decision-making process (Burgman *et al.*, 2021). The best suited style of DST is circumstance specific; there is significant historical use of DSTs in multiple sectors, including finance and healthcare. In finance, DSTs analyse market trends and risks, while in healthcare, they assist with diagnostics and treatment planning through real-time data analysis (Govindan *et al.*, 2020). The application of DSTs in these sectors underscores the growing demand for data-driven decision support, now increasingly applied in environmental management and climate science. In the land sector, DSTs facilitate informed decision-making by analysing diverse data sources and modelling techniques to support climate goals and sustainable practices (Wong-Parodi *et al.*, 2020).

GIS technology captures, stores, and analyses spatial data from sources like satellite imagery, aerial photos, and GPS surveys, revealing trends and relationships in a spatial context (Alam *et al.*, 2022). Urban planners use GIS with hydrological models, topographic data, and land use information to assess flood risks and develop management strategies. It also evaluates biomass crop potentials, maps land suitability, and optimises land use to reduce environmental impacts. However, GIS accuracy depends on data quality, and continuous improvements are essential (Alam *et al.*, 2022). System dynamics models, developed by J.W. Forrester, simulate dynamic systems and feedback loops to analyse complex systems over time, identifying strategic intervention points (Richardson, 2022). These models, used in healthcare for assessing policy responses to viral outbreaks, depend on high-quality input data and collaboration between modelers, policymakers, and data collectors. Optimisation models identify optimal solutions for resource allocation and planning by evaluating decision sets. In supply chain management and transportation, they optimise production scheduling, distribution, and routing, though solving large-scale problems in real-time often requires computational capacity and simplifications that may affect optimality (Van Engeland *et al.*, 2020).

DSTs significantly enhance decision-making across sectors, particularly in environmental management and climate science, due to increasing challenges like climate change, biodiversity loss, and resource depletion (Wong-Parodi *et al.*, 2020). DSTs offer analytical frameworks, modelling capabilities, and data-driven insights to help policymakers and stakeholders address these issues effectively. Technological advancements in remote sensing, GIS, and big data analytics, has enabled the collection and analysis of large environmental datasets for accurate predictions and scenario modelling, expanding DST capabilities in environmental management and climate science. The growing

recognition of the urgency and severity of environmental challenges has prompted governments, international organisations, and regulatory bodies to prioritise environmental management and climate action, with DSTs playing a crucial role in supporting policy development to facilitate this. Addressing complex environmental issues requires integrated approaches that consider multiple factors; DSTs enable stakeholders to adopt a system thinking approach, integrating diverse data sources, modelling techniques, and stakeholder perspectives to develop holistic solutions to environmental challenges.

3.1.3. DST Limitations

DSTs alone are not always sufficient for addressing the complex challenges of climate change. Integrating alternative approaches, such as expert consultation or advisory panels, can enhance the legitimacy of climate decisions and provide qualitative judgment to complement DSTs' quantitative analysis (Kiker *et al.*, 2005). Participatory processes like community-based participatory planning (CBPP) involve local communities in project prioritisation, though scaling these processes poses logistical challenges. Adaptive management approaches, which iteratively learn from experience and adjust strategies, help DSTs stay current with changing circumstances, optimising their deployment in the decision-making cycle (Tompkins and Adger, 2004). This combination of methods can foster more robust policy development by identifying co-benefits and trade-offs, ultimately leading to more holistic decision-making. The growing popularity of DSTs stems from their role in facilitating dialogue, with the National Academy of Sciences highlighting "deliberation with analysis" as crucial for environmental decision-making (Wong-Parodi *et al.*, 2020; National Research Council, 2009). DSTs support iterative decision-making stages, including awareness building, planning, and policy implementation, and encourage multi-stakeholder decision analysis and participatory processes (Wong-Parodi *et al.*, 2020; Hall *et al.*, 2012).

DSTs enable interdisciplinary groups to engage in discussions, establishing a common language and structured discourse, which aids in capacity building through standardised tools and methods. However, common language alone may not transcend contextual differences or adequately cover the nuances of complex situations. Despite this, DSTs with user-friendly interfaces and standardised terminology are generally more accessible, making it easier for stakeholders with varying expertise to navigate and interact with these tools, increasing their adoption and effectiveness. The user interface (UI) of DSTs is crucial for their effectiveness, as a well-designed UI enhances communication and usability, fostering trust and promoting tool uptake (Wong *et al.*, 2020). If users lack confidence in the tool—whether due to its functionality, their ability to use it, or perceived biases—the tool's utility is compromised (Abu-Salma *et al.*, 2017). Participatory development of DSTs invites user input, improving planning rigor, project accountability, and stakeholder engagement, and integrating scientific knowledge into climate change policy development (Rose *et al.*, 2016; Hochman and Carberry, 2011). Successful DSTs often feature a clear delivery plan, strong evidence base, and effective marketing, empowering users and integrating scientific knowledge into the wider context of climate change policy development.

3.2. Climate Calculators

Climate or 'carbon' calculators*, sometime known as navigators or simulators, are DSTs that help individuals, organisations, or governments minimise their carbon footprint by identifying high-emission areas and scenarios for reduction. These calculators use algorithms and emissions factors to assign GHG emissions quantities to specific behaviours or activities. Examples like the Carbon Trust or WWF calculators estimate emissions from an individual on energy consumption, transport use, waste generation, and lifestyle choices, motivating more sustainable practices. The accuracy of these calculators depends on the quality of user input data and the reliability of the assumptions within the calculator. Additionally, emissions factors are not universal and are dependent on location and technology, which introduces variability into the calculations. This means that carbon footprint calculators can provide good estimations of emissions, rather than precise measurements.

The Climate Action Tracker (CAT) policy impact calculator, developed by CAT, is an online tool that assesses GHG emission trajectories and temperature outcomes under current climate policies (CAT, 2024). It allows users to explore the impacts of different policy scenarios, such as renewable energy applications and emissions reduction targets, on global emissions pathways. The interactive platform lets users adjust key parameters and visualise outcomes, but the simplified model may not fully capture policy interactions, market dynamics, and other variables, leading to uncertainties and limitations in the results. The World Bank's Carbon Tax Calculator assesses the impacts of carbon pricing policies on GHG emissions and socio-economic indicators (World Bank Group, 2024). It explores different carbon tax scenarios and their effects on emissions, government revenue, and energy prices. However, it does not account for the distributional impacts of carbon taxes across different socio-economic groups, potentially leading to inequitable policy consequences, especially for vulnerable or low-income populations. Complementary tools or methods to assess equity implications can help promote fair policy design. Complimenting tools like this with additional tools or methods to assess equity implications can help promote fair policy design (Narassimhan *et al.*, 2018). The Climate Policy Simulator by Climate Interactive is another interactive tool that models the potential impacts of climate policies on GHG emissions, temperature rise, and other socio-economic indicators (EN-Roads, 2024). It facilitates scenario analysis for policy-makers, researchers, and the public, increasing the legitimacy and robustness of climate policies, as diverse perspectives and expertise are built into the development process. However, the tool does not account for human behaviour and cultural factors that influence policy implementation and effectiveness, such as consumer preferences and adoption rates of cleaner energy, which can be challenging to model accurately (Lincoln, 2023).

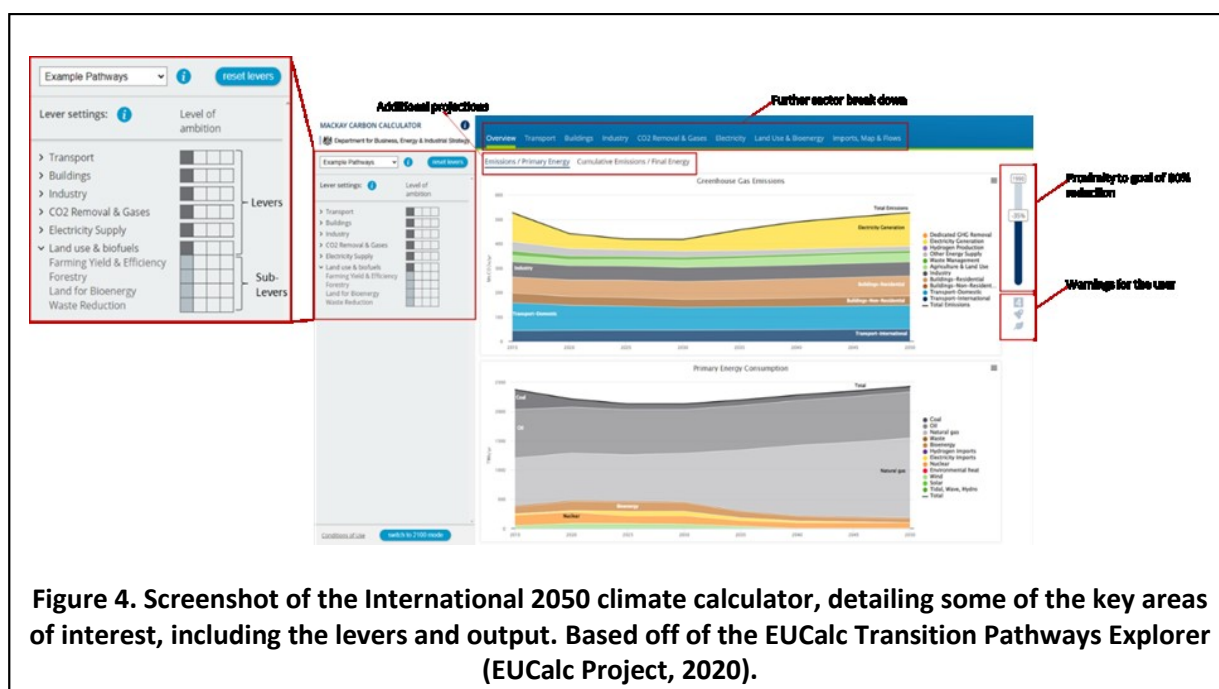
Overall, climate policy impact calculator outputs have inherent uncertainty and complexity; climate change is influenced by rapidly changing factors, making it difficult to model accurately (Pindyck, 2024). These calculators rely on assumptions, data inputs, and modelling methods that introduce uncertainties to the results. This makes predicting future scenarios with certainty challenging. However, DSTs provide users with actionable insights into climate-related decisions and actions, requiring human interpretation and complementary tools to minimise uncertainty (Wong-Parodi *et al.*, 2020). Despite these challenges, DSTs empower individuals and policymakers to better understand the environmental impacts and opportunities of different decisions. DSTs can empower individuals and policy-makers to better understand the environmental impact and opportunities different decisions provide. It is this empowerment that makes climate calculators effective DSTs.

*see www.imperial.ac.uk/2050-calculator for full list of calculators within the programme

3.2.1. The International 2050 Climate Calculator Programme

Background

The climate calculator is an interactive, open-source platform modelling energy and emissions pathways for decarbonisation. It allows users to explore emission pathways and their consequences, such as GHG emissions, temperature changes, and other climate-impacted variables across sectors. For each possible 2050 pathway created, the user can further investigate impacts on land-use, electricity, energy security, energy flows etc. (Figure 4). Each sector has several levers and sub-levers, which have adjustable ambition levels. The greater the ambition level, the greater the climate change mitigation effort in that sector (EUCalc Project, 2020).



The first climate calculator was developed in the UK in 2009 to meet the world's first legally binding emissions target of an 80% reduction by 2050 compared to the 1990 baseline (2050 Pathways Calculator, 2010). Unlike other models that determine optimum pathways, this calculator explored all available options to address uncertainties about future technologies (Strapasson *et al.*, 2020). It was designed to incorporate real scientific evidence into energy debates and provide non-policy prescriptive knowledge to inform decision-making. The tool evaluates existing policies and informs the strategic direction of energy and climate change policies. Its open-source nature fosters dialogue about emissions among businesses, civil society, and the public, enhancing transparency and engagement (UK Govt., 2013; Strapasson *et al.*, 2020). The success of the UK 2050 calculator influenced the development of the UK's 2011 emissions reduction strategy and led to the creation of the My2050 calculator, which garnered over 17,000 public submissions and an insight into the thoughts of the public on the energy transition to net zero (My2050, 2011).

Now the UK climate calculator exists in three formats: the 2050 Excel spreadsheet, a web-based tool, and the My2050 version (UK Govt., 2023). The International 2050 Calculator Programme has since facilitated the development of calculators in over 30 countries. Funded by the International Climate Fund in 2012, calculators were built in 10 developing countries by locally-based teams. Each team adapts the established methodology to address specific national issues, reflecting the diverse challenges and opportunities each country faces (UK Govt., 2023). This flexibility allows for tailored calculators but also introduces variability in their effectiveness as decision support tools (DSTs),

particularly in complex sectors like land management. Due to this flexibility on how the calculators are built and tailored to each country, not all calculators will include the exact same components, in the same capacity (Strapasson *et al.*, 2020). The in-country teams developing the calculators need to navigate very different statistical reporting systems and capacity and sector coverage in each of the countries along with a diversity in climate mitigation options. This is an important aspect of the co-design, co-production method.

As such, the role the calculators play as DSTs will vary both country-to-country as well as sector to sector. Whilst this variability allows for the calculator to be tailored to each countries' specific needs, it also opens the potential for there to also be variability in the effectiveness of the calculator as a DST, especially for complex sectors like land. Understanding the efficacy of these calculators is crucial, as they significantly influence land management policies and commitments. The calculators aim to establish pathways to policy goals, aiding users in developing actionable routes through their warning and lever systems (Figure 4). However, hitting climate targets is not just about partaking in COPs and submitting NDCs, it is also about the commitment to these targets; there is a reality of mediating the complexity of what is being promised into actionable interventions. Overall, there is a gap in knowledge and research regarding the way in which climate calculators and the land sector interact and how this interaction could impact things like country commitments when trying to reduce global GHG emissions: there is little is known about the effectiveness of the climate calculator as a DST within the context of the land sector.

Niche in the DST space

Initially, climate policy and science were predominantly centred on an energy system perspective, emphasising the reduction of GHG emissions through the transition from fossil fuels to renewable energy sources, improvements in energy efficiency, and the development of low-carbon technologies (Strapasson *et al.*, 2022). This approach risks side-lining land use and associated impacts. However, after 2010, there was a growing recognition of the critical role that land use plays in climate mitigation and adaptation strategies (Nabuurs *et al.*, 2022). This shift became particularly pronounced in the lead-up to COP21 in Paris, where the inclusion of land use and forestry in the negotiations highlighted the importance of integrated approaches to climate policy (Forsell *et al.*, 2016).

These discussions underscored how land management, reforestation, and sustainable agriculture are vital components in achieving comprehensive and effective climate action. Most existing climate models need to balance specific details of sectors against representing a comprehensive energy system (Figure 5), alongside deciding on the transparency of data used (Climact, 2020). Many that balance both lose detail, indicating that a balanced approach that neither focuses exclusively on detailed sector-specific issues nor on broad, comprehensive energy system interactions is most common. This suggests that many models aim to provide a moderate level of detail and coverage, making them versatile tools for various applications, but often favour one characteristic over the other. The trade-off between detail and comprehensiveness highlights the need for continuous improvement and integration of new data to enhance model accuracy and reliability.

There is not a strong presence of national scale climate and energy calculators that are as open-access and co-designed focused. This is one of several components that makes the 2050 climate calculator unique and particularly relevant to this research. The fact that the calculator is designed to facilitate the creation of realistic interventions, on a country by country basis, with the co-design process allowing for specificity within the tailoring process, promotes buy-in from the nation developing it (Strapasson *et al.*, 2022). The programme facilitates realistic interventions tailored to individual countries, promoting national buy-in through stakeholder involvement. This co-design process enhances trust, accountability, and transparency, essential for tool utility.

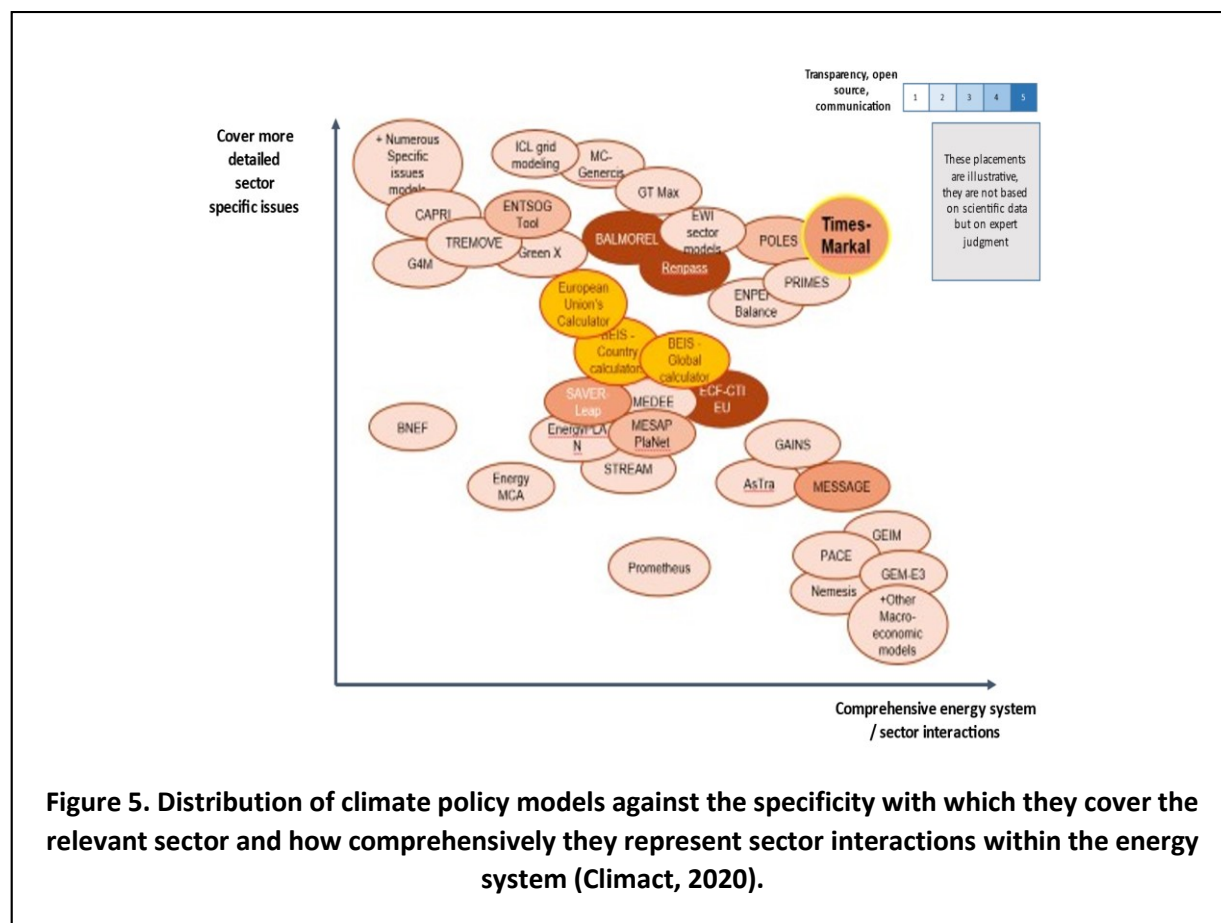


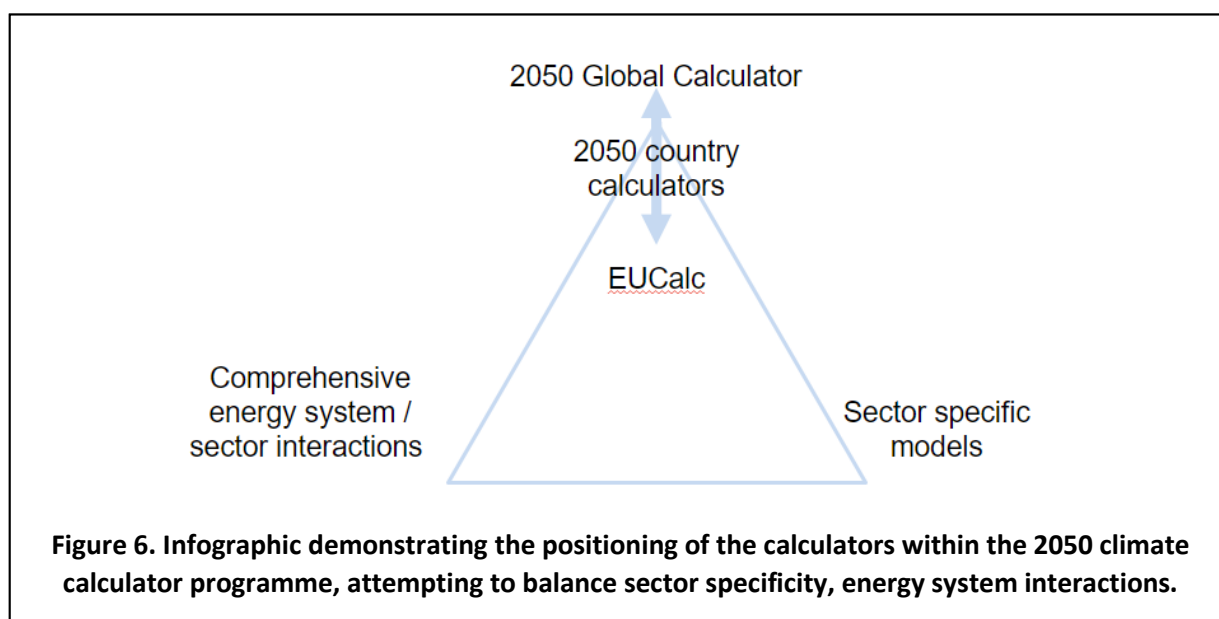
Figure 5. Distribution of climate policy models against the specificity with which they cover the relevant sector and how comprehensively they represent sector interactions within the energy system (Climact, 2020).

The International 2050 Climate Calculator programme is an example of a DST development programme that incorporates user involvement as one of the core developmental components to each national calculator. It is a UK International Climate Finance (ICF) funded technical assistance programme (DESNZ, 2013). The programme supports ODA-eligible countries to develop their own national 2050 climate calculator. Whilst the EU Calculator model is constructed on a software called KNIME, and the Global Calculator used both Excel and a software called Ruby, the 2050 climate calculators are, in general, based on system dynamics modelling using Excel. The Excel based modelling increases accessibility to a broader range of potential users and stakeholders (Strapasson *et al.*, 2020). Stakeholders who are methodically involved in the co-design and development of the national calculator, at multiple stages throughout the development. These iterative steps are built into the creation process to make the tool as tailored and specific as possible on a case-by-case basis, to most effectively help develop and implement policies (DESNZ, 2013; Strapasson *et al.*, 2022). The 2050 Climate Calculators enables sensitivity analysis to test result robustness under different assumptions and promotes transparent methodologies, enhancing credibility and informed decision-making. The programme involves stakeholder engagement and expert peer reviews to ensure accuracy and relevance, helping the programme stand out as producing comprehensive, user-friendly, and policy-relevant decision support tools that inform climate policy development (Strapasson *et al.*, 2022). Many countries are using technoeconomic models to approach emissions reductions, however multifaceted approaches are required. There are trade-offs and unintentional consequences to climate mitigation and adaptation, reminding us that action cannot blindly prioritise fossil fuel reduction, for instance, in order to curb GHG emissions.

Real World Utility of the Climate Calculators

The calculators within the 2050 Climate Calculator Programme are non-policy prescriptive and designed to help the user develop an understanding of successful and actionable routes through the curated outputs. However, hitting climate targets is not just about partaking in COPs and submitting NDCs, it is also about the commitment to these targets; there is a reality of mediating the complexity of what is being promised into actionable interventions. 2050 climate calculators aim to navigate the multifaceted demands on economic sectors, emphasising that emission mitigation is one goal among many (Strapasson *et al.*, 2020). When considering the land sector and land use, it is complex beyond the mitigation potential it presents; there are tensions to be found at the heart of provisioning at a societal level and providing at a national level. For example, 50% of Kenya's energy supply is biomass (Takase *et al.*, 2021). Food is predominantly locally sourced and subsistence-provided, with most materials being used across the economy be sourced from and provided by the land sector (Takase *et al.*, 2021; Nabuur *et al.*, 2022). This showcases the interconnectedness of the land sector to the other economic sectors, as well as its complex role it must hold in DSTs to be fairly represented. The goal of the climate calculator programme is to match the outputs of the national level calculators to the capacity and capabilities of the groups at national level to better understand climate change capabilities within the land sector (Strapasson *et al.*, 2022). Countries are having to balance the need to reduce land emissions in a way that is amenable to the socioeconomic context of those communities.

Tools like the 2050 Global Calculator, 2050 country calculators, and EUCalc purportedly balance comprehensive energy system analysis with sector-specific and region-specific considerations (Figure 6). The EUCalc and newer national calculators aim to provide detailed analyses, addressing the complex interplay between sectors and energy systems, particularly in Europe. This balanced approach embodied by the climate calculators helps justify their use in navigating the multiple demands on the land sector by providing a versatile and comprehensive analytical tool (Strapasson *et al.*, 2020). By incorporating insights from global, regional, and sector-specific models, these calculators offer a versatile tool for addressing the interconnected challenges of the land sector.



The land sector's complexity (see chapter 1.2), presents unique challenges for decision support tools (DSTs). The climate calculators claim to offer detailed, sector-specific analyses that navigate these complexities. However, it is necessary to critique their actual performance in this regard. By evaluating the effectiveness of these tools in the land sector, which is not only critical for emission mitigation but also for societal provisioning and national economic stability, it can question if the calculators provide actionable insights that reflect the land sector's nuanced realities. This is particularly important as the land sector's role extends beyond mitigation potential to include vital societal and economic functions.

It is this role of helping bridge complex gaps such as this that the climate calculators should embody. In successfully implementing tools, it is therefore imperative to bridge the science-policy gap along with decision-making processes (Grêt-Regamey *et al.*, 2017). Investigating the utility of the 2050 climate calculators is crucial due to the ongoing discrepancies between NDC commitments and actual emission reductions needed to limit global warming to 1.5°C. Despite the comprehensive design and multi-sectoral integration of these calculators, emissions gaps still exist, and global emissions continue to rise (see chapter 1.1.6). Evaluating whether these tools are indeed effective in bridging the gap between policy commitments and actionable interventions is essential, revealing if the calculators have helped, if at all, alleviate the emissions gap in previous years and how to improve upon their capacity to adequately address the intricate realities of the land sector.

Moreover, understanding the utility of these calculators in facilitating effective climate interventions can help bridge the science-policy gap, ensuring that decision-making processes are informed by accurate and actionable data. Investigating their success in the land sector can highlight best practices and methods for improving the climate calculators as DSTs, thereby enhancing their capacity to link knowledge to action effectively. This evaluation is necessary to ensure that climate calculators not only fulfil their designed roles but also contribute meaningfully to achieving climate targets in a sector marked by significant complexity and interconnectedness.

4. NDC Analysis

4.1. Introduction

4.1.1. Overview of NDCs

Nationally determined contributions (NDCs) are a core component of the Paris Agreement (COP21) and are integral to the achievement of the long-term COP21 goals. Each participating country, or Party, is required to prepare, communicate, and maintain successive NDCs that detail their efforts to reduce national emissions, and the domestic mitigation measures they intend to implement. These contributions, which cover a five-year span, collectively determine whether the global targets of the PA are met. Preferably, NDCs also include a financing strategy, outlining either the country's capacity to cover climate finance or their need for international support. By regularly updating their NDCs, countries are expected to progressively increase their ambitions towards greater emissions reductions and adaptive measures.

NDCs encompass interventions across various economic sectors and often align with national development plans. Including all sectors ensures a holistic approach to economic and societal transformations aimed at mitigating climate change. The NDCs are a government obligation, often lead by one or more national ministries. Each sector's commitments can be identified as either 'conditional'—dependent on financial support from other nations or organisations—or 'unconditional.' In keeping with the need for each NDC to identify their financial strategy, conditional commitments are provisional on the financial support from other nations or organisations. At present, of the 193 countries that ratified the Paris Agreement, all have submitted the first NDC; 151 have presented a new or updated NDC as of November 2021 (UN website). As a system designed to translate global emissions and climate targets into national level policy, the NDCs play an important role in global climate mitigation efforts. The success of the NDCs in turn reflects the success of the short- and medium-terms targets each country has self-defined, with different countries focusing on different sectors.

Whilst all countries should include all emitting sectors within their NDCs, the emphasis placed on different economic sectors varies by country. This variation arises from the unique economic, social, and environmental contexts of each country (see chapter 1.1.3-1.1.5). For example, a country with a significant agricultural sector may prioritise land use and agricultural practices in its NDCs, while a country with a large industrial base might focus more on energy production and consumption. These priorities reflect national circumstances, capabilities, and developmental goals, shaping the strategies each country adopts to meet its climate commitments. This diversity in national priorities underscores the importance of NDCs not just for individual countries but as integral components of a global effort to tackle climate change across all economic sectors. Investigating NDCs allows an understanding of how individual country efforts contribute to the global climate narrative and address broader systems, such as the interconnected food and energy systems. Energy production and consumption, agricultural practices, and dietary patterns all influence land use decisions and their subsequent impact on GHG emissions. Thus, analysing NDCs provides a comprehensive view of how countries aim to balance these critical areas within their climate commitments, highlighting the interconnectedness of national actions within the global framework.

The land sector provides critical insight into how countries aim to balance various areas within their climate commitments. This sector is uniquely positioned to influence and be influenced by energy production, agricultural practices, and dietary patterns and investigating the emissions gap and how to bridge it through a land sector lens, acknowledges that the land sector embodies complex human, political and resource interactions of climate change.

4.1.2. Prior Research and Rationale

Research has highlighted the significant role of the land sector, particularly agriculture and forestry, in mitigating climate change and in achieving the goals of the PA. The land sector is also recognised for its significant potential in carbon sequestration and emission reductions, and overall emissions reduction potential. However, practical challenges in implementing land sector mitigation strategies are a common concern. These challenges include technical, financial, and institutional barriers. For example, Hönle et al. (2019) discuss the difficulties in measurement, reporting, and verification (MRV) systems, which are crucial for tracking progress and ensuring accountability. This shows the necessity of robust MRV systems and international frameworks to support consistent and transparent reporting. However, capacity to do so is not globally uniform and does not necessarily acknowledge the historical contexts for developed versus developing countries. International bodies and agreements play a crucial role in providing the necessary technical and financial support, as well as in facilitating knowledge sharing and capacity building (Grassi *et al.*, 2017).

This support is especially important to implement with the increasing attention on the role that rapidly growing LMICs (low and middle-income countries) hold in mitigating climate change. Estimates for show that in 2011 CO₂e emissions from these countries consisted of 67% of global GHG emissions. Yet minimising these emissions not only requires international support to overcome the technical, financial, and institutional barriers inhibiting land-based climate mitigation, it also requires international recognise of the need for continued economic growth in many developing countries. Developing countries, particularly Low and Middle-Income Countries (LMICs), face a tension between developmental needs and global climate targets. This highlights the necessity to analyse developed and developing countries both in conjunction with each other and separately to balance the development of equitable mitigation commitments, and the continued increase in GHG emissions during the growth of developing countries.

It is because of the above that comprehensive and transparent accounting methods for GHGs in the land sector are so crucial. Clear and standardised accounting can help ensure that the contributions of both developed and developing countries are accurately measured and fairly compared, facilitating international support and cooperation (Lee and Sanz, 2017). Accurate accounting also provides the data needed to balance climate goals with developmental needs, ensuring that mitigation efforts are both effective and equitable. Consistent methodologies, such as the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Paustian *et al.*, 2006), are recommended for estimating and reporting GHG emissions and removals for AFOLU (Herold and Böttcher, 2018). Using a common framework for classifying land categories and for defining what constitutes a forest, which can differ significantly between countries and affect reported emissions and removals, can improve comparability across commitments and aid amalgamation efforts (Herold and Böttcher, 2018).

Furthermore, Herold and Böttcher (2018) highlight not only the importance of consistency with reporting, but the necessity of including all relevant pools and gases within the accounting processes. This sentiment is seen across various studies (den Elzen *et al.*, 2013), as the inclusion of soil organic carbon, deadwood, and non-CO₂ gases like CH₄ and N₂O have valuable roles within agriculture, land use and LUC. All major GHGs, not just CO₂, needs to be accounted for to obtain a complete picture of countries' contributions to climate change, providing a clearer picture of how land management practices impact GHG fluxes (den Elzen *et al.*, 2013; Herold and Böttcher, 2018). These studies emphasise the dynamic nature of emissions and the need for up-to-date data to inform climate policies and NDCs. However, in practice some countries may face difficulties in estimating and reporting land-based emissions due to limited capacity, but also due to the fact that land is a large and ever changing sector that is difficult to maintain up-to-date data on (Grassi *et al.*, 2017). This underscores further the

importance of international cooperation and support to help countries develop robust and standardised accounting frameworks, ensuring that all relevant GHG sources are considered to the best of global abilities, and that mitigation efforts are comparable across different national contexts.

Despite the critical need for consistency and thorough accounting within NDCs and the land sector, there is a recurring theme of ambiguities and variations in how countries report and commit to land sector activities in their NDCs (Grassi *et al.* 2017; Fyson and Jeffrey, 2019). While there is clear evidence of the inclusion of land sector activities within NDCs, the modalities of inclusion of the land sector vary significantly between NDCs (Grassi *et al.*, 2017). Whilst there will naturally be variation in what components of the land sector are included within an NDC depending on each countries' specific geographies and adaptive capacities, there are **variations in how key terms and activities are defined, such as what constitutes "forest" or "deforestation."** (Fyson and Jeffrey, 2019). This variability compounds the challenges of creating uniform standards and methodologies for land-based emissions reporting, risking the collective efforts being incommensurate with unified global action. These ambiguities can undermine the transparency, comparability, and accountability of NDCs (Fyson and Jeffrey, 2019; Grassi *et al.*, 2021; Nabuurs *et al.*, 2022). With ambiguous LULUCF treatment resulting in an uncertainty range in of up to 2.9GtCO₂eq (Fyson and Jeffrey, 2019), this can affect the overall credibility and effectiveness of global efforts to meet the PA goals through resulting overestimation of the potential mitigation contributions from the land use sector (Grassi *et al.*, 2021).

4.1.3. NDC Objectives

The centrality of the land sector in global climate mitigation efforts and the need for clear, comprehensive, and transparent approaches to NDCs cannot be overstated. Variable and non-specific definitions of land use terms complicate the assessment of the ambition and effectiveness of land-based climate contributions. This chapter aims to address these issues by examining the inclusion of the land sector in NDCs, revealing the complexities and challenges of integrating national and global climate actions (Figure 3). By focusing on land sector commitments, the research seeks to better understand how these commitments and interventions can be more effectively addressed and implemented.

The analysis utilises data from the NDCs to indicate each country's approach to land-based mitigation, including carbon sequestration and emissions reductions. By reviewing actions taken by countries involved in the 2050 Climate Calculator program and the top eight global GHG emitters, the research provides a representative comparison of stated commitments versus actual actions. This comparison is crucial for understanding how well the Climate Calculator program can bridge gaps in emissions reporting and enhance the utility of NDCs in achieving long-term climate goals. Assessing the alignment between NDCs and climate calculators will help identify reporting gaps and improve the effectiveness of climate strategies.

4.2. Methods

4.2.1. Country Selection

Firstly, the countries to be analysed were chosen from the 197 countries which ratified the Paris Agreement and submitted NDCs. To narrow down the number of countries, only those which were also participants in the International 2050 Calculator Programme were included, leaving just over 30. By using the 2050 Calculator programme as a pre-requisite for analysis meant all the countries had that association as at least one common variable. In addition to these countries, the 8 biggest global emitters were added, if not already included on the list (Table 2). These countries were included in the NDC analysis as the way they approach their climate mitigation could have a domino effect on other countries, including those already part of the climate calculator programme.

Table 2. The countries included in the COP21 NDC analysis and the reason they were included.

Country	Reason for Inclusion
Australia	Calculator Programme
Austria	Calculator Programme
Bangladesh	Calculator Programme
Belgium	Calculator Programme
Brazil	Both
Canada	Top 8 Emitter
China	Both
Colombia	Calculator Programme
Costa Rica	Calculator Programme
Czechia	Calculator Programme
Ethiopia	Calculator Programme
Ghana	Calculator Programme
India	Top 8 Emitter
Indonesia	Calculator Programme
Ireland	Calculator Programme
Japan	Both
Kenya	Calculator Programme
Mauritius	Calculator Programme
Mexico	Calculator Programme
New Zealand	Calculator Programme
Nigeria	Calculator Programme
South Africa	Calculator Programme
South Korea	Calculator Programme
Saudi Arabia	Calculator Programme
Switzerland	Calculator Programme
Thailand	Calculator Programme
UK	Both
USA	Both
Vietnam	Calculator Programme
Zambia	Calculator Programme
Zimbabwe	Calculator Programme

The reason that the number of countries included within this analysis were limited (Table 3) firstly being that analysing all 186 parties that have submitted their first NDCs is too many to analyse for the given time frame. The above inclusion criteria (Table 2) made the list manageable. Secondly, bounding the list of countries primarily to those that are associated with the climate calculator ensures that when land is investigated within climate calculators it can be directly compared to the countries' land sector commitments analysed in their NDCs. This is important as, just like with the NDCs, the manner in which land is included within the climate calculator, if at all, is completely determined by the country itself. Specifically, the dataset extracted has been designed so that can be directly compared to the dataset from the systematic map. This makes understanding the difference between the COP21 NDCs and the subsequent actions much easier. Additionally, it makes the analysis highly repeatable for future NDCs, such as those elicited by COP26.

Table 3. Breakdown of the DAC categorisation of the countries analysed

Country	Not a DAC listed ODA recipient	Upper Middle Income	Lower Middle Income	Least Developed
Bangladesh				x
Brazil		x		
China		x		
Colombia		x		
Costa Rica		x		
Ethiopia				x
Ghana			x	
India			x	
Indonesia			x	
Kenya		x		
Mauritius		x		
Mexico		x		
Nigeria			x	
South Africa		x		
Thailand		x		
Vietnam			x	
Zambia				x
Zimbabwe			x	
South Korea	x			
Saudi Arabia	x			
Australia	x			
USA	x			
Czechia	x			
UK	x			
Belgium	x			
Austria	x			
Ireland	x			
Japan	x			
New Zealand	x			
Switzerland	x			
Canada	x			
Total	13	9	6	3

58% of the countries analysed were on the DAC list of ODA recipients (n=18) (Table 3). With the countries receiving ODA funding spread across the three categories, indicating a variety of countries being investigated. There is an assumption that many ODA recipient countries have had economies that are heavily reliant on natural resource extraction and agriculture and so investigating the variety that this subset of NDCs will have could be crucial for understanding the utility of the climate calculator in helping find national pathways to lower emissions.

Czechia, the UK, Austria, Belgium and Ireland all come under the 'EU' NDC. Therefore, when counting frequencies within the NDCs, these were all kept under just the EU. This meant that a total of 27 NDCs were analysed.

4.2.2. Data Extraction

A systemised approach was applied, similar to that of Fyson and Jeffrey (2019), where inclusion of the Land Sector in the COP21 NDCs was categorised, and the type of data extracted was binary (yes/no) with some areas for explanation. The full data was collected if the paper included land (Table 4) (yes/no).

Table 4. Different terms and manners of referencing land and warranting full extraction of data.

Accepted Land References Included
AFOLU
LULUCF
Agriculture
Forestry
Land Use
Land Use Change
Land Management
Established land-based policy (E.g. REDD+)

The initial metadata extraction included detailing information such as, "part of the 2050 EU Calculator Project", "DAC List of ODA Recipients", "Member of the EU" and "Year 2050 Calculator was Launched" (Appendix A).

Data collection proceeded to review whether or not the land sector had been mentioned (y/n), the nature of its inclusion (AFOLU or LULUCF or other), if the land sector was included in the unconditional commitments (y/n) or the conditional commitments (y/n), and the metrics used to define the land-based commitment (% of forest restoration, MtCO₂ eq. reduction, rate of deforestation reduction etc).

Binary coding (yes or no) was chosen as it established the necessary dataset for quantitative analysis. Supplementary to this was space for elaboration, which was used to explain concepts or add notes to any data extracted if required. The conditionality of each of the land-based commitments was defined, and the nature of the land commitments categorised into 4 categories that emerged through the extraction process (AFOLU, LULUCF, Agriculture [not as a subsector of AFOLU] and, land and forestry [not as a subsector of LULUCF]). 'Agriculture' and 'Land and Forestry' was identified as their own categories as they were often referred to within the same NDCs where 'AFOLU' and/or LULUCF was in use but were contextually being treated as separate considerations. E.g. When Agriculture was mentioned in the same sentence as LULUCF, such as the New Zealand NDC where "Forestry and other

land use” is mentioned separately to “Agriculture”. Or referencing “AFOLU”, “Agriculture” and “Forestry” as three separate sectors, such as the South Africa NDC (Table 5).

Table 5. Showcasing the different manners in which the Land terminologies were used, differentiating between the use of AFOLU/LULUCF and agriculture/ land and forestry in context of this research, not as subsectors of the former acronyms.

Terminology	Example	NDC
AFOLU	“AFOLU for land-based sector”	Indonesia
LULUCF	“This includes emissions from the land use, land-use change and forestry (LULUCF) sector based on IPCC Guidelines.	Mauritius
Agriculture	“Promote sustainable Agriculture and Good Agricultural Practice (GAP)”	Thailand
Land and Forestry	“[...] focus on sustainable forest management, afforestation and regulating diversion of forest land for non-forest purpose [...]”	India

4.2.3. Analysis and Limitation Mitigation

The data was analysed using document and frequency analysis (Love, 2003). Document analysis can be applied in qualitative, quantitative, and sometimes mixed modes of research frameworks (White *et al.*, 2006). Document analysis focuses on understanding the document as a whole, including its context, purpose, and the conditions under which it was created, which is ideal to encapsulate the necessary context behind the NDCs.

For this research quantitative document analysis was used to systematically analyse the text content of the NDCs and code the content, including land terminology use, conditionality and metrics used (see section 4.2.1.). This analysis technique, alongside frequency analysis, helps determine the prevalence and distribution of different coded themes (e.g. land terminologies) across the data (Ashley and Boyd, 2006).

Frequency analysis was used on the coded data extracted from the NDCs (yes/no) to understand the frequency of use of land terminologies and conditionality. Measuring frequencies, percentages, and means, provided simple and clear overviews of the data. The land terminology that and NDC used was coded, as well as the conditionality, so that the relationship between these and the countries’ DAC listed ODA status and geographic location could be visualised, in order to investigate if there was a correlation between land terminology used, conditionality ODA status and geography. Frequency analyses and visualisation is used is a commonly used across various disciplines including social sciences, political sciences and environmental sciences. Whilst the analysis technique can be prone to coder bias this was mitigated by clearly defining terminologies being extracted (see 4.2.3. and 1.2. for land terminologies) so that there are clear categories for the data to be coded into, helping reduce bias and double counting (Gheyle and Jacobs, 2017).

The Methods

Including countries among the top 8 global GHG emitters or members of the International 2050 Calculator Programme ensures comprehensive COP21 NDC analyses. The inclusion of the International 2050 Calculator Programme ensures an in-depth NDC analysis due to its robust framework and comprehensive toolset for evaluating various emission reduction pathways across all sectors, including energy, transport, industry, agriculture, land use, and forestry. Although this selection limits the number of countries analysed, it is beneficial as it allows for a manageable and demographically varied set of countries to be analysed within a shorter time frame. Additionally, whilst bounding the countries investigated predominantly by those involved in the programme may introduce a bias (the countries willing to make a national climate calculator may also be politically and financially inclined implement climate mitigation measures) this a sentiment that should be applicable to all countries that ratified their NDCs during COP21. So, whilst this potential bias must be accounted for during analysis, it should not bias the data or negate the value of the tailored results and recommendations this research can elicit. While analysing all submitted NDCs would provide a comprehensive global view of the land sector, the scope of this research necessitated focusing on countries within the climate calculator programme to tailor the results to the DSTs in question. The research focus on these countries also helps provide relevant insights into LMICs, where the agricultural sector significantly impacts GDP and AFOLU emissions are critical.

4.3. Results

4.3.1. Land Terminology

100% of the countries included land within their NDC, either by referencing that they will comply with IPCC standards for monitoring and mitigation (e.g. The US and Australian NDCs), or through full inclusion within national plans to reduce GHG emissions.

89% of the NDCs included “Agriculture”, not as a subsection of AFOLU (n=24); 74% (n=20) of the NDCs included “land or forestry”, not as a subsection of LULUCF, and 48% (n=13) included “LULUCF”.

AFOLU was mentioned the least frequently within the NDCs, only appearing in 44% (n=12) of them (Table 6). This is potentially due to the fact that “AFOLU” is one of the most recent terminologies to be included within international climate policy, as well as a reflection of parties choosing language that they feel best represents their land sector. This is explored further in section 4.4.1.

4.3.2. Conditionality of Land Commitments

37% (n=10) of the NDCs did not specify if the land-based policies they were presenting were conditional or unconditional. Of this 37% (n=10), none of the countries, other than India, were on the DAC list of ODA recipients (Table 6).

63% of the NDCs (n=17) included at least one land-based policy that was defined as ‘conditional’ or ‘unconditional’. 15% (n=4) of the NDCs only included land in their conditional targets and 11% (n=3) of the NDCs only included land in their unconditional targets. 26% (n=7) of the NDCs had conditional and unconditional targets including the same land terminologies. The remaining 11% (n=3) included at least one reference to the land sector where conditionality was specified, and an additional reference to the land sector where conditionality was unspecified (Table 6).

This inconsistency with specifying conditionality of targets is potentially linked to the whether a country is developed or not; countries that do not require ODA support might be less likely to clarify that the commitments are unconditional, as they are less likely to be a country that requires financial support to make them so. This is explored further in section 4.4.2.

4.3.3. Land and Conditionality

Of the 48% (n=13) NDCs that included “LULUCF”; 7 NDCs did not specify conditionality, 2 NDCs included it in a conditional capacity and 4 included it in both conditional and unconditional commitments (Table 6).

Of the 44% (n=12) NDCs that included “AFOLU”; 2 NDCs did not specify conditionality, 4 NDCs included it in a conditional capacity, 2 NDCs mentioned it in an unconditional capacity and 4 included it in both conditional and unconditional commitments (Table 6).

Of the 74% (n=20) NDCs that included “land or forestry”; 8 NDCs did not specify conditionality, 3 NDCs included it in a conditional capacity, 4 NDCs mentioned it in an unconditional capacity and 6 included it in both conditional and unconditional commitments (Table 6).

Of the 89% (n=24) NDCs that included “Agriculture”; 9 NDCs did not specify conditionality, 4 NDCs included it in a conditional capacity, 4 NDCs mentioned it in an unconditional capacity and 7 included it in both conditional and unconditional commitments (Table 6).

Table 6. Presence of the four different categories of 'Land' that could be presented within the NDCs

Country	AFOLU	LULUCF	Agriculture (not as a sub-sector)	Land/Forestry (not as a sub-sector)
Australia			unspecified	unspecified
Bangladesh			both	both
Brazil			unconditional	unconditional
China			unconditional	unconditional
Colombia	conditional		conditional	
USA				unspecified
Costa Rica	conditional		conditional	conditional
EU	unspecified	unspecified	unspecified	unspecified
Republic of Korea		unspecified	unspecified	unspecified
Ethiopia	both	both	both	both
Ghana		both	unspecified	conditional
India			unspecified	unspecified
Indonesia	unconditional	unspecified	unconditional	unconditional
Japan		unspecified	unspecified	unspecified
Kenya	conditional	conditional	conditional	conditional
Mauritius	both	both	both	both
Mexico	unconditional		unconditional	unconditional
New Zealand		unspecified	unspecified	
Nigeria			both	both
Saudi Arabia			unspecified	unspecified
South Africa	both		both	both
Switzerland		unspecified	unspecified	
Thailand			conditional	unspecified
Canada	unspecified	unspecified		
Vietnam		both	both	
Zambia	both		both	both
Zimbabwe	conditional	conditional		

“Unspecified” means that the term was used within the NDC but was not explicitly allocated to a conditional or unconditional target

“both” means that the term was used for both a conditional and unconditional target

“Unconditional” or “Conditional” means that the term was only used within the context of an

Colombia, Costa Rica, Kenya and Zimbabwe were the only countries that included land in an exclusively conditional capacity. Kenya was the only country that had all four categories of land terminology included within the NDC, specified as conditional (Table 6).

Bangladesh, Ethiopia, Mauritius, Nigeria, South Africa, Vietnam and Zambia had both conditional and unconditional commitments for every land terminology they referenced within their NDC. Ethiopia and Mauritius were the only countries that had both commitments for all four categories of land terminology (Table 6).

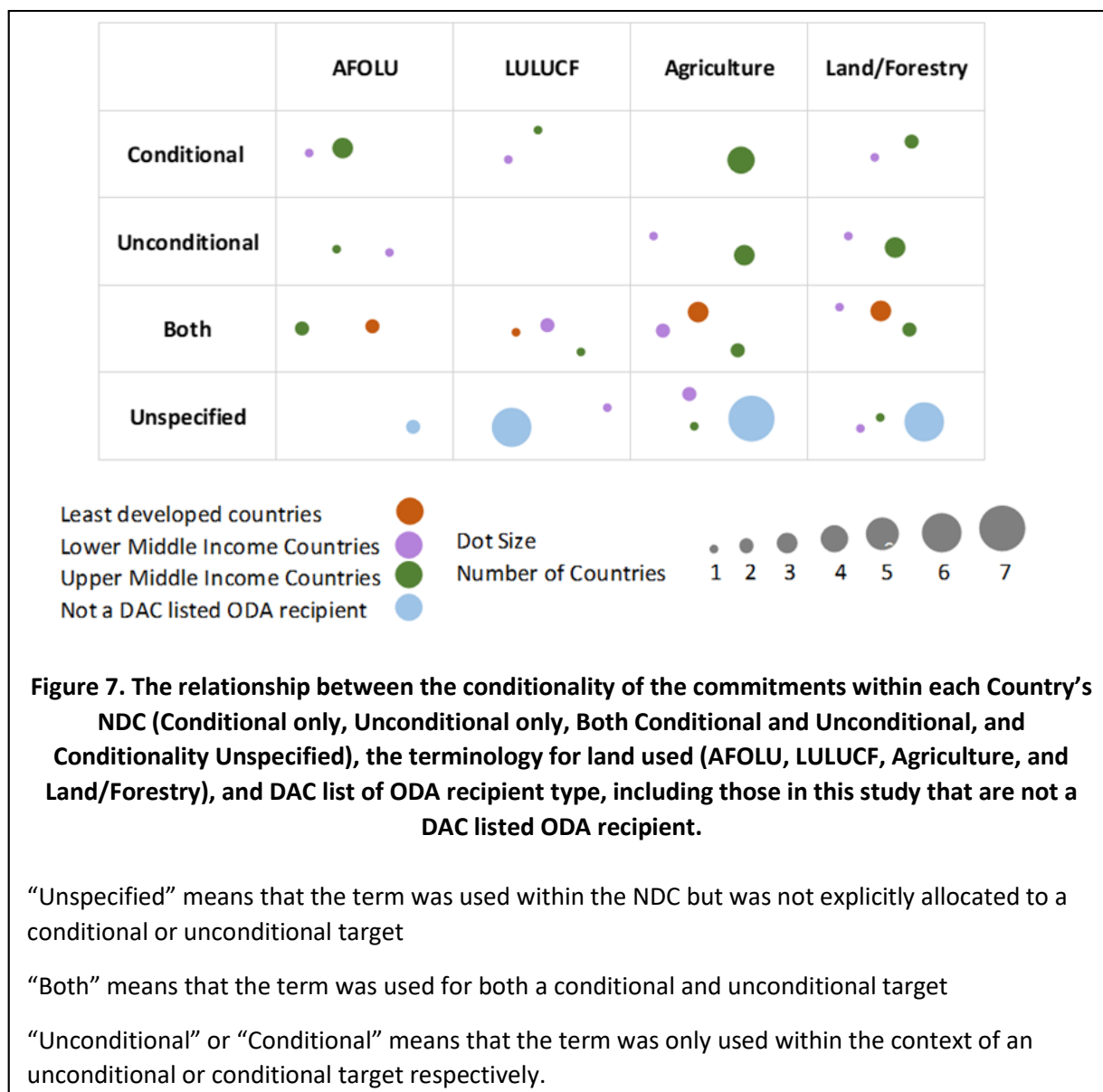
Australia, the EU, Republic of Korea, India, Japan, New Zealand, Switzerland and Canada did not specify commitment type for any of the land terminology they referenced within their NDC. The EU was the only NDC that had all four categories of land terminology included within the NDC, without specifying conditionality (Table 6).

Brazil, China and Mexico were the only countries that included land in an exclusively unconditional capacity. None of these included all four categories of land terminology within their NDC (Table 6).

Ghana, Indonesia and Thailand included at least one reference to the land sector where conditionality was specified, and an additional reference to the land sector where conditionality was unspecified. Indonesia was the only one to include all four land terminologies, with 'AFOLU', 'Agriculture' and 'land or forestry' included in an unconditional manner, and 'LULUCF' in an unspecified manner (Table 6).

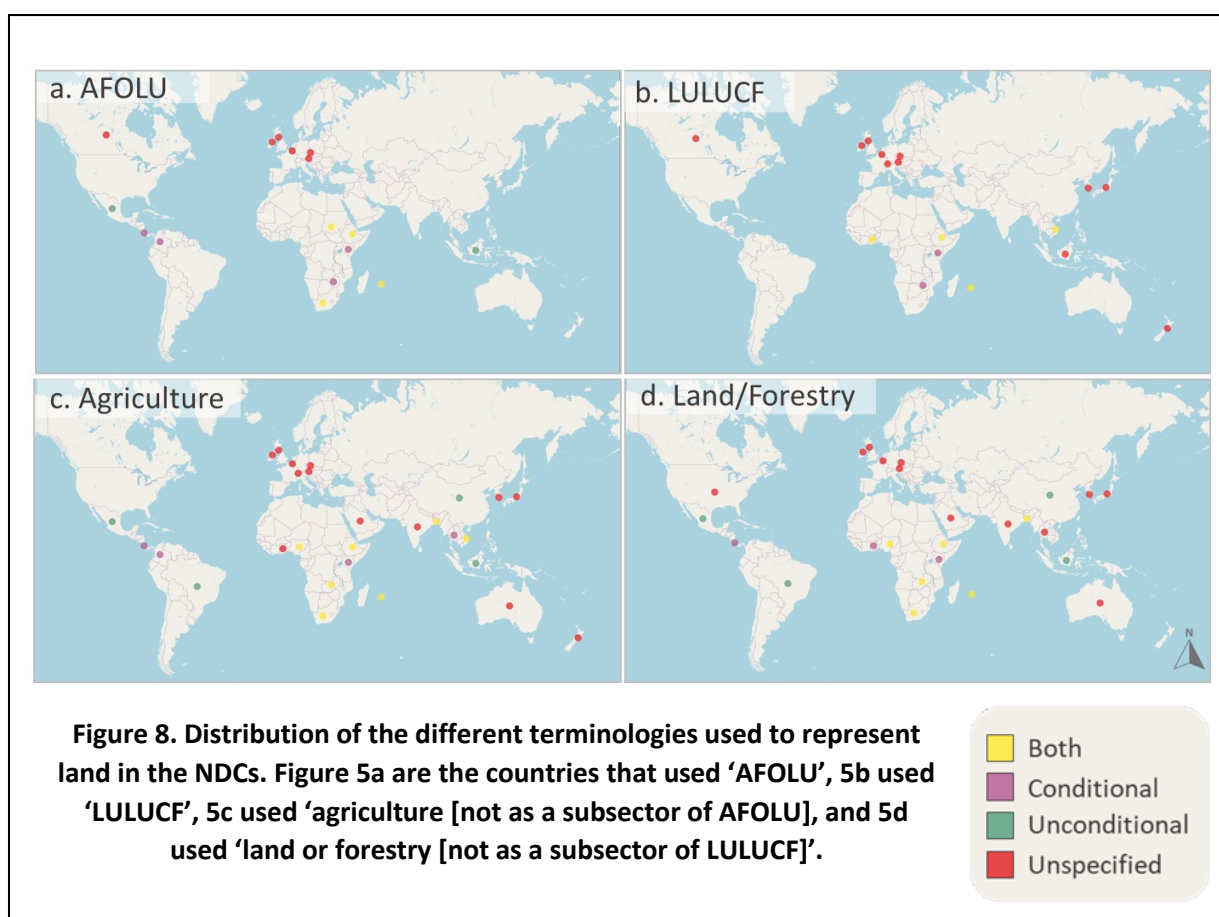
The majority of countries that did not specify the conditionality of their land sector commitments were not DAC listed ODA recipients. Least developed countries included both conditional and unconditional commitments for the land terminologies they used. Lower middle-income countries and upper middle-income countries were seemingly distributed across the terminologies and conditionalities (Figure 7).

The only gap that is present is LULUCF only being mentioned in an unconditional capacity; LULUCF is either mentioned with unspecified capacity, a conditional capacity, or both conditional and unconditional (Table 6, Figure 7). These results likely reflect the varying priorities, capacities, and circumstances of the countries, for instance High-income countries like Australia, the EU, and Canada not specifying commitment types may indicate their greater flexibility and internal capacity to address these issues without reliance on conditional terms. This is explored further in section 4.4.3.



4.3.4. Global Distribution of Land Terminology and Conditionality

NB. The EU NDC is shown as a cluster of 5 dots on Figure 8, representing the 5 countries that are included under the first EU NDC that also have a climate calculator within the International 2050 climate calculator programme.



The use of 'AFOLU' is less prevalent in the eastern countries, with the most representation being in Europe, because of the EU NDC, and African countries (Figure 8a). All uses of 'AFOLU' that have conditionality specified are in the global south.

The use of 'LULUCF', is lacking in the Americas, but otherwise use of the term, whilst not used by many, is spread across Europe (due to the EU NDC), Africa and eastern countries (Figure 8b). Most uses of 'LULUCF' in the global south have specified conditionality, excluding Australia and Indonesia.

The use of 'Agriculture' is globally distributed (Figure 8c), as is the conditionality of the commitments.

The use of 'land and forestry', is slightly less prominent than 'agriculture', but is also globally distributed (Figure 8d), as is the conditionality of the commitments although most of the terms use in the global south has specified conditionality.

These results likely reflect regional priorities and capacities related to land use and agriculture, as well as reflecting the different adoption rates of 'AFOLU', as newer land terminology, across different regions.

4.4. Discussion

This chapter aimed to contextualise the land sector on a global scale by determining historic land-based commitments and countries' intended land-based actions. Specifically, this chapter examined the way that the land sector was incorporated into the NDCs of countries that are involved with the International Climate Calculator Programme, and/or are a top 8 global emitter. By examining how countries incorporated land within their NDCs, the analysis provides critical insights into the consistency, clarity, and emphasis of land-based climate commitments across different nations. This discussion follows the structure of evaluating the four key areas that were highlighted within the results: Inconsistent language use indicates fragmented climate strategies (section 4.4.1.); Inconsistent statement of conditionality increases ambiguity around countries' actual capacity (section 4.4.2.); Selective reporting of the land sector can bias presentation and lessen transparency (section 4.4.3.); and there are Regional disparities in how the land sector is framed and the support therefore required. (section 4.4.4.).

4.4.1. Inconsistent Land Terminologies Indicates Fragmented and Incomplete Strategies

All NDCs in this study included land, either through adherence to IPCC standards or by incorporating land-related strategies within their national plans to reduce GHG emissions, suggesting a universal recognition of the importance of the land sector. However, there is considerable variation in how specific land-related terms are used. Less than half the NDCs included "LULUCF," or "AFOLU," (Table 6), whilst 74% included "land or forestry," and 89% included "Agriculture,." The prominence of agriculture reflects the vital role it plays globally; the state of agriculture heavily influences national economies and livelihoods (Pawlak and Kołodziejczak, 2020; Rusmayandi, *et al.*, 2023). Adaptation measures within agriculture are essential to ensuring resilience against climate change, particularly when ensuring food security in developing countries (Ethiopian Panel on Climate Change, 2015; Pawlak and Kołodziejczak, 2020). The Paris Agreement is one of several international agreements and frameworks, alongside the SDGs, that emphasises the importance of promoting sustainable agriculture and land use (Nabuurs *et al.*, 2022). Yet agriculture and food security are significant components within AFOLU (Smith *et al.*, 2014; Nabuurs *et al.*, 2022), so this does not explain the reduced number of NDCs including 'LULUCF' and 'AFOLU'.

'AFOLU' being the least mentioned could be a reflection of the term only being introduced more recently (IPCC, 2006). Varying capacity and willingness to adopt new terms and frameworks could see different rates of adoption globally. Adoption of new concepts into national and global policy is rarely quick, nor without contention over terminology concept (Friant *et al.*, 2021). Whilst this study did not focus specifically on the term 'AFOLU', it highlights the phenomenon of different actors seeking to influence terminology meaning and approaching defining the term with conflicting approaches (Friant *et al.*, 2021). Whilst 'AFOLU' has clear definitions (IPCC, 2006; Smith *et al.*, 2014; Nabuurs *et al.*, 2022), if as a terminology it has not yet been fully integrated into policy design, it could lead parties to use language they believe best represents their land sector, potentially at the expense of uniformity and transparency (Otchere-Darko and Ovidia, 2020). It could be that the challenge mitigation in AFOLU poses, due to MRV, reluctance in stakeholders, and potential threats to food security (Tzemi and Breen, 2019; Lamb *et al.*, 2021; Fujimori *et al.*, 2022), make focus towards 'Agriculture' and 'Land and/or forestry' over 'LULUCF' and 'AFOLU' a priority. Such trends indicate deliberate avoidance and potential neglect of other crucial aspects of these terms, such as land-use change, which is exceptionally important when determining effective land-based climate mitigation (den Elzen *et al.*, 2013; Fyson and Jeffrey, 2018).

Whilst specificity over language selection is important to fairly represent a Party's land sector and adaptive capacity (Forsell *et al.*, 2016), tailoring commitments to be realistic should not be at the

expense of comprehensive land sector representation (Grassi *et al.*, 2017). This deliberate curation of language is also a greater indication of the fact that not only is land terminology inconsistent, but that the definitions for each of the terms are being only loosely applied (Otchere-Darko and Ovadia, 2020). The inconsistency in land terminology across NDCs and the absence of food, food systems, and diet highlighting a significant gap in the comprehensiveness of land representation (Smith *et al.*, 2014; Nabuurs *et al.*, 2022). This omission suggests that while countries are addressing agricultural practices and land use in terms of emissions, they may not be fully representing the interconnectedness of the energy system, food systems, and the land sector on climate change. This lack of holistic consideration could undermine efforts to create integrated and effective climate strategies that encompass all aspects of land use and its connection to human systems (Hönle *et al.*, 2019). The inconsistency in land use terminology and the omission of critical aspects like food systems from NDCs indicate fragmented and incomplete strategies, potentially leading to an underestimation of the full impact of land-related emissions.

4.4.2. Inconsistent Conditionality Increases Ambiguity Around Countries' Actual Capacity

There was significant variation in how countries specify the conditionality of their land-based policies within their NDCs. Whilst there is an expectation that not all parties will have the same number and type of conditional and unconditional commitments, due to the complex legacy of capacity, over a third (37%) of the NDCs did not specify conditionality at all. This showcases a lack of uniformity in how commitments are reported and presented. Lacking uniformity can complicate the assessment of global progress and the allocation of resources (Pauw *et al.*, 2020), where the varying levels of specified conditionality make it challenging to aggregate party commitments and plan effective distribution of financial support for conditional targets (Weiler *et al.*, 2018; Pauw *et al.*, 2019).

Interestingly, the countries that did not specify conditionality, except for India, are not on the DAC list of ODA recipients, implying that these are more likely to be developed countries with less reliance on external financial support (Mill-Novoa and Liverman, 2019). High-income countries, such as Australia, the EU, and Canada, generally did not specify the conditionality of their land sector commitments, potentially indicating their greater capacity to address these issues independently (Mill-Novoa and Liverman, 2019). Limiting specificity on commitments may allow Parties to retain flexibility in the implementation of policies and adjust interventions based off evolving circumstances (Shepsle, 1992). Whilst this study did not focus on the NDCs, parallels can be seen between the discretionary authorities in Shepsle's study and the Party's involved in the Paris Agreement (Taibi *et al.*, 2020). In these circumstances, transparency is deliberately obfuscated to avoid exposing any political sensitivities greater specificity could elicit (Taibi *et al.*, 2020). Parties may be hesitant to make binding commitments that could be difficult to fulfil or enforce, especially if they face domestic opposition or lack consensus on climate policies (Shepsle, 1992; Pauw *et al.*, 2020; Taibi *et al.*, 2020).

In contrast, the majority of the NDCs (63%) included at least one land-based policy defined as (un)conditional, with some countries only including land in either their conditional or unconditional targets, while others included both. This pattern suggests that countries in need of financial support are more inclined to specify the conditionality of their commitments, highlighting their dependency on international assistance for achieving their targets (Weiler *et al.*, 2018). Conditional targets allow developing countries to leverage financial and technological assistance from developed countries as a form of climate justice and equitable climate responsibility as they transition to low-carbon development pathways (Weiler *et al.*, 2018; Mill-Novoa and Liverman, 2019).

The inconsistency in specifying conditionality points to a broader issue of transparency and accountability in international climate commitments. Countries that do not require ODA support may

feel less compelled to clarify the unconditional nature of their commitments, potentially leading to a lack of clarity and comparability in the commitments made (Shepsle, 1992; Taibi *et al.*, 2020). This inconsistency can undermine trust and coordination among nations, making it challenging to gauge collective progress and identify gaps in support and action (Mill-Novoa and Liverman, 2019). The lack of clarity and consistency in specifying the conditionality of land-based policies can lead to misunderstandings and misrepresentations of a country's actual capabilities and commitments (Jernnäs *et al.*, 2019). This can result in an overestimation of global progress and an underestimation of the support required by developing nations. Without clear and transparent commitments, it becomes difficult to mobilise the necessary financial and technical assistance to support conditional targets (Jernnäs *et al.*, 2019), potentially widening the emissions gap. Furthermore, the uncertainty surrounding the conditionality of commitments can hinder the development of robust and coordinated international strategies to mitigate climate change (Taibi *et al.*, 2020).

4.4.3. Selective Reporting of the Land Sector Biases Presentation and Lessens Transparency

All four of the different land terminologies has been represented within the NDCs in varying capacities and with varying conditionality. For example, 'LULUCF' is frequently specified as conditional or unspecified, but rarely unconditional, whilst 'AFOLU' has a reasonably balanced representation across conditional, unconditional, and unspecified commitments, but is most often conditional or both conditional and unconditional (Table 6). 'Land or Forestry' is distributed evenly across all types of conditionality, with a notable portion being unspecified, whilst 'Agriculture' is widely mentioned with a balanced distribution across conditional, unconditional, and unspecified commitments (Table 6). This likely reflects the varying priorities, capacities, and circumstances of the countries (Smith *et al.*, 2014). There is no common denominator that links all these regions together; they span different continents, economic statuses, and environmental contexts. Ethiopia and Kenya are low-income countries in Africa with significant agricultural sectors, while Mauritius is a small island developing state (Takase *et al.*, 2021; Wendimu, 2021; Doorga, 2022). The EU represents a coalition of high-income countries with advanced economies, and Indonesia is a rapidly developing country in Southeast Asia with extensive forestry resources (Fünfgeld, 2020; Costa and Aubert, 2022). This suggests that the inclusion of diverse land terminologies might be more influenced by individual national policies and priorities rather than a common regional or economic characteristic (Warner *et al.*, 2019). Each country's unique environmental challenges, policy frameworks, and strategic priorities likely drive their comprehensive approach to land terminology in their NDCs, highlighting the importance of tailoring climate commitments to specific national contexts.

Least developed and lower middle-income countries frequently included both conditional and unconditional commitments for the land terminologies they used. Some countries (e.g., Kenya, Indonesia) specified all four land terminologies with varying types of conditionality, reflecting a more detailed and nuanced approach. Countries like Kenya and Indonesia, might be seeking to demonstrate a comprehensive approach while also indicating areas where they need support (Mill-Novoa and Liverman, 2019). Overall, Lower middle-income and upper middle-income countries were distributed across the terminologies and conditionalities, suggesting a diverse range of priorities and capacities within this group.

The inconsistency, or selective reporting, of the land sector presentation indicates parties' deliberate use of language and terminology that represents their land sector in the best light, requiring the least amount of emissions reduction (den Elzen *et al.*, 2013). This also indicates a wider problem that these countries might bias terminology use to best suit their policy needs and external funding opportunities (den Elzen *et al.*, 2013; Fyson and Jeffrey, 2019). It is important that parties do not cherry-pick language that resonates more with their domestic audience and policy goals at the expense of

transparency. This can lead to inconsistencies in reporting and a lack of comparability across NDCs (Hasan *et al.*, 2020; Hoan *et al.*, 2021). The disparity in how land-based commitments are specified could hinder coordinated global efforts to track and achieve climate targets, complicating the assessment of overall progress and the allocation of resources. The Paris Agreement aims to work towards a common aggregated outcome; a disparity in land use terminologies across the NDCs may represent incommensurate language barriers.

4.4.4. There are Regional Disparities in Land Sector Framing and Support Required

There are distinct geographical patterns in the usage of different land terminologies and their conditionalities within the NDCs (Figure 8). This is important because the way in which the different countries interact with the land sector suggests different applications of the land sector. The term 'AFOLU' is less prevalent in eastern countries but is notably represented in Europe, mainly due to the EU NDC, and in African countries (Figure 8a). Interestingly, all specified conditional uses of 'AFOLU' are found in the global south. 'LULUCF' is not used in the Americas but has a broader distribution across Europe, Africa, and eastern countries, with most global south uses specifying conditionality, except for Australia and Indonesia (Figure 8b). The term 'Agriculture' shows a global distribution, with its conditionality also widespread (Figure 8c). 'Land and forestry' is used less prominently than 'Agriculture' but still shows a global distribution, with most global south instances specifying conditionality (Figure 8d).

These results likely reflect regional priorities and capacities related to land use and agriculture. The prevalence of 'AFOLU' in Europe and Africa may be due to the comprehensive nature of the EU NDC and the significant role of agriculture and forestry in African economies (Takase *et al.*, 2021; Wendimu, 2021). The distribution of 'LULUCF' terms, particularly its absence in the Americas and conditional usage in the global south (except Australia and Indonesia), suggests regional differences in land use policy and capacity for independent action (Verma *et al.*, 2023). Global use of 'Agriculture' and 'land and forestry' terms reflects the universal importance of these sectors, with conditional commitments indicating varying degrees of dependence on international assistance (Mill-Novoa and Liverman, 2019; Varamesh *et al.*, 2022). This suggests that while agriculture and forestry are universally acknowledged as crucial for climate action, the specific terms and the conditionality attached to them vary significantly based on regional contexts and capacities. Consequently, this disparity in terminology and conditionality could lead to challenges in creating a unified global strategy for land-based climate mitigation, as different regions may prioritise and report their land sector commitments in ways that best align with their unique circumstances and resources.

The combined analysis of land terminology, conditionality, and geography highlights regional differences in climate policy approaches. The global south's tendency to specify conditionality for land terms reflects a need for international assistance, while the global north's more unconditional commitments indicate greater self-sufficiency. Europe's extensive use of technical terms like 'AFOLU' and 'LULUCF' underscores its advanced policy frameworks and integration of land use into climate strategies (Taibi *et al.*, 2020). These results suggest that on a global scale, there are significant regional disparities in how land sector commitments are framed and what support is needed to achieve them (Jernnäs *et al.*, 2019). The reliance on conditionality in the global south points to a need for increased international cooperation and support to enable these countries to meet their climate goals. The varied use of terminologies also indicates that a unified global approach might be challenging, given the different levels of adoption and familiarity with specific terms.

4.4.5. Chapter Take Aways

Conditionality of climate commitments varied across the global north-south divide and across land terminologies, reflecting the complexities inherent within the land sector. 'Agriculture' and 'Land and/or forestry' were the most used terminologies, being used in all commitment types (conditional, unconditional, both and unspecified), with an even distribution of use globally. This is potentially because the scope and focus of 'agriculture' and 'land and/or forestry' are more specific and focused on particular sectors, making them easier to address in policies and discussions (See section 4.4.1.). Conversely, 'AFOLU' and 'LULUCF' encompass a broader range of activities and interactions, making them more complex and potentially harder to include in the NDCs, documents that require high levels of transparency and justification. In national and international policies, simpler and more direct language is often preferred to ensure clarity and effective communication (Cunliffe *et al.*, 2019). Using 'agriculture' and 'land and/or forestry' might help convey concise concepts, yet can represent an over reliance of an NDC towards policies towards forests, or renewable energy, without discussing the uncertainties and land use components of this (Mills-Nova and Liverman, 2019).

The lack of dominant use of 'AFOLU' and 'LULUCF' suggests the matter of expert capacity and flexible interpretation of the definitions, leading to **erroneous application of terms**. These two terminologies are tightly (and quantitatively) defined by the FAO and the IPCC (IPCC, 2006; Shanti *et al.*, 2019). This implies that without a strong understanding and adherence to these definitions, countries may apply terms inconsistently, undermining the comparability and effectiveness of their climate commitments. Part of the legislature surrounding AFOLU terminology and use is the safeguard food security under climate change mitigation policies (Verschuuren, *et al.*, 2022). Failing to include food security not only emphasises the NDCs not integrating 'Agriculture' commitments into the established 'AFOLU' framework, but also failing to appropriately represent the entirety of the land sector within their NDCs.

The omission of diet and food systems within the NDCs can be seen as part of this broader trend. Food systems and diet are integral to land use and land use change, which are core components of the 'LULUCF' and 'AFOLU' categories (Liu *et al.*, 2020). However, the complexity and international dimension of food systems make it challenging to address them explicitly within the NDCs. The omissions of food systems and the reduced inclusion of 'LULUCF' and 'AFOLU' could be intrinsically linked; food and diet are primary drivers of land use change, so should be directly linked with LULUCF (Liu *et al.*, 2020; Crippa *et al.*, 2021; Verma *et al.*, 2023). Whilst the intricate nature of global food supply chains, including import and export activities, might make incorporating food systems into national commitments challenging, the **omission of critical aspects like food systems from land sector indicates fragmented and incomplete NDC strategies**. Countries may fail to capture the full scope of emissions and potential mitigation opportunities due to a lack of standardisation and comprehensiveness, which hampers accurate progress measurement and effective strategy implementation, ultimately widening the emissions gap and undermining global climate goals.

Overall

The results suggest that the PA faces significant challenges in effectively translating global needs into coherent national land sector targets, as evidenced by the inconsistent use of land-related terminologies and the varied inclusion of critical aspects like food systems across NDCs. Additionally, the results reveal diverse relationships between countries and the land sector, with variations in terminology and conditionality reflecting differing regional priorities, capacities, and reliance on external support. This disparity underscores the necessity for increased international cooperation to achieve the global climate targets envisioned by the PA.

Evaluating the original PA NDCs, despite the availability of updated versions, remains relevant for several reasons. Firstly, they provide a baseline understanding of countries' initial land sector commitments, crucial for comparing subsequent updates and assessing policy evolution. Given the rise in global emissions since 2015 (Figure 2), the original NDCs reveal early priorities for land-based climate action, allowing for a critical evaluation of their alignment with global reduction goals. This helps determine whether initial strategies were robust or lacked ambition and feasibility. Additionally, this analysis provides insight into the effectiveness of climate calculators and models used during that period, by comparing their projections with the commitments made in the NDCs. Understanding these initial assumptions and projections can shed light on their role in shaping policy and their accuracy in predicting outcomes.

5. Systematic Map

5.1. Introduction

5.1.1. Interventions Since the PA

Since the Paris Agreement in 2015, many of the 195 signatory countries have strengthened their climate commitments, increasing pledges to curb emissions and support adaptation efforts, as seen in the annual UN climate conferences (COP) (Mor *et al.*, 2023). However, concerns about the future of global commitments have emerged due to the absence of U.S. President Joe Biden and Chinese President Xi Jinping, leaders of two of the largest GHG-emitting nations, from COP28 in Dubai in December 2023 (Tankersley and Friedman, 2023). The first global stocktake in September 2023 warned that the world is not on track to meet the PA's long-term goals, highlighting ongoing challenges despite some progress, such as a reduced estimate of global temperature rise from ~4°C to 3°C since 2015 (UNFCCC, 2023). It is ambiguous as to whether these reforms were a direct consequence of PA implementation or if government actors already mobilising against climate change would have conducted themselves the same regardless of the agreement.

Enforcing monitoring and reporting of carbon emissions is one of the main challenges associated with the PA (Fyson and Jeffrey, 2019). If a country within the agreement fails to meet obligations, other than soft power from other members via diplomatic means to coerce actions, there is no ability from the agreement to force a country to comply. Such a dynamic was evident during COP24 in Katowice, 2018, where tensions arose around the endorsement of the IPCC's 1.5°C impact report. While the Katowice Agreement aimed to operationalise the PA with a common reporting framework, some countries, such as China, flagged that accepting externally imposed targets and timelines that could impact its economic growth. The final agreement included a more flexible approach to transparency, allowing countries with reduced capacity (such as developing nations, which includes China) to have leeway in the way they report their emissions (Harmwille *et al.*, 2019). Whilst such measures are invaluable in ensuring that international agreements acknowledge historical context and just distribution of climate responsibility, build trust among countries and strengthen global efforts, these negotiations and concessions underscore the complexity of international climate agreements.

Despite this effort to promote the implementation of PA commitments and overall predicted impact of the PA, there is a notable gap in understanding how different countries have specifically responded to the land sector as a result of the Agreement. This is imperative to ensure that global efforts are aligned with the necessary scale and urgency to meet climate targets, making a 2°C limit achievable, let alone a 1.5°C (Rogelj *et al.*, 2016; Roe *et al.*, 2021). As such, a systematic map has been designed, aiming to address this gap by exploring the literature on land-based interventions deployed after COP21, with the goal of investigating the success of the PA in translating global climate goals into actionable national land sector targets. Doing this will help catalogue the direct actions taken within the land sector since the Agreement and evaluate their effectiveness in relation to hitting anticipated climate targets (Objective 1.2., Table 1).

The previous chapter has helped raise critical questions that guide this research, particularly regarding whether language use between academic studies and NDCs is consistent. By tracking language across academic literature, climate calculators, and expert opinions, this study will assess where climate calculators fit within the science-policy nexus and explore the assumptions that either enhance or limit their effectiveness as decision-support tools for the land sector (Figure 3). Given the diverse efforts and needs within the global land sector, understanding these dynamics is crucial for both understanding the efficacy of land commitments to date and how the climate calculators fit into this narrative to effectively support national-scale interventions (Chapter 6).

5.1.2. Research Done to Date

There is a substantial body of research focused on evaluating NDCs and how various parties have represented their different sectors (Crumpler *et al.*, 2019; Roe *et al.*, 2021). However, most studies concentrate on assessing the commitments outlined in NDCs, specifically how these commitments contribute to global emissions reductions by 2030, rather than on the progress made by different countries in implementing them (Duguma *et al.*, 2014). Furthermore, much of this research examines NDCs as a whole, rather than focusing on specific economic sectors like land use. This focus on the overall picture, rather than sector-specific progress, means that the nuances of how individual sectors contribute to climate goals can be overlooked (Guguama *et al.*, 2014). With AFOLU-related NDC actions make up about 25% of planned GHG reductions in 2030 (Grassi *et al.*, 2017) it is critical to understand where efforts are succeeding or falling short. Among the studies that do explore the inclusion of land use in NDCs, it is noted that very few countries provide quantitative data on the land-use sector's contribution to their targets or detailed implementation plans (Herold *et al.*, 2018). This challenge is compounded by difficulties in tracking NDC progress, particularly within the land sector, where inconsistent tracking methods highlight the need for more thorough investigation (Herold *et al.*, 2018). The fact that current tracking methods are challenging and inconsistent suggests the need to investigate what has been studied and reported on to identify the areas of NDC land progress that are successful and areas that need more focus to better align with global reduction targets by 2050.

Whilst less prevalent than studies that focus on evaluating NDC commitments, there are studies that concentrate on the progress of implementing the land-based commitments within these NDCs (Smith *et al.*, 2014). However, many of these studies tend to focus on a specific component of the land sector, such as forestry (Fyson and Jeffrey, 2019; Vongvisouk *et al.*, 2020; Wiltshire *et al.*, 2022) or agriculture (Pawlak and Kolodziejczak, 2020; Pawlak and Kolodziejczak, 2020). Whilst this is beneficial for providing detailed insights into particular these specific components of land, such as the effectiveness of forestry management practices or agricultural carbon mitigation strategies, it means that these studies primarily focus on one specific element of the land sector. Whilst studies may briefly acknowledge other aspects of the land sector, most do not extensively address complex systems such as food security or the integration of broader AFOLU strategies (Fragkos *et al.*, 2018; Mills-Nova and Liverman, 2019; Rodríguez-Arce *et al.*, 2024). This has the consequence of limiting the understanding of how these land-based NDC commitments interact with other critical areas, potentially overlooking synergies or trade-offs that are essential for holistic climate action planning.

Typically, studies focus on a specific region or country, which, whilst increasing the level of detail and tailored outputs that the study can produce, combined with a limited scope of the land sector, can further limit the applicability of the findings to land-based NDC progress more generally. Many studies focus on Brazil, investigating the realistic application of NDC commitments to the complex social, economic, and environmental pressures placed on the land sector (Gallo and Albrecht, 2019; Wiltshire *et al.*, 2022). A significant focus on Brazil may stem from its vast and biodiverse landscapes, which play a critical role in global climate regulation and its position as one of the world's largest emitters due to deforestation and agricultural practices. This focus suggests that Brazil's land sector is seen as a key battleground for climate action, where success or failure could have significant global implications. However, whilst gaining detailed insight into certain areas is beneficial, the fact that these analyses do not include a discussion on how Brazil's approach compares to other countries' land-based strategies for Paris Agreement compliance (Gallo and Albrecht, 2019) means that the broader lessons that could inform global NDC implementation efforts are often overlooked. Consequently, these studies may miss opportunities to identify best practices or common challenges that could be applied across different regions, limiting their contribution to global climate strategies.

Some papers, such as the comprehensive review by Fobissie *et al.* (2019), analysed the different components of land use and isolated the frequency of agriculture and forestry in African NDCs. This review also explored how these components are integrated into a broader AFOLU context. This approach is beneficial because it not only takes a more holistic view of the land sector, capturing the interplay between agriculture, forestry, and other land uses, but also highlights the complexity and interdependencies within the sector (Lamb *et al.*, 2021). Fobissie *et al.* (2019) showcases how different NDCs within one interconnected region, such as Africa, can be compared both individually and collectively. Whilst this study does a good job in providing a detailed regional analysis and illustrating the interconnectedness of NDC commitments within a specific area, it is possible to take the research a step further by adopting a more global perspective. This would involve comparing land-based NDCs across multiple regions and exploring how different countries' strategies contribute to global AFOLU outcomes (Herold and Böttcher, 2018). Additionally, they identified that to hit full mitigation potential in the land sector, there is need to look for ways to strengthen and improve the performance of the AFOLU (Fobissie *et al.*, 2019). Doing this would require an understanding of what interventions have already occurred and how these have helped progress towards NDC goals. Applying a systemised approach to investigating progress on a broader scale provides insight into common challenges, best practices and enhances understanding on how regional approaches contribute to global climate goals. This broader perspective could help develop more cohesive, coordinated global strategies for land-based action.

This research aims to understand the global trends emerging in response to the PA land sector commitments and to see if these trends align with the key findings from the NDC analysis. While some studies have investigated specific aspects of these commitments, there has been a lack of comprehensive research that examines the full scope of land-based actions taken since the PA. This gap likely exists because the land sector encompasses a diverse array of activities, each with varying levels of complexity and interdisciplinary challenges, making broad analyses difficult. As a result, previous studies have often adopted narrower scopes to facilitate more focused and manageable analysis, but this research seeks to broaden the scope to capture a more holistic understanding of global land sector responses. Additionally, a significant emphasis of the PA, and the subsequent interventions, has been on balancing climate action with sustained economic growth, particularly for developing countries. This focus may have led countries with substantial land-based mitigation potential, many of which are developing nations, to prioritise adaptation measures like energy and job security over land sector interventions. Land-based strategies are often costly, time-intensive, and challenging to align with goals for energy and economic growth, making them more complex to implement for countries striving to balance climate action with immediate development needs.

5.1.3. Scope and Rationale

This systematic map is designed to evaluate interventions through identifying, selecting, and analysing all relevant studies on the topic, including a comprehensive range of evidence (Haddaway *et al.*, 2016). This approach minimises bias, reducing the likelihood of excluding important studies. By including a wide range of studies from different geographic regions and contexts, this systematic map aims to produce generalisable findings (James *et al.*, 2016), allowing more reliable conclusions about the broader impacts of the PA on the land sector. Ultimately, a deep dive into the interventions and impacts within the land sector, especially in the context of the Paris Agreement, is critically important for several reasons. Not only does the land sector represent a substantial proportion of global GHG emissions (Grassi *et al.*, 2017), it is also highly vulnerable to the impacts of climate change, which can severely impact biodiversity, livelihoods and food security (Lamb *et al.*, 2021). Governments and stakeholders invest significant resources in implementing policies and interventions in the land sector to help mitigate these impacts. Assessing the effectiveness of these interventions ensures

accountability and informs future policy decisions, helping to optimise resource allocation and maximise impact.

Main Question

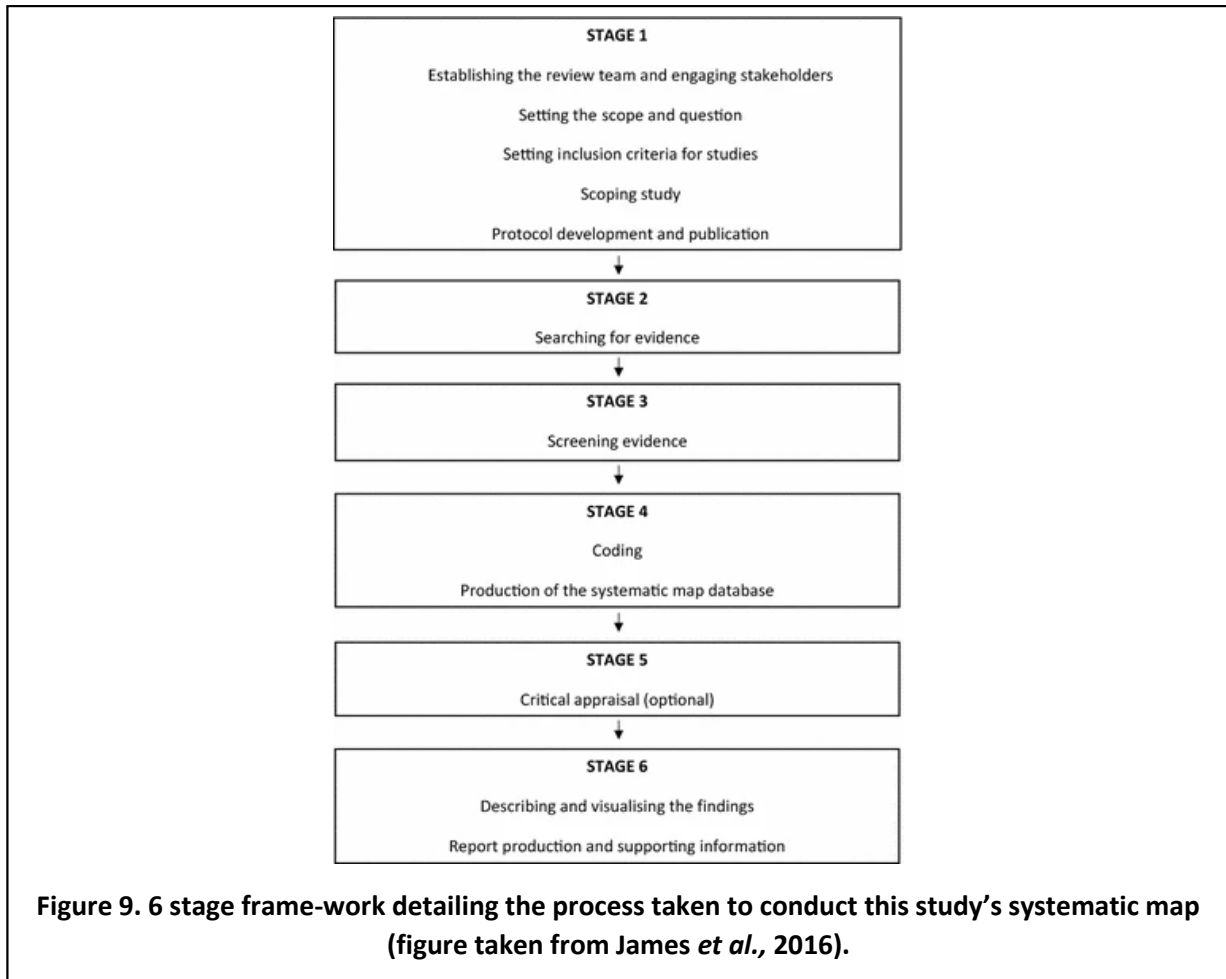
What interventions has the Paris Agreement driven within the Land sector?

Interventions including any management, monitoring or mitigation schemes or initiatives.

-
1. Which countries are on track with their targets?
 2. What areas of the land sector are most frequently studied?
 3. What policies or schemes are most frequently incorporated into studies regarding the land sector?

5.2. Methods

This systematic map followed the 6-stage process detailed by James *et al.* (2016). This process was used because the study specifically focused on the translation of systematic mapping methodology from social sciences for use in environmental sciences, providing the first process-based methodology for systematic maps. Additionally, this process has been widely used in environmental science research, presenting a widely accepted, 6 stage frame-work to design the methods for this study off (Figure 9).



Due to the nature of the systematic map of exploring a research gap, as well as the time constraints associated with the research, it was determined that it would be more expedient to include stakeholder engagement at a later stage of the overall research (see Chapter 6 and 7).

This research developed a search string after identifying the research questions and scope (see section 5.1.3.), in order to systemise as many stages of the process as possible.

The inclusion and exclusion criteria were developed in parallel to the search string, with later stages of screening being refined iteratively after the initial title screening (see section 5.2.2.). Data extraction and coding was done via content analysis (see section 4.2.3. and section 5.2.4. for greater detail).

This systematic map did not include stage 5 (Figure 9), but aimed to mitigate any author bias that this could have introduced during stage 6 where the results were synthesised and visualised (see section 5.3.).

5.2.1. Questions and Search String

To create the search string, generic terms for the two key words: (Paris Agreement) AND (Land Sector) were developed (Appendix B).

The search string started as the following:

("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions")
 AND
 ("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Land Change")

The search string started with these base terms in order to try and illicit a broad range of papers. From the lack of consistency seen in chapter 4 with definitions, it was determined that a broader scope would be more appropriate and then to have strict inclusion/exclusion criteria afterwards to reduce the number of papers afterwards (Roman-Cuesta *et al.*, 2016). This increased the number of papers being returned. Next, 'conditional' and 'unconditional' was added to the search string, as well as the composite parts of LULUCF to ensure comprehensive coverage of the NDCs and the land sector (Droli *et al.*, 2019), as well as including 'carbon-sequestration' due to the prevalence of the activity in land-based policy as a desired outcome (Palomo *et al.*, 2019). Finally, in order to try and include all papers that would potentially be framed in a way that approaches the PA targets, rather than the NDCs specifically, other terms that were added were around the 2°C target (Schleussner *et al.*, 2016), AR5 (Morgan, 2016), RCPs (Sui *et al.*, 2018) and COP21 (Ji *et al.*, 2015). This produced the final search string:

("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments" OR "Post-Paris*" OR "RCP2.6" OR "2 degrees" OR "AR5" OR "COP21")
 AND
 ("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation" OR "Carbon Sequestration" OR "Carbon Sink" OR "agri*" OR "land*" OR "land use*" OR "Carbon seq*")

The final amount of hits was 14,933, which was reduced to 12,474 by limiting the papers to those published in 2016 and onwards.

5.2.2. Inclusion Criteria and Screening

This search string was used in both Scopus and Web of Science on the 8th of July 2020, with a total of 14,993 papers sourced from both sites (Figure 10). Scopus and Web of Science were chosen because they are two of the most comprehensive and widely recognised databases for academic research, offering extensive coverage across multiple disciplines (Zhu and Liu, 2020). Whilst relying on these databases might mean that some relevant studies published in less mainstream journals or regional databases could be overlooked, this can be mitigated by the breadth and depth of the coverage provided by these platforms (Mongeon and Paul-Hus, 2016). Additionally, using both Scopus and Web of Science together helps to cross-verify results and ensure that the most pertinent studies are included in the analysis, thus minimising the risk of significant omissions (Zhu and Liu, 2020).

The papers were sorted into year (2016-2020) and then, using a random selection of papers across this time span, the titles were evaluated to confirm and refine the first stage title inclusion and exclusion criteria (Table 7).

In July 2021, the initial search string was done a second time, to gather the papers that had been published during the systematic mapping process and to ensure the literature was as up to date as possible. This was not done a third time because the time and resources required to continuously update the search would have outweighed the benefits of including a relatively small number of additional studies (Moher *et al.*, 2007). Whilst it might mean that some of the very latest research is not captured, this can be mitigated by the fact that the majority of key studies and trends are likely to have already been included in the two comprehensive searches (Moher *et al.*, 2007; Mendes *et al.*, 2020). Moreover, any significant new developments in the field would likely be identified through ongoing literature reviews and subsequent updates to the research (Mendes *et al.*, 2020). (Additional discussion around this can be found in section 5.2.4.).

Data extraction was conducted of the primary literature, as well as a google web search to identify relevant grey literature. This google search was done using the same search string as for the primary literature, with the first 100 search results investigated. The search was limited to the first 100 papers because Google's ranking algorithm tends to prioritise the most relevant and credible sources within the top results (Farooqi *et al.*, 2021). Whilst it might mean that some potentially valuable grey literature further down the search results is missed, this can be mitigated by the fact that the most authoritative and widely recognised documents are typically found within the first few pages (Farooqi *et al.*, 2020). Additionally, the inclusion of grey literature from the primary literature search helps to ensure a more comprehensive overview.

Table 7. The inclusion and exclusion criteria designed for the title screening phase, filtering down the papers from the initial search string.

Inclusion Criteria	Notes	Exclusion Criteria	Notes
'Paris Agreement' within title		Papers not in English	
'AFOLU' or 'LULUCF' within title	Unless the title also explicitly states that data collection/ analysis pre-dates 2015	Papers published pre-2016 or related to pre-Paris Agreements	
'Nationally Determined Contributions' or 'NDCs' or 'emission scenarios' within the title		Papers with a focus on Marine based systems	
Title references long- or short-term plans to hit 2020, 2030, 2050 or 2100 targets	Unless the title also explicitly states the topic to be based on tourism, energy use, energy efficiency or the direct impact of the US leaving the Paris agreement	Papers with a focus on Waste management, water resources or water management	
Title references long- or short-term plans to cap warming at 2 degrees or less	Unless the title also explicitly states the topic to be based on tourism, energy use, energy efficiency or the direct impact of the US leaving the Paris agreement	Papers which discuss the ramifications of the US leaving the Paris Agreements	Unless the title also explicitly mentions AFOLU, LULUCF or the Land Sector
'AR5' or 'COP21' within the title	Unless the title also explicitly references tourism, energy use, energy efficiency or the direct impact of the US leaving the Paris agreement	Papers which discuss BioGas production and efficiency	
Title references a review of policies, management or monitoring to have occurred post-2015	This does not have to explicitly include a reference to Paris Agreements or NDCs as many papers referring to policy post-2015 will refer back to AR5, COP21 or the Paris Agreements	Papers referring to the impact of the Paris Agreements or Land Use on tourism	
'REDD+' within the title	Unless the title also explicitly states that data collection/ analysis pre-dates 2015	Papers talking about the effect of climate change on ecosystems	Unless the title also specifically refers to the Paris Agreements, NDCs, COP21 or AR5.
'Climate Change Mitigation plans' or 'long term mitigation policies'	There can be ambiguity in the way in which different countries refer to this- if uncertain, it is better to add into the 'Questioned Titles' section for further analysis		

After the title screening process, 1,557 papers remained (Figure 10) and the abstract (Table 8), then main body (Table 9), inclusion and exclusion criteria was used to complete the next two stages of screening. Grey literature was taken through the title (Table 7), abstract (if relevant) (Table 8), and main body (Table 9) screening criteria as well.

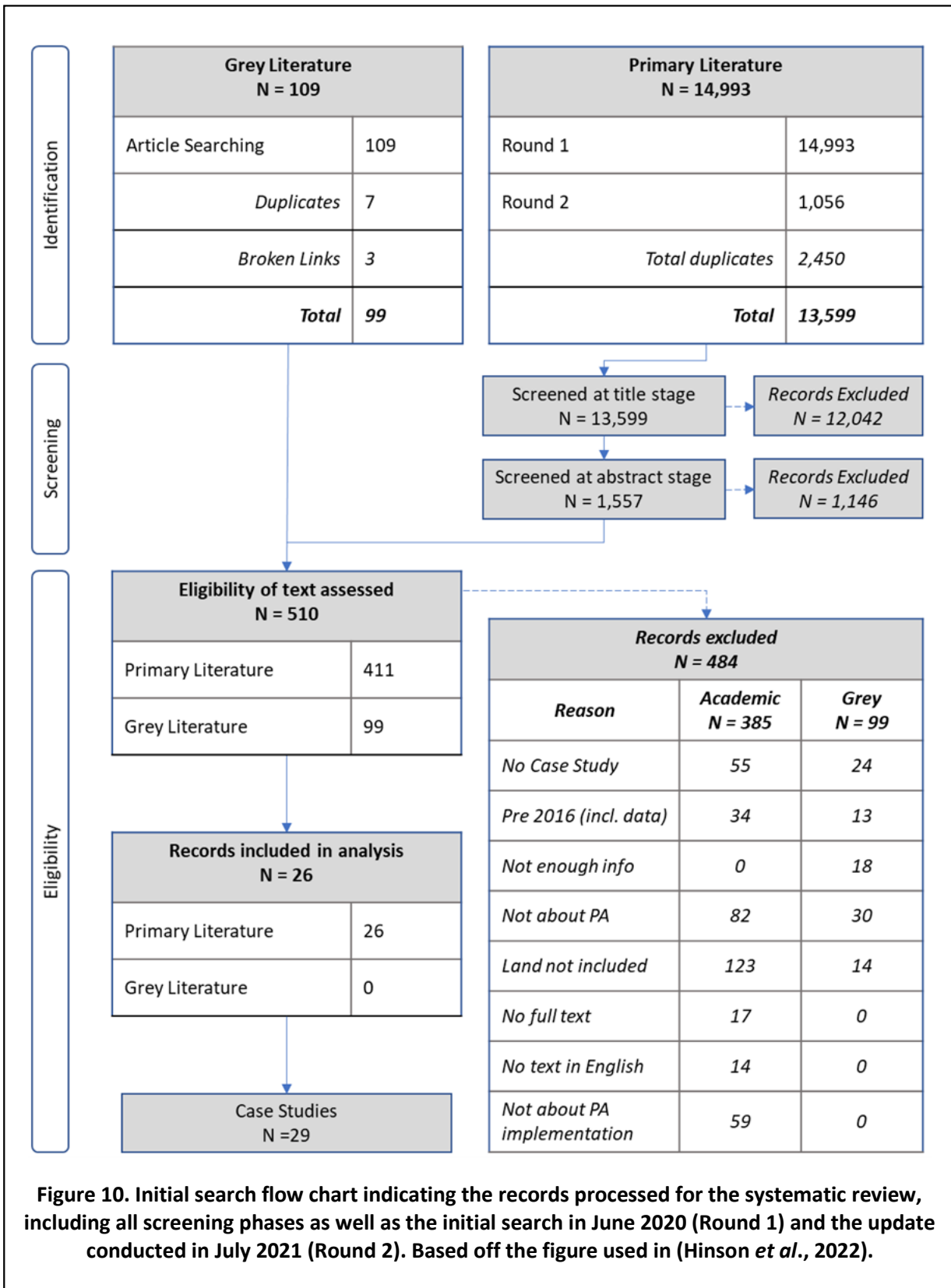


Figure 10. Initial search flow chart indicating the records processed for the systematic review, including all screening phases as well as the initial search in June 2020 (Round 1) and the update conducted in July 2021 (Round 2). Based off the figure used in (Hinson *et al.*, 2022).

Table 8. The inclusion and exclusion criteria designed for the abstract screening phase, filtering down the papers from the title screening.

Inclusion Criteria	Notes	Exclusion Criteria	Notes
Refers to 'AFOLU' or 'LULUCF' or the Land Sector	This can relate to fulfilling NDC (conditional or unconditional) commitments, adhering to Paris Agreement legislated standards, 2020-2100 GHG emission reduction targets or REDD+ implemented management or monitoring (unless there is explicit mention of the REDD+ component pre-dating 2016).	No mention of any Land Sector in any regard e.g. no land management, policies or monitoring, nor any mention of 'AFOLU' or 'LULUCF'	This includes papers that discuss climate change mitigation as an additional, but not primary, focus of the paper, such as when the focus is on land management for increasing biodiversity
	'Land Sector' references include: - Land Use (LU) - Land Use Change - Diet, in terms of LU - Reforestation, Afforestation or deforestation reduction - Habitat restoration or preservation - Land as a Carbon sink - Agriculture, Climate Smart Agriculture - Carbon sinks/forest sinks etc	Papers looking at the impact climate change has had/is having on the Land Sector	This is also when the paper is investigating secondary impacts, such as mal-adaptations, or negative response measures, to the measure implemented off the back of the Paris Agreements.
Refers to the Paris Agreements	Post-Paris measures include: - National policy implementation - New/updated management techniques - New/updated monitoring measures This can also relate to the following terms, instead of the Paris Agreements: - Nationally Determined Contributions (NDCs) - AR5 or COP21 - 2020-2100 GHG emission reduction targets	Any papers where the abstract does not adhere to the exclusion criteria of the title screening stage: - Papers not in English - Data gathered pre-2016 - Papers focused on: -Marine systems -Waste management -Water resources -Water management -US withdrawal from the Agreements -BioGas production -Tourism	Other examples include: - Renewable energy - Carbon market schemes
N.B. Both a reference to "land" (or a variation of) AND a reference to "the Paris Agreement" (or a variation of) must be included within the abstract.		If the REDD+ management and monitoring was implemented pre-Paris Agreements and has no reference on the influence the Paris Agreements has on the REDD+ programme/implementation	REDD+ papers can be included, but only when there is a direct link within the abstract to implementation due to Paris Agreement or is studying an update within the REDD+ from Paris.

Table 9. The inclusion and exclusion criteria designed for the main body screening phase, filtering down the papers from the abstract screening.

Inclusion Criteria	Notes	Exclusion Criteria	Notes
Policy, monitoring, managerial or 'other' action taken within the land sector as a direct result from the Paris Agreement	E.g. Actions countries have taken within the land sector to achieve their Nationally Determined Contributions	There is no country acting as a case study	e.g. a global look at the land sector since the PA or general look at the land sector
Policies that have been updated since the PA, in order to hit PA targets	National Action Plans, National Strategies, Climate change national strategies, REDD+		

5.2.3. Data Extraction

During the main body screening, and prior to completing the data extraction of the remaining papers, a Kappa analysis was performed. This was done by numbering all the accepted titles and using a random number generator to select 20 of them. These 20 papers, alongside the abstract inclusion and exclusion criteria was provided to two independent reviewers who allocated the papers into 'accepted' and 'rejected'. The kappa analysis showed that there was a significant similarity, supporting the quality and robustness of the inclusion and exclusion criteria.

The data was extracted from the 26 accepted pieces of primary literature (Figure 10). This data was analysed using comparative analysis methods (see section 4.2.3 and 5.2.4); the synthesis of results into graphs, tables and matrices that visually represent the data, in order to interpret them.

The data extracted was coded similarly to chapter 4, allowing for comparison between the different studies. Including data on where the studies in the papers were located, data on what information the paper included on NDC targets, land terminologies (Table 4), and the metrics used to monitor land sector progress (Figure 11; Appendix B).

Initially, if the data could only be extracted from 20% or fewer of the papers, then there was insufficient data to keep that variable of interest for the final presentation and data analysis. However, due to having a smaller number of papers in the final phase of extraction than anticipated, all columns of data were kept. This is so that, even if only one paper has that information, it can be represented at the analysis and results stages of the research. It was deemed relevant to do this as it helped highlight areas where a lack of reporting and research was occurring, as well as where there was an abundance.

LULUCF	AFOLU	Does it mention						overall target		land sector targets defined by uncon vs condit.?
		includes agriculture?	baseline year of NDC	If yes, what is the baseline year	target year	does the GHG emissions include the land sector?	overall target description mentioned?	emissions reduction	% of emission reduction	
yes	no	yes	yes	1990	2030	yes	yes	yes	0.4	yes
no	yes	no	no	n/a	2030	yes	no	n/a	n/a	no
yes	no	no	yes	2011	2030	yes	yes	yes	0.05	yes
yes	no	yes	no	n/a	2030	yes	yes	yes	0.29	yes
yes	no	yes	no	n/a	2030	yes	yes	yes	0.29	no
yes	no	no	no	n/a	2030	yes	yes	yes	0.4	no

Figure 11. Excerpt from the systematic map metadata extraction table demonstrating the type of variables that the papers were analysed for to illustrate how and what data was collected.

5.2.4. Analysis and Limitation Mitigation

The data was analysed using document analysis (see section 4.2.3), narrative synthesis and descriptive analysis.

Narrative synthesis is a method of summarising and explaining the findings of multiple studies in a systematic map, focusing on identifying patterns, themes, and relationships within the data (Lisy and Porritt, 2016). It is used for analysis of systematic map results because it allows for the integration and interpretation of diverse types of evidence, particularly when quantitative synthesis (like meta-analysis) is not feasible due to variability in study designs, outcomes, or contexts (Popay *et al.*, 2006a). Whilst there are some limitations to narrative synthesis, including the potential for subjectivity in interpreting and combining findings, these limitations are mitigated by employing a transparent and structured approach to the synthesis (Pavlenko, 2008; Lisay and Porritt, 2015). For this research, this was done by presenting predefined criteria for data extraction (see section 5.2.1-5.2.3) and interpretation, and involving cross-checking points to reduce individual biases (see Kappa analysis information in section 5.2.3).

Descriptive analysis is a method of summarising and organising data to provide a clear overview of the basic features of the dataset, such as frequencies, patterns, and distributions. It was used for this analysis of systematic map results because it enabled the categorisation and quantification of the information gathered, helping to identify trends, gaps, and the overall scope of the research landscape (Lawless *et al.*, 2010). There are some limitations to descriptive analysis, including its inability to explore deeper causal relationships or to provide insights beyond the basic characteristics of the data. These limitations are mitigated by complementing descriptive analysis with more in-depth analytical techniques, such as narrative synthesis, which can provide a richer understanding of the data and its implications.

These three techniques—document analysis, narrative synthesis, and descriptive analysis—complement each other by providing a comprehensive approach to analysing systematic map results. They allow for both qualitative and quantitative insights of the results, which was necessary for this systematic map, as there were some components where there were only 5 papers being analysed. Combining these approaches meant that certain areas of the results could be analysed more quantitatively (see section 5.3.1 and 5.3.3), as well as through a more qualitative analysis approach (see section 5.3.2.). Narrative and descriptive analysis enabled results to be synthesised through discussion and thematic similarities between the papers, as there was insufficient data to statistically or quantitatively draw conclusions from (Popay *et al.*, 2006b).

Limitations of these methods could include the potential for subjectivity in document analysis and narrative synthesis, and the risk that descriptive analysis might oversimplify complex data (Pavlenko, 2008). However, these limitations are minimal because the methods, when used together, balance each other out (Popay *et al.*, 2006b). Structured approaches, transparent criteria, and cross-validation among different techniques help mitigate biases and provide a well-rounded, robust analysis (Popay *et al.*, 2006b).

The Methods

The benefit of a systematic map is that, as a methodology, it ensures comprehensive coverage of relevant studies, including peer-reviewed articles, reports, and grey literature, providing a holistic understanding of land-based interventions and their outcomes. However, the review does rely on published pieces of work (e.g. research articles, reports, and other academic literature). If there is limited research available that has gone through the peer reviewed process, the methodology might miss out on the specific adaptations made by countries in the land sector, especially as adaptations may be implemented at the policy level, which may not always be extensively documented in academic literature. However, this systematic map deliberately included a process for grey literature inclusion, to mitigate the impacts of this. Additionally, through the systematic map process, gaps and limitations in the existing literature can be identified, highlighting areas where further research is needed. This means that a well-rounded discussion around any potential gaps in the results can be had, acknowledging any potential limitations of the research. This helps to guide future research recommendations.

One limitation of systematic maps is that they take time to conduct the entire process, from search string to synthesis of findings. This is especially relevant when considering the time constraints set upon this study. As a result, there may be a time lag between the publication of the included studies and the analysis and synthesis of the results. Rapid changes in policy and practice may not be adequately captured by systematic map. Despite this, the tailored design of this systematic map facilitates a comparative analysis of different land-based interventions, including their design, implementation, and outcomes. This links to chapter 4, as it is a recognition of the interventions conducted post Paris Agreement. The update of the methods in 2021 (see section 5.2.2.) did not yield a comparatively high number of hits and did not garner a significant increase in the final set of papers analysed. The effort and resources required to conduct another update may not justify the relatively small increase in the dataset. Additionally, rather than focusing on the quantity of studies included, a deep dive into the available dataset helps identify the direct actions taken from the first set of NDCs, helping be able to specifically see the real-world reflection of those NDCs. Ultimately, there is enough data and information synthesised from this research to start addressing the relevant questions around real world implementation of the first round of NDCs, allowing this thesis to next evaluate what state the climate calculators were in to allow this to happen.

5.3. Results

26 papers contained enough information to be fully extracted (Figure 10); from these, there were 29 case studies. One paper contained four case studies (Manan *et al.*, 2017), whilst the rest had one case study per paper. The majority of these papers were released in 2019 and 2020 (Figure 12). This may be due to the fact that the NDCs were due to be updated in 2020 and so 2019 and 2020 saw the highest level of evaluation of the first round in the lead up to this, marking an increase of global focus on implementing and assessing the impacts of the Paris Agreement.

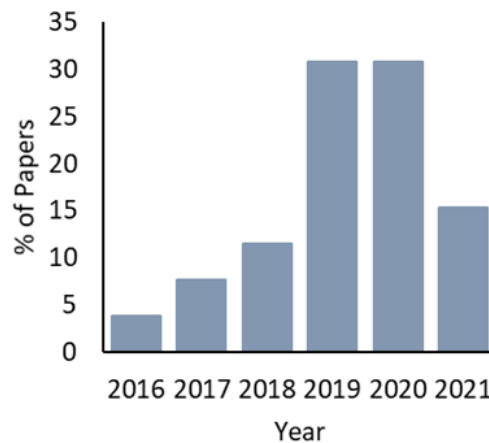


Figure 12. A break-down of the year the extracted-from papers (n=26) were published.

The studies in these papers were focused on varying regions around the world (Figure 13), with 62% (n=18) of the studies located in the global south. The greatest representation was from South East Asia and Europe. These regions might have been particularly active in implementing land sector interventions in response to the Paris Agreement, or because research and funding opportunities are more readily available.

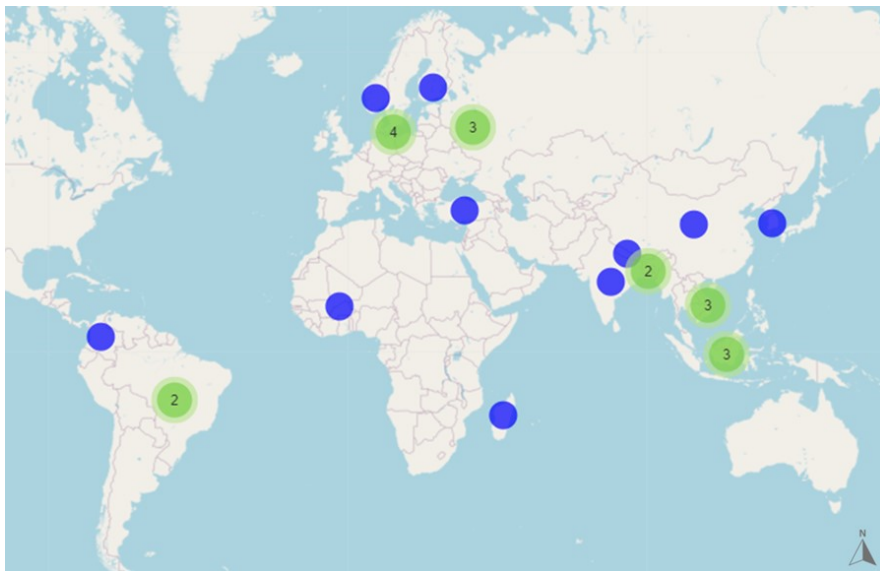


Figure 13. Global distribution of the studies within the research papers that were extracted from for the systematic map. Two additional papers were extracted from, but were global studies, rather than case specific. Blue dots indicate a single case study, whilst green indicate multiple.

Just under a 59% (n=17) of the countries were DAC listed ODA recipients; 14% (n=4) were in least income, 24% were lower middle income (n=7), and 21% were Upper middle income (n=11) of the DAC. This could be because many of the interventions in the land sector are often targeted at countries with significant development needs, where the impact of such interventions can be most pronounced.

The papers were reviewed to see what terminology and concepts they included (coded yes/no). 'Emissions reductions' was mentioned in 69% (n=18) of the papers (Figure 14). 65% (n=17) papers described what the overall target of the NDC was for the area the case study was focused on, whilst 41% (n=12) included the baseline year the NDC in question was working off. 79% (n=23) explicitly stated that land was included in that region's GHG emissions reduction effort. The way that land was referenced within the papers ('LULUCF', 'AFOLU' or 'Agriculture'), varied. 66% (n=19) included LULUCF, 21% (n=6) included AFOLU, 72% (n=21) included Agriculture (Figure 14). All these terminologies and concepts can be considered core components of hitting climate goals. Inconsistent reference to all of the concepts across the studies could be because the focus and scope of the studies varied, leading to differences in the emphasis on certain terminologies and concepts.

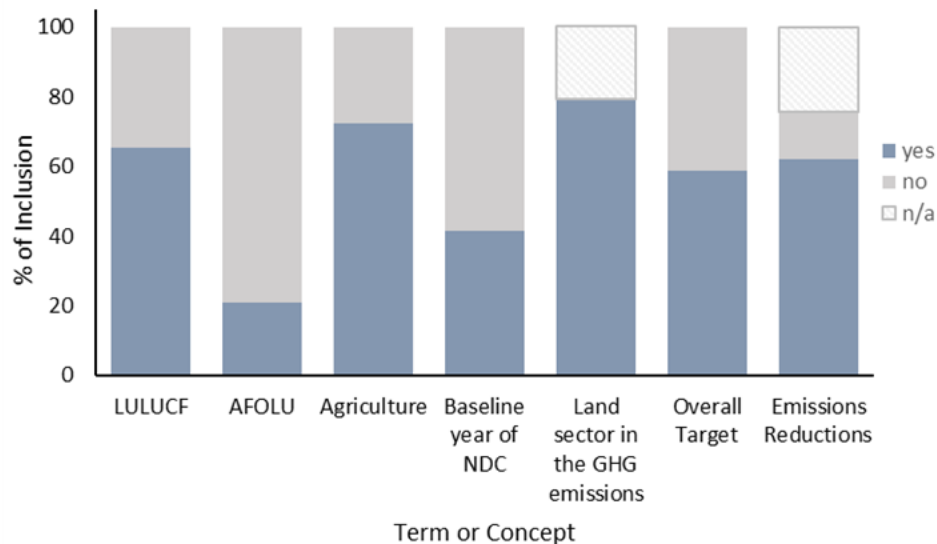


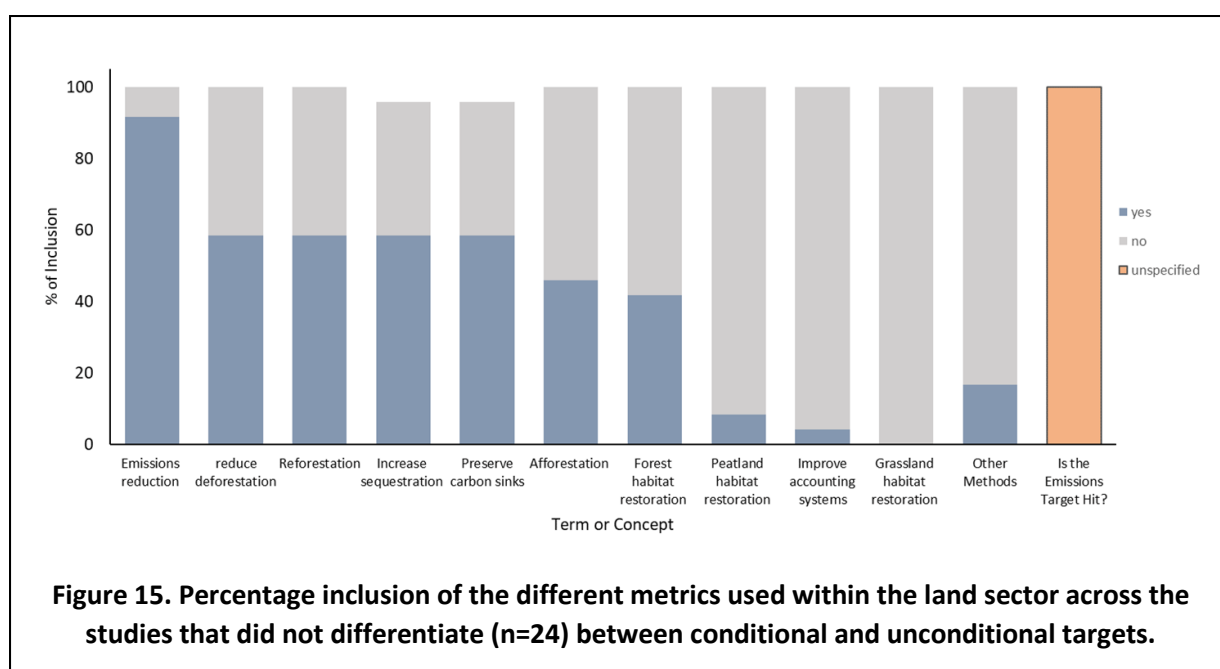
Figure 14. Rate of inclusion for various terms and concepts, relating to the land sector and emissions reductions in the case studies.

5.3.1. Most Studies Did Not Specify Conditionality

83% (n=24) of studies did not specify whether the land commitments discussed were part of conditional or unconditional commitments (Figure 15). Almost all of these studies mentioned emissions reduction (n=22) (Figure 15). This could be because conditional and unconditional commitments often involve nuanced distinctions tied to the availability of international support or domestic resources, which may not have been the central concern of the studies.

These papers were coded further to understand which components of the land sector they were focusing on (coded yes/no), specifically the metrics that the studies were using to monitor progress of commitments within the land sector. 58% (n=14) of the studies used the following as metrics, 'reducing deforestation', 'reforestation', 'increasing sequestration' and 'preserving carbon sinks'. 45% used 'afforestation' (n=11) and 'forest habitat restoration' (n=10). Less than 10% used 'peatland habitat restoration' (n=2), 'improving accounting systems' (n=1), and 'grassland habitat restoration' (n=0) (Figure 15). Variation in how commonly a metric appears might be because of how central to global climate strategies, and the ease of measuring and monitoring, they are.

None of these studies specified whether the targets described were hit or not (Figure 15).



5.3.2. Five Studies Specified Conditionality

Only 5 papers specified whether the land-based interventions were part of conditional or unconditional commitments. 4 of those papers were in Asia, one in Vietnam (Hoan *et al.*, 2019), one in Bangladesh (Hasana *et al.*, 2020) and two in Indonesia (Tacconi and Muttaqin, 2019a; and Tacconi and Muttaqin, 2019b) (Table 10). This concentration suggests that the land sector in Asia is receiving significant scholarly attention, potentially due to the region's high vulnerability to climate impacts and the critical role of land-based activities in these economies.

Table 10. The locations that the case studies within the 5 papers that included specifications on conditionality of NDC targets were focused on

Number	Paper	Region	Country
1	(Forsell et al, 2019)	EU	/
2	(Hasan et al, 2020)	South Asia	Bangladesh
3	(Tacconi & Muttaqin, 2019a)	South East Asia	Indonesia
4	(Hoan Do et al., 2021)	South East Asia	vietnam
5	(Tacconi & Muttaqin, 2019b)	South East Asia	Indonesia

Three papers (Tacconi and Muttaqin, 2019a; Hoan Do *et al.*, 2021: and Tacconi and Muttaqin, 2019b) detailed both the conditional and unconditional targets, rather than just the unconditional (Table 11). Metrics used within the papers varied as well, although 4/5 of the papers included preserving/improving carbon sinks as a key goal, or metric for success (Table 11).

Hasan *et al* (2020) and Hoan Do *et al.* (2021) were the only two papers in the entire systematic map to state whether the commitments they were detailing were on track to hit the targets. Both specified that the conditional emissions reduction targets were not being hit.

Hoan *et al* (2020), uses 7 different land-based metrics (Table 11), with 'emissions reduction' the only one mentioned in both conditional and unconditional target setting, and 'other interventions' as the only one mentioned in only conditional target setting within the land sector. The other five terms were referenced only in relation to unconditional targets. Hoan *et al*'s paper is looking at participatory land-use scenario development in the northwest of Vietnam and suggests that a lack of participation and acknowledgement of traditional land-use practices has inhibited the successful implementation of the NDCs. This is the only paper to mention food and food systems as they relate to the land sector. This is mentioned in the capacity of recognising food-crop yields, as well as in acknowledgement of the fact that the provision of food is an ecosystem service and one of the components that makes land so complex to manage.

Hasan *et al* (2020) used 2 metrics, and only within the context of an unconditional NDC. Taconi and Muttaqin (2019a), used 4 metrics, within the context of both unconditional and unconditional NDCs ('Emissions reduction', 'Reduce deforestation', 'Forest habitat restoration', 'Peatland habitat restoration'). Taconi and Muttaqin (2019b), used 8 metrics, within the context of unconditional NDCs ('Reforestation', 'Afforestation', 'Increase sequestration', 'Preserve / improve carbon sinks') and both conditional and unconditional NDCs ('Emissions reduction', 'Reduce deforestation', 'Forest habitat restoration', 'Peatland habitat restoration'). Forsell *et al* (2019), used 2 terminologies, both in the context of unconditional NDC. The variable use of metrics is potentially a result of the diversity and evolution of terminologies used to describe climate action commitments and the land sector across different studies.

Table 11. The different metrics that were detailed within the 5 papers the conditionality of the NDC target they were associated with

Terminology	Conditional	Unconditional	Both
Emissions reduction		2- (Hasan et al, 2020)	3- (Tacconi & Muttaqin, 2019a) 4- (Hoan Do et al., 2021) 5- (Tacconi & Muttaqin, 2019b)
Reduce deforestation		4- (Hoan Do et al., 2021)	3- (Tacconi & Muttaqin, 2019a) 5- (Tacconi & Muttaqin, 2019b)
Forest habitat restoration			3- (Tacconi & Muttaqin, 2019a) 5- (Tacconi & Muttaqin, 2019b)
Peatland habitat restoration			3- (Tacconi & Muttaqin, 2019a) 5- (Tacconi & Muttaqin, 2019b)
Reforestation		4- (Hoan Do et al., 2021) 5- (Tacconi & Muttaqin, 2019b)	
Afforestation		4- (Hoan Do et al., 2021) 5- (Tacconi & Muttaqin, 2019b)	
Increase sequestration		4- (Hoan Do et al., 2021) 5- (Tacconi & Muttaqin, 2019b)	
Preserve / improve carbon sinks		1- (Forsell et al, 2019) 2- (Hasan et al, 2020) 4- (Hoan Do et al., 2021) 5- (Tacconi & Muttaqin, 2019b)	
Improve accounting systems		1- (Forsell et al, 2019)	
Other Interventions	4- (Hoan Do et al., 2021)	2- (Hasan et al, 2020)	

5.3.3. Conditionality and Terminology Use

For each paper, when a land use metric was used, it was associated with the way the paper was presenting the land sector (e.g. 'only AFOLU mentioned' or 'Only LULUCF mentioned'), as well as the conditionality of the commitment the metric was measuring the progress of (e.g. conditional, unconditional or not defined by conditionality (unspecified)). These were mapped out on a matrix (Figure 16), with the dot size representing the number of papers each combination occurred in.

Across all studies within this systematic map (including those that did and did not specify conditionality) the way land was referenced and the metrics used differed greatly across the papers, as well as conditionality (Figure 16).

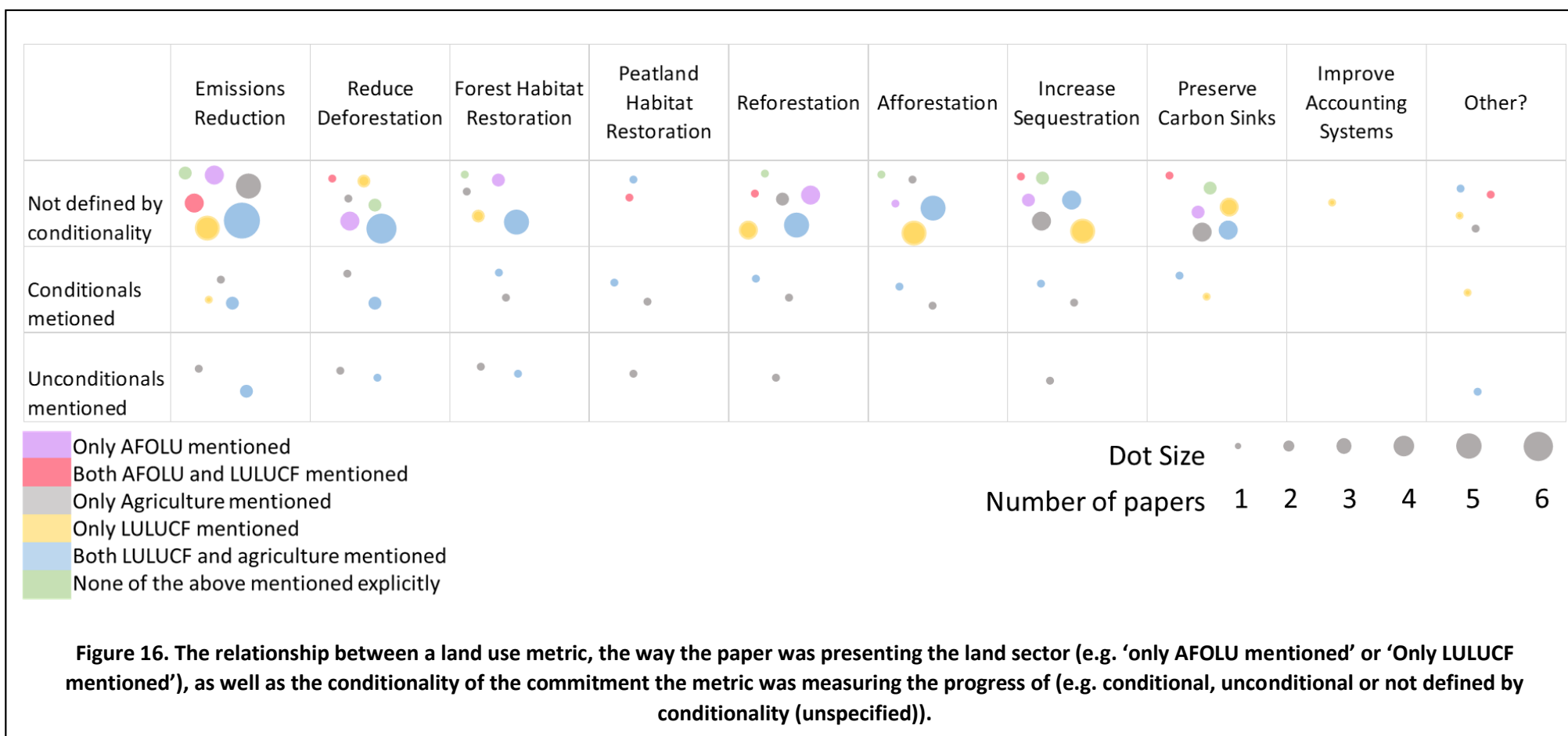
"LULUCF with agriculture", unspecified conditionality is the most common combination (Figure 16, blue dots) (n=31 incidents across all papers). 'only LULUCF mentioned', unspecified conditionality is the second most prevalent combination, (n=24 incidents across all papers). This is dissimilar to the NDCs in chapter 4 (Table 6); when forestry or land was mentioned within the studies of the systematic map, it was mentioned alongside LULUCF.

"Both AFOLU and LULUCF" (Figure 16, red dots) were only mentioned in papers that did not define the conditionality of the actions being taken.

Reforestation/afforestation are the types of metrics that were most prevalent in the papers that did not specify conditionality (Figure 16) and in those that did (Table 11).

The only concept that was more prevalent in the studies that did define conditionality was the preservation, or improvement, of carbon stocks (Table 11).

Across all the studies in this review, improving accounting systems was only mentioned once (Forsell *et al*, 2019). These results may reflect the types of interventions that countries are most willing or able to commit to and implement, due to established systems for executing these interventions, or because they have access to substantial funding for research and development.



Across all the studies, there was some addition of other predominant policy schemes (Table 12). Of these, most the papers were those that did not specify conditionality (n=20).

REDD+ (Reducing emissions from deforestation and forest degradation) and NAP (National Action Plan) were the most predominantly occurring and were found in 38% (n=10) and 31% (n=8) of the papers within this study respectively (Table 12).

Tacconi and Muttaqin (2019a and 2019b) were the only papers specifying conditionality that included REDD+, Hoan *et al.* (2021,) and Tacconi and Muttaqin (2019a) were the only ones that specified conditionality that included NAP, and Forsell *et al.* (2019) was the only one to specify conditionality and included other policies (n=3) (Appendix B).

Of the papers (n=7) that included other policy schemes and grey pieces of literature, Foresell *et al.*, 2019 was the only paper that specified conditionality. Other policies included different regulations, strategies and protection acts (Appendix B).

Table 12. The policy schemes present within the systematic review and the number of times in which they occurred.

Policy Scheme	Number of papers	Citations
REDD+	10	Fumuro et al, 2020; Tacconi and Muttaqin, 2019; Meehan et al, 2019; Soto Golcher et al., 2018; West and Fearnside, 2021; Rakotovao et al, 2021; Laudari et al, 2021; Rottering et al., 2018; Tacconi et al., 2019; and Bhan et al., 2017a.
NAP	8	Hasana et al, 2020; Gençay et al, 2019; Zougmore et al., 2016; Hoan Do et al., 2021; Trung et al., 2020; Meehan et al, 2019; Laudari et al., 2021; and Tacconi et al., 2019
Other	7	Forsell et al, 2019; Nabuurs et al, 2017; Bentsen et al, 2019; Bhan et al., 2017b; Fumuro et al, 2020; Bhan et al., 2017a; and Laudari et al., 2021.

5.4. Discussion

This chapter aimed to contextualise the land sector on a global scale by cataloguing direct action taken within the land sector since the Paris Agreement to evaluate the progress made. Specifically, this chapter undertook a systematic map to evaluate primary and grey literature to see if a pattern emerged regarding land-based interventions designed or reinforced by the Paris Agreement. By examining what land-based progress has occurred, and where, the systematic map provides critical insights into the way different commitments have been acted upon, and further the current understanding of the emphasis different countries place on land-based climate commitments.

This discussion follows the structure of evaluating the four key areas that were highlighted within the results: unequal distribution global research effort reduces land policy making accuracy (section 5.4.1.); there are differences in the framing of the land Sector in NDCs and in practice (section 5.4.2.); ambiguity in policy details obfuscates real-world impacts of climate measures (section 5.4.3.); and research fails to capture land sector complexities and interactions with other systems (section 5.4.4.).

5.4.1. Unequal Distribution of Global Research Effort Reduces Land Policy-Making Accuracy

Most of the studies in the systematic map being published between 2019 and 2020 indicated these years marking an increasing global focus on implementing and assessing the impacts of the PA (Higgins *et al.*, 2019). The uptake in publications during these years could be attributed to the maturation of projects initiated soon after the agreement was ratified in 2016. This trend might also reflect the broader academic and policy-driven interest in understanding how land-based solutions contribute to climate mitigation and adaptation, spurred by the urgency of meeting the Paris Agreement targets. Particularly as many of the studies focused on regions in the global south (Figure 13), with pressing environmental challenges and opportunities specific to these regions (Harper *et al.*, 2018). This could be because many of the interventions in the land sector are often targeted at countries with significant development needs, where the impact of such interventions can be most pronounced (Lamb *et al.*, 2021), or where the focus may be on halting deforestation rather than restoration. DAC-listed ODA recipients, particularly those in lower and middle-income categories, are often prioritised for international aid and development programs aimed at addressing climate change, biodiversity loss, and sustainable land use (Amos *et al.*, 2013; Lamb *et al.*, 2021). In Europe, the strong policy frameworks and commitment to sustainability initiatives create a conducive environment for conducting and publishing research on land sector interventions.

However, only 26 papers could be fully extracted from (Figure 10); from these, there were 29 case studies. This reveals a significant gap in primary research on the success of land sector actions since the PA. While many papers address the land sector and post-PA (Figure 10), fewer than 15% provide enough detailed data for comprehensive analysis. The reasoning behind this is not evident within the systematic map but may be because the land sector is representative of a greater percentage of GHG emissions in developing and tropical countries (Lamb *et al.*, 2021), as opposed to highly agriculturalised western developed countries. The predominance of studies from the global south (Figure 13), indicates that these are important regions to global land-based mitigation, and align with previous research (see section 5.1.2.). However, whilst the reduced representation from the global north may indicate that these regions have less scope for land-based mitigations, this is not true (Law *et al.*, 2018; Roe *et al.*, 2021). This raises **concerns about equity in research collaboration, knowledge production, and representation of diverse perspectives and contexts in climate discourse, and potentially indicates a lack of ownership and responsibility in more developed countries to make progress within their land sector.**

The complexity and uncertainty in evaluating specific interventions, coupled with the academic focus often being geared to broader audiences, could lead to a reduced emphasis on discussing NDC land-based interventions and conditionalities (Fragkos *et al.*, 2018). Academic papers often aim to reach broader audiences, including policymakers and practitioners, who may prioritise practical implications over technical details (Schwanen *et al.*, 2011). This can result in a skewed representation of policy effectiveness, as authors may avoid detailed policy discussions to reduce criticism, and a potential bias against publishing null or negative findings further distorts the perception of success (Dwan *et al.*, 2013; Tennant and Ross-Hellauer, 2020; Ioannidis, 2024). This skew towards positive outcomes can mislead decision-makers, undermining the development of effective, evidence-based strategies (Ioannidis, 2024). As a result, **decision-makers might rely on incomplete or overly optimistic data when formulating or evaluating land-based policies**, which could undermine the development of more effective and evidence-based strategies. The imbalance in publication practices, especially in the global north, underscores the need for greater transparency and inclusion of all research outcomes, including those that do not align with prevailing political ideologies to ensure a more accurate and comprehensive understanding of policy impacts.

5.4.2. There are Differences in the Framing of the Land Sector in NDCs and in Practice

Emissions reduction is a core component of hitting climate goals, the fact it is not mentioned in nearly a third of the studies (Figure 14) could be because the focus of some studies might have been on other aspects of land sector interventions, such as adaptation strategies, biodiversity conservation, or sustainable land management practices, rather than directly on emissions reductions (Roe *et al.*, 2019; Roe *et al.*, 2021). Additionally, certain studies might have focused on land-use practices or policy frameworks that do not explicitly measure or report emissions reductions but instead emphasise qualitative improvements in land management or policy implementation (Duguma *et al.*, 2014). While emissions reduction is crucial for achieving climate goals, some interventions may prioritise resilience-building, ecosystem services, or socio-economic outcomes, with some studies indirectly contributing to emissions reductions without explicitly mentioning it as a primary outcome. Moreover, the terminology used in the papers might vary, with some studies possibly using alternative metrics like "increase sequestration," "preserve carbon sinks," or "'habitat' restoration," (Figure 15), which could serve similar purposes but were not coded as "emissions reductions" in the review process. This variation in language might lead to underreporting of the concept in the systematic map, even if the studies contribute to emissions reduction goals (Otchere-Darko and Ovadia, 2020).

The fact that 79% of studies stated the land sector involvement in overall GHG emissions reduction efforts could underscore the recognition of the importance of land-based interventions in addressing climate change. However, this systematic map is explicitly investigating papers that have studied the interventions in the land sector post PA. By not explicitly mentioning the land sector's contribution to overall emissions reductions, there may be missed opportunities to highlight the significance of land-based interventions in achieving broader climate goals (Hahn and Reimsbach, 2015). Additionally, omitting this could potentially obscure the interconnectedness of different sectors in contributing to GHG emissions reduction efforts. While most of studies included "LULUCF" (66%) and "Agriculture" (72%), a smaller proportion included the term "AFOLU" (21%). This variation in terminology reflects different conceptualisations and classifications of land-based activities within the climate change discourse and mirrors terminology use in the NDCs (see section 4.3.1 and 4.4.1.) (Sovacool, 2023). This indicates that despite regional differences in terminology, there is a general alignment in how land-based activities are integrated into climate strategies worldwide.

However, not all the terminologies used to present the land sector in the systematic map reflected those in chapter 4. For this study there was a differentiation between AFOLU and agriculture, not as a

subsector of AFOLU, as seen by the fact that “LULUCF with agriculture” was the most common combination of land sector representation (Figure 16), with ‘only LULUCF mentioned’ second most. This is dissimilar to the NDCs in chapter 4 (Table 6); when forestry or land was mentioned within the systematic map, it was mentioned as a component of LULUCF. **This suggests that there may be a divergence between how NDCs conceptualise and present land sector interventions at policy level vs how these interventions are implemented on the ground.** NDCs might simplify these categories to streamline policy frameworks and reporting processes, whilst the frequent combination of “LULUCF with agriculture” and the integration of LULUCFs composite parts in the systematic map studies, indicates that real-world applications of land sector interventions often require a more nuanced and integrated approach that acknowledges the complexities of LULUCF (Forsell *et al.*, 2016).

5.4.3. Ambiguity in Policy Details Obfuscates Real-World Impacts of Climate Measures

Across the studies, information about the NDC targets was inconsistent; just over half described the overall target, and less than half included the baseline year for comparison. While baseline data can be assumed to be part of the NDC, omitting the overall goal diminishes the clarity and transparency of the findings, making it difficult to assess the effectiveness of the NDC targets (Allen *et al.*, 2022). Without a clear statement of the overall goal, it becomes challenging to contextualise progress and compare results with other assessments, limiting the understanding of how well countries are aligning with their PA commitments. This issue is compounded by the fact that 83% of the studies did not specify whether the land commitments were conditional or unconditional. Although most studies mentioned emissions reduction, they often overlooked the conditionality of the commitments, reflecting a broader trend in the literature where the focus is on implementation and impact rather than the conditions attached (Karisson *et al.*, 2020).

The conditionality of commitments is not always clear (see section 4.4.2.; Grassi *et al.*, 2017), which could lead researchers to prioritise other aspects, such as the effectiveness of policies or the implications for biodiversity, over a detailed exploration of whether the commitments are conditional or unconditional. With only five studies in the review distinguishing between conditional and unconditional components, it can be synthesised that there is an underrepresentation and ambiguity around the conditionality of commitments within progress and intervention research. This oversight obscures the dependencies on external support that many countries face, complicating efforts to evaluate the feasibility and ambition of NDC goals (Cunliffe *et al.*, 2019). Moreover, the lack of transparency regarding conditionality is underscored by the fact that only two papers—*Hasan et al.* (2020) and *Hoan Do et al.* (2021)—explicitly stated whether countries were on track to meet their land sector targets. Both papers concluded that Vietnam and Bangladesh were not on track, emphasising the need for transparency and accountability in NDC reporting. The scarcity of such tracking raises concerns about the feasibility of commitments, pointing to challenges like inadequate resources and institutional capacity, and underscores the need for more comprehensive analysis across all regions (Fanzo *et al.*, 2021).

5.4.4. Research Fails to Capture Land Sector Complexities and Interactions with Other Systems

The presentation of land use in climate-related research varies significantly, reflecting a broader ambiguity in how the land sector is addressed within the literature. In this review, the combination of “LULUCF with agriculture” was the most common, while terms like “AFOLU” and “LULUCF” were mentioned only in studies that did not define the conditionality of the actions (Figure 11). This suggests that land-based interventions might be implicitly considered part of unconditional NDC commitments, leading to an oversight in distinguishing between conditional and unconditional targets. This oversight could stem from established norms within the research community, where the explicit consideration

of NDC conditionalities is not typically prioritised, but is more likely due to the complexity of integrating land use into national climate strategies (Forsell *et al.*, 2016; Jernnäs *et al.*, 2019). The lack of clear distinction between conditional and unconditional targets may stem from challenges in attributing specific land-based interventions, leading to an incomplete understanding of their role in achieving climate goals. This highlights a gap in the literature and the need for future research to better define these distinctions.

The variation in terminologies and metrics related to land use further complicates this picture. The studies reviewed used a wide range of terms and metrics (Figure 13), potentially reflecting the diversity of research objectives. Studies focusing on carbon sequestration in forests (Nabuurs *et al.*, 2017) is likely to have different goals than another examining the impact of agricultural practices on methane emissions (Romanovskaya *et al.*, 2020). Such diversity in research goals results in varying terminologies and metrics being employed. That said, reforestation and afforestation commitments were prevalent in papers regardless of whether they specified conditionality (Figure 15, Table 11). Interestingly, the preservation or improvement of carbon stocks was the only concept more commonly addressed in studies that defined conditionality (Table 11). This focus on widely recognised metrics like "reducing deforestation," "reforestation," and "increasing sequestration" may be due to their broader applicability and established methodologies, which make them easier to measure and monitor. These activities are central to global climate strategies and directly contribute to significant carbon savings. In contrast, metrics like peatland and grassland restoration, which are more relevant to specific ecosystems, were less commonly used, possibly due to their regional specificity and the lower prevalence of these ecosystems in the areas studied.

This variation in terminologies reflects not only the complexity of climate mitigation strategies but also differences in how researchers conceptualise and categorise these strategies. For example, while Hasan *et al.* and Forsell *et al.* focused on a narrower set of terminologies within specific contexts, Taconi and Muttaqin (2019a, 2019b) expanded their terminology significantly, offering a more nuanced view of climate actions. The increased number of terminologies in Taconi and Muttaqin's studies, particularly when distinguishing between unconditional and conditional NDCs, may offer deeper insights into specific climate actions and their anticipated impacts, potentially influencing policy development and implementation. This highlights the need for a standardised lexicon to facilitate clearer communication and comparison of climate policies and their effectiveness.

Compounding these issues is the limited attention given to the intersection of land use and food systems within NDC commitments. Notably, Hoan *et al.* (2021) was the only paper among the reviewed studies that mentioned food systems, an area often overlooked in discussions on land use and emissions reduction strategies. This omission underscores a significant gap in the literature, where the critical role of food systems in environmental management is frequently underrepresented (Azmi *et al.*, 2023). By acknowledging the importance of food-crop yields and the provision of food as vital ecosystem services, Hoan *et al.*'s paper broadens the scope of land management discussions. It emphasises the need for more comprehensive strategies that address both environmental and socio-economic objectives, suggesting that future research should more consistently incorporate the interplay between food security and land use to develop sustainable solutions.

Although food systems are not overtly mentioned in most studies, there are references to other mechanisms that could help address the complexity of the land sector, such as REDD+ and a country's NAP (National Action Plan). These policies, while valuable, are not specifically focused on land, and few studies include documents that address the complexity of land use, including its intersection with food systems and energy. REDD+, for instance, aims to increase carbon sequestration but has limitations such as monitoring challenges, issues with permanence, and concerns about fairness,

making it an unreliable sole indicator of a country's progress on land-based Paris Agreement commitments (Lee and Sanz, 2017; Hein *et al.*, 2018). Similarly, while National Adaptation Plans (NAPs) complement NDCs by addressing climate adaptation, they are not land-specific and often lack mandatory land-related targets (Mills-Novoa and Liverman, 2019). This leads to the same gaps found in NDCs, where land use can be overlooked (Strapasson *et al.*, 2017). The reviewed studies also highlight that 'other policies' often fail to fully address the intricate dynamics of the land sector, underlining the need for more targeted, integrated approaches in climate policy.

Despite the various policies and initiatives aimed at addressing land use within climate strategies, such as REDD+ and NAPs, significant gaps remain. These policies often lack the specificity needed to fully encompass the complexities of the land sector, particularly when it comes to integrating food systems and their interplay with other critical sectors like energy. The inconsistent use of terminologies, the oversight of food systems in NDC commitments, and the reliance on limited metrics like reforestation highlight a broader issue: **research and policy frameworks frequently fail to capture the intricate dynamics of the land sector**. This failure to adequately address the interconnectedness of land use with other environmental and socio-economic systems undermines the effectiveness of climate strategies and points to a crucial need for more comprehensive research that can inform better-integrated policy approaches.

5.4.5. Chapter Takeaways

The review yielded few papers, likely due to two primary factors. First, while an insufficient or poorly constructed search string might be suspected, this is unlikely given the systematic approach and careful selection of terms used to maximise relevant papers. Second, it appears that academic reporting on land sector interventions is lacking, even though organisations like Climate Action Tracker (CAT) and the Food and Agriculture Organisation (FAO) have documented numerous ongoing interventions and progress. This suggests a gap between policy implementation and academic reporting. The scarcity of academic papers disrupts the flow of information essential for effective climate action, as it hinders evidence-based policymaking. Understanding where land sector interventions are documented—whether in academic journals or reports from organisations like CAT or FAO—is crucial for ensuring stakeholders have the necessary information to contribute to climate strategies and improve the connection between research, policy, and public awareness.

This systematic map addresses the thesis's first aim and second objective by providing evidence of the successes and shortcomings of interventions. By gathering and analysing data on implemented policies, projects, and practices across various countries, the review offers a clear picture of how well nations have translated their NDC commitments into tangible actions. It also highlights the challenges posed by language variability across the land sector policy landscape (see chapter 4 and 5), which complicates efforts to create unified strategies and assessments. This variability highlights a significant challenge in developing and implementing effective land sector policies and tools. For this research, it implies that whether or not the calculators designed to support NDC policy development follow this pattern of variability will be interesting to observe. If they do, it might indicate a need for greater standardisation in the metrics and terms used, ensuring these tools can be effectively applied across diverse contexts. Alternatively, if the calculators adopt a more standardised approach, it could help drive consistency and comparability in land sector policies and practices, facilitating better global coordination and assessment of climate action progress. This comprehensive approach ensures that all relevant data is considered, supporting more robust and effective climate policies and actions.

6. Climate Calculator Analysis

6.1. Cataloguing the climate calculators

6.1.1. Research Done to Date

The integration of land use into climate calculators is a crucial yet underdeveloped area in climate modelling. Existing calculators, such as those used in the 2050 Calculator framework, often include land sector metrics, but the extent and accuracy of this integration vary widely. These tools can be invaluable for policymakers, offering a way to estimate the impacts of land use changes on greenhouse gas emissions and sequestration. However, the current models often oversimplify the complex interactions between land use, food systems, and energy sectors, leading to potential inaccuracies in their projections (Popp *et al.*, 2017; Harper *et al.*, 2018).

Research into climate calculators, particularly those from the 2050 Climate Calculator program, has primarily focused on their utility and effectiveness in helping countries plan their pathways to net zero (Strapasson *et al.*, 2020). Scholars and practitioners from institutions like the International Energy Agency (IEA), the World Bank, and various academic bodies have examined these tools, often praising their ability to model energy transitions and policy impacts (Garcia *et al.*, 2022). However, much of this research has been energy-centric, with less attention given to how well these calculators incorporate land use and its associated challenges (Hertwich *et al.*, 2008; Drysdale *et al.*, 2019). Studies have noted the need for better integration of land-based mitigation strategies, but few have delved deeply into how this can be achieved or assessed the existing tools' accuracy in this domain. Whilst there have been studies that look at the interplay between the 2050 climate calculators and the land sector (Strapasson *et al.*, 2022), these have not looked at the way the land sector is integrated into the calculators, and how this reflects the landscape dynamic of the NDCs that they are meant to be supporting.

Although climate calculators were originally designed to present a whole-system narrative, aiding countries in developing net zero pathways, their effectiveness in assisting with specific sectors, particularly the land sector, is critical. Given that the land sector is deeply interlinked with other sectors (see section 1.2.) it can be argued that the utility of these calculators as decision-support tools in the land sector directly reflects their overall efficacy in supporting comprehensive, system-wide climate strategies. Therefore, understanding enhancing the integration of the land sector within these calculators is not only essential for sector-specific decision-making but also pivotal in ensuring these tools can truly serve as holistic supports for national and global climate actions (Milne *et al.*, 2009). Given the critical role of land use in achieving global climate targets, it is essential to explore how these calculators can be improved to better account for land sector complexities (Strapasson *et al.*, 2017). This study aims to fill that gap by critically evaluating the current state of land use integration in climate calculators and providing insights that could enhance their accuracy and utility. By doing so, it contributes to a more holistic understanding of how these tools can support effective climate action, particularly in the land sector.

6.1.2. The Presence of Land Within the Climate Calculators

The way the land sector is included and represented within each national climate calculator is ultimately up to the discretion of each country. The manner of inclusion, or explicit exclusion, can indicate elements of that country's relationship with the land sector, as well as potential priorities in terms of climate action (Lachapelle and Paterson, 2017).

For instance, the inclusion of different land components, such as agriculture and forestry may indicate that these are significant contributors to that country's GHG emissions, such is the case in countries

with large agricultural industries or extensive forested areas (e.g. Brazil, where there are vast areas of the Amazon rainforest and a significant agricultural sector). There is potential that countries that include detailed strategies for the land sector within their calculators either prioritise land-based mitigation measures or recognise the importance land plays in a holistic approach to climate mitigation and adaptation (Lachapelle and Paterson, 2017; Strapasson *et al.*, 2017). In contrast, countries that omit land sector details might either view these measures as less critical or face barriers such as high implementation costs or technological challenges (den Elzen *et al.*, 2013). This disparity highlights the varying levels of emphasis and resource allocation in climate strategies, affecting overall policy effectiveness and adaptation approaches.

A simplistic, or non-comprehensive approach to land sector representation in the calculator might suggest that the country does not see land-based measures as critical to their climate adaptation strategy, or that the measures required to implement effective land-based mitigation have too great of an implementation cost (financially, technologically or otherwise) to be feasible (Pollard *et al.*, 2004). Additionally, countries that have lower economic dependence on the land sector might see reduced representation within the calculator, reflecting the national focus on other sectors such as industry and urban development, or sectors that could be considered greater sources of GHG emissions reduction (Newell and Mulvaney, 2013; Fawzy *et al.*, 2020). Limited or absent land sector representation might reflect gaps in environmental policies in other circumstances, or the potential for lower prioritisation of the land sector over all. Conversely, comprehensive land sector integration could signal a commitment to land-based climate action, indicating an openness to broader discussions on sustainability and biodiversity (Abbass *et al.*, 2022). The inclusion of agriculture and forestry, for example, suggests these are key emission sources for a country, reflecting either a priority for land-based mitigation or a more holistic approach to climate strategy. However, the level of land sector integration in these calculators can also be influenced by external factors, such as the availability of national data (Roe *et al.*, 2019; Strapasson *et al.*, 2020). Countries with extensive historical data and advanced technological capabilities are better equipped to accurately represent land sector changes in their calculators, while those with less developed data collection might struggle (Yates *et al.*, 2018; Strapasson *et al.*, 2020). This discrepancy can disadvantage less developed countries, where limited data may hinder the depth of land sector representation, resulting in a no-win situation. Nevertheless, the 2050 international climate calculator team plays a crucial role in supporting the development of new calculators, helping to overcome these technological and data limitations (Strapasson *et al.*, 2020).

Whilst the structure of a national climate calculator should provide valuable insight into the relationship that country has with the land sector, it is important to accommodate the context and external factors that will be influencing the calculators design (Forsell *et al.*, 2016). The way land is included into the calculator *should*, as a non-policy prescriptive tool, directly reflect the interplay between a nation's economic sectors and its GHG emissions, but *could also* inadvertently indicate economic priority, policy focus and technological capacity. With limited research done on the linkage between policy instruments and policy outcomes (Capano and Howlett, 2020), it is more important than ever to understand the role that climate calculators play in supporting policy development in such a pivotal sector such as land. Methodological constraints, transitional phases and internal and international influences need to be considered as potential role players in climate calculator development, ultimately helping reflect the complex relationship each country has with the land sector and the multiple approaches there are to integrate these into broader climate strategy.

6.1.2. Methods

Calculator Identification

The official list of countries that participated within the 2050 international climate calculator programme were taken off the Imperial College website (Imperial College, 2024)*. The first of these calculators (UK) was launched first in 2009 (Table 13). There were 6 countries where the calculator was not accessible due to broken web links (Taiwan, Indonesian, Thailand, Mexico, Ecuador and Brazil, Table 13).

Countries were excluded if there was no longer functioning link to the country's national calculator. Several of the links were broken over time; attempts to access functioning links were made by contacting individuals from the country development team, if they were not possible to contact, or unsuccessful the calculator was excluded.

Table 13. List of countries that have a launched climate calculator, and the year in which that calculator was launched.

Country	Name	Year
UK	Mackay Carbon Calculator	2009
China	China 2050 Pathways	2012
Belgium	2050 Pathway Explorer- Belgium	2013
South Korea	2050 Greenhouse gas Pathways Calculator	2013
India	India Energy Security Scenarios	2014
Japan	Japan 2050 Low Carbon Navigator	2014
South Africa	South Africa 2050 Pathways Calculator	2014
Global	The global calculator	2015
Australia	Australian 2050 Pathways Calculator	2015
Austria	Climate target path calculator for Austria 2050	2015
Bangladesh	Bangladesh 2050 energy and carbon emissions calculator	2015
Columbia	2050 carbon calculator	2015
Mauritius	The Mauritius 2050 Pathways Calculator	2015
Nigeria	NECAL	2015
South East Europe	South East Europe 2050 Carbon Calculator	2015
Switzerland	Swiss Energy Scope	2015
Vietnam	Vietnam 2050 calculator	2015
Czech Republic	CO 2 emissions calculator until 2050	2016
Ireland	The Irish 2050 Calculator	2016
New Zealand	The Wellington 2050 Energy Calculator	2016
EU	Transitions pathway explorer, EUCalc	2019
Taiwan		2013
Indonesia		2014
Thailand		2015
Mexico		2015
Ecuador		2016
Brazil		2016

*see www.imperial.ac.uk/2050-calculator for full list of calculators within the programme

There is a wide distribution of all the countries that have participated within the programme (Figure 17), with the greatest number of countries yielding from Europe or Asia.

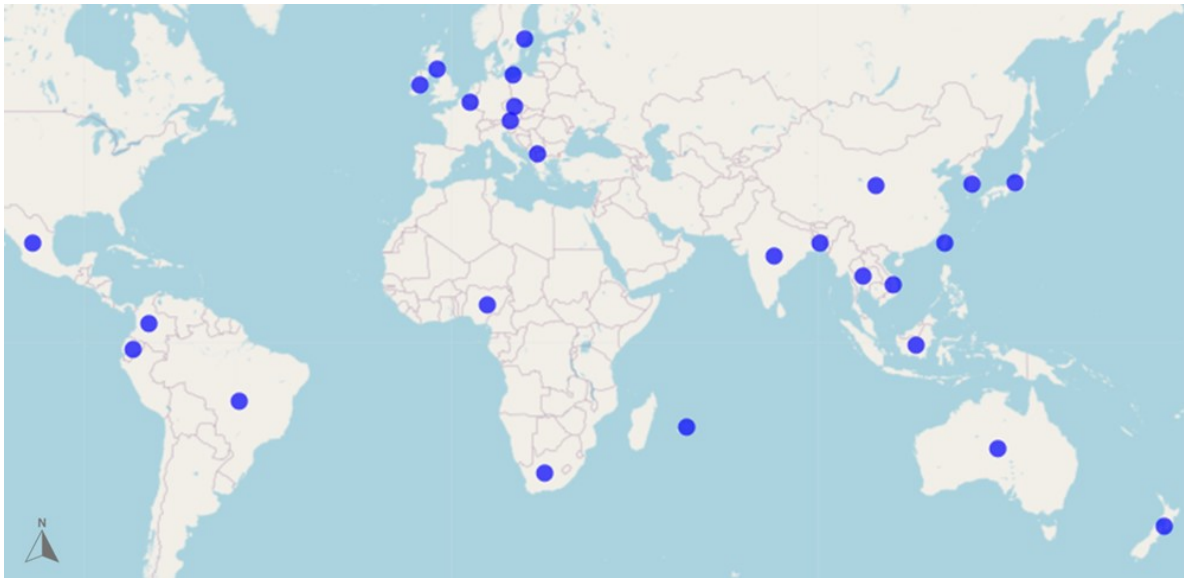


Figure 17. Distribution of countries officially part of the 2050 calculator programme, excluding the global calculator.

Data Extraction

Information was extracted in order to identify the officially stated reasons for calculator development (“Engage in debate”, “Explore Plans to net zero” etc (Appendix C)), the manner in which land was included into the inputs of the calculator (and whether this was presented in “Lever Groups” or not), and the outputs of the calculator (emissions graphs, land use maps etc), if at all (Appendix C).

The terminologies that were determined to be ‘related to land’ were influenced both by the calculators themselves and by both chapter 4 and 5 of this thesis (see sections 4.2.2., 4.3 and 5.3). This is because the language used reflects global perceptions of land, making it a relevant factor in determining how to extract land-related data from the climate calculators.

Analysis and Limitation Mitigation

The data was analysed using content analysis (Love, 2003). Content analysis can be applied in qualitative, quantitative, and sometimes mixed modes of research frameworks (White *et al.*, 2006). Whilst similar to document analysis (see section 4.2.4.), content analysis examines all mediums in which words appear, whilst document analysis focuses on written documents (Love, 2003). Content analysis primarily focuses on the content within the text or media, often quantifying the presence of certain words, themes, or concepts to understand patterns and trends.

For this research quantitative content analysis was used to systematically analyse the text content of the climate calculator tools themselves, as well as the relevant webpage and associated supporting documentation. The content was coded, including advertised uses for each of the calculators, the land terminology used for the input and outputs of the tool, and the way inputs and outputs were presented. This analysis technique helped determine the prevalence and distribution of different coded themes (e.g. land terminologies) across the data (Ashley and Boyd, 2006).

The Methods

Conducting a content analysis of the tools and their websites provides several benefits for understanding how the land sector is represented within these tools. Firstly, it has allowed for systematic assessment and comparison across the calculators to both compare within the programme but across chapter 4 and 5. This can reveal the consistency and reliability of the information provided, as well as highlight any significant discrepancies or gaps (White *et al.*, 2006). However, there are limitations to this method. Content analysis may not capture the dynamic and interactive aspects of climate calculators, such as user engagement and real-time data updates (Bardus *et al.*, 2016). Additionally, the static nature of some of the associated documents might miss out on recent methodological improvements or updates in calculators. There's also the challenge of varying levels of transparency and detail in the documentation provided by different calculators, which can hinder a thorough comparative analysis. Despite these limitations, this method still provides a foundational understanding of the underlying principles and data informing these tools. This groundwork is essential for further, more dynamic studies and for making informed recommendations for improving the accuracy and utility of climate calculators in addressing land sector impacts.

6.1.3. Results

Of the countries that had accessible online calculators, one was classified as Least Developed (Bangladesh), two were Lower Middle Income (Nigeria and Vietnam), 6 were Upper Middle Income and 3 were not national level calculators (Global, EU and South East Europe) (Table 14). Just under half the calculators (n=10), were national level calculators that were not DAC listed ODA recipients.

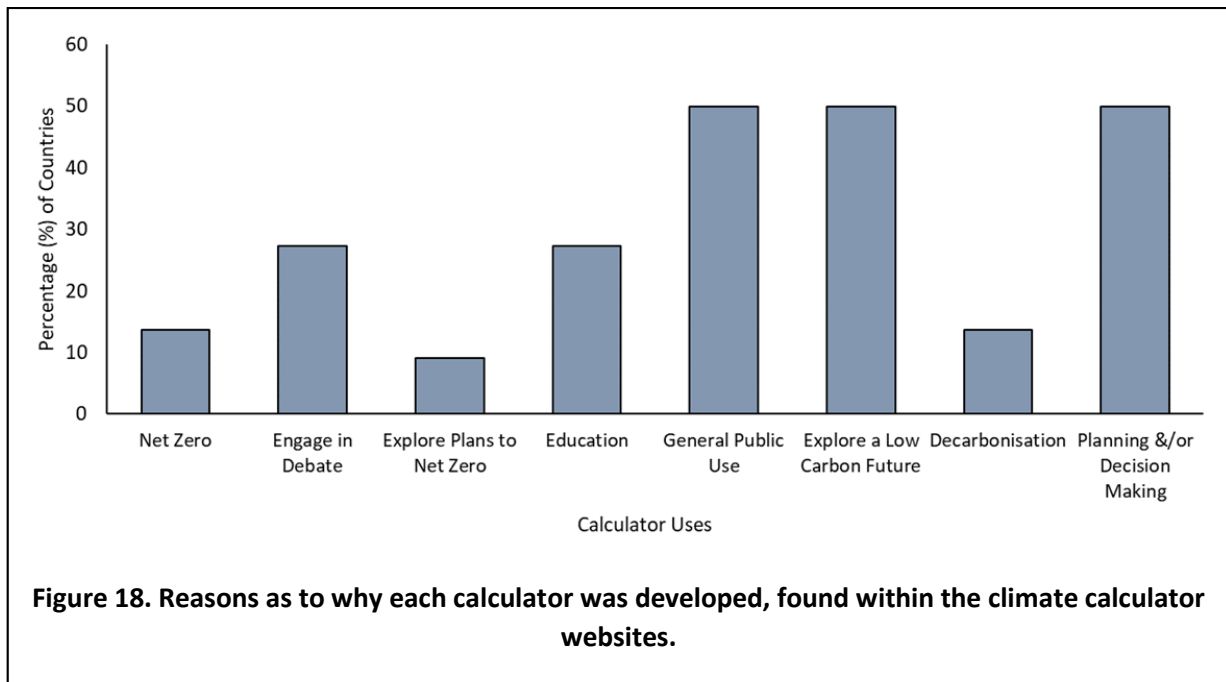
Table 14. Categorisation of the country or region that has a climate calculator, and whether it is a DAC listed OFA recipient.

Country/Region	Not a DAC listed ODA recipient	Upper Middle Income	Lower Middle Income	Least Developed
Australia	x			
Austria	x			
Bangladesh				x
Belgium	x			
China		x		
Columbia		x		
Czech Republic	x			
EU	/			
Global	/			
India		x		
Ireland	x			
Japan	x			
Kenya		x		
Mauritius		x		
New Zealand	x			
Nigeria			x	
South Africa		x		
South East Europe	/			
South Korea	x			
Switzerland	x			
UK	x			
Vietnam			x	

This could be because it has only been in recent years that the climate calculator programme has been included into the UK's technical assistance programme, which is part of UK International Climate Finance (ICF) (UK Govt., 2013).

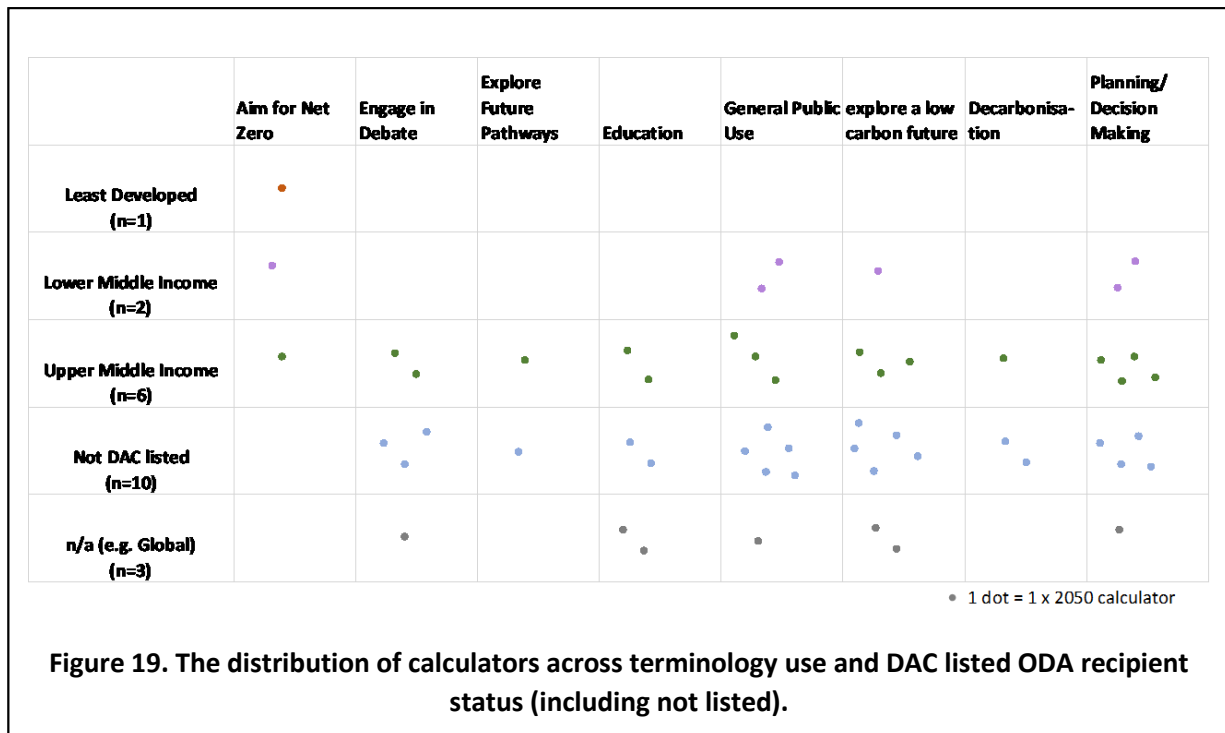
Calculator Use

Each calculator comes with a webpage that contains information to any users or interested parties about the background of the calculator and the reasons it was developed (Appendix C). There were mostly between 1 and 6 reasons that were mentioned; Bangladesh was the only one that did not specify any reasons as to why the calculator was developed. Most calculators cited 2 reasons (n=10), with the most frequently occurring were "General Public Use", "Explore a Low Carbon Future", and "Planning and/or Decision Making" (Figure 18).



“Education” was cited only by countries that were either not DAC listed ODA recipients, or Upper Middle Income (Figure 19). “Aim for Net Zero” (or “Net Zero”) was only cited 3 times, all by countries receiving ODA support, whilst “Decarbonisation” was used by countries that were either not DAC listed ODA recipients and 1 Upper Middle-Income country (Figure 19).

“Explore a Low Carbon Future” was one of the three most frequently used (Figure 18) and was proportionally used by about half the number of countries within each of the DAC listed ODA recipient categories (including not listed) (Figure 19). This is interesting because all three of these terminologies are arguably referencing a very similar concept, so might prove interesting to investigating the potential meaning behind the different terminology use. The differences in cited use could reflect the different phases that each calculator was built on, or the different ways the calculator programme has expanded since its conception in 2009.



Lever Inputs

It was seen that there were two types of lever input formats. The first was the levers being sorted into groups (Figure 20a), the second the levers listed out (Figure 20b).

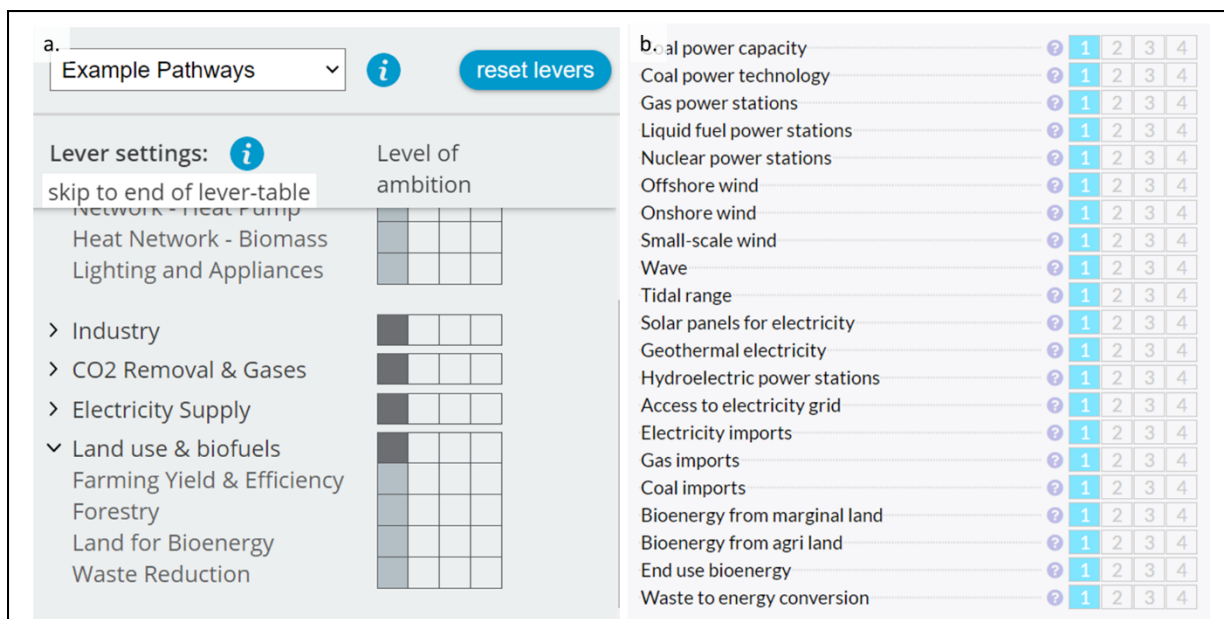
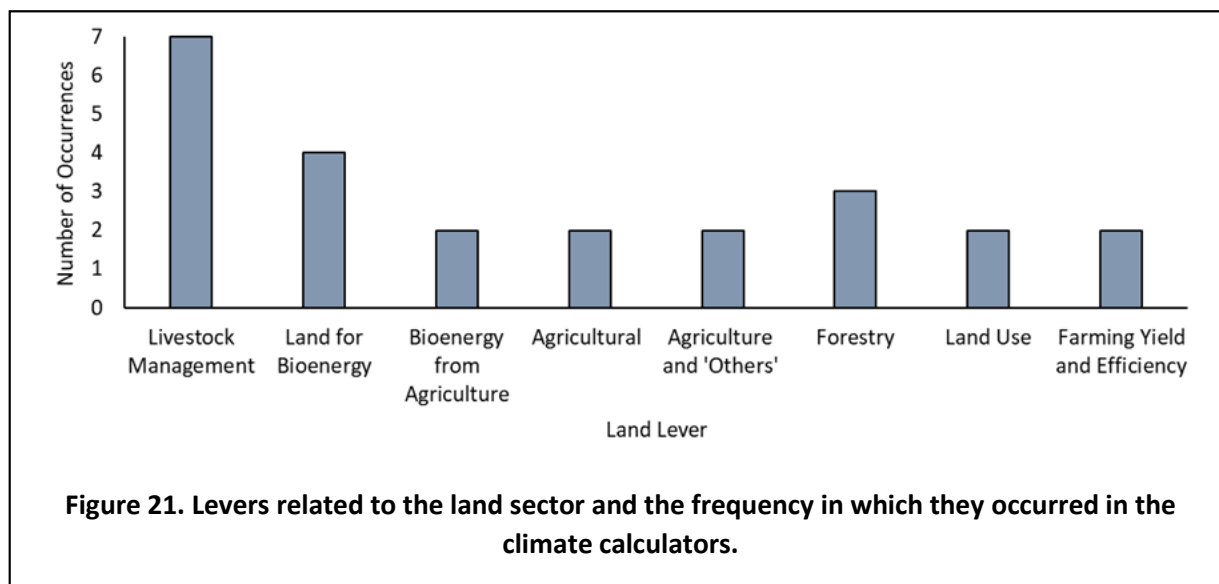


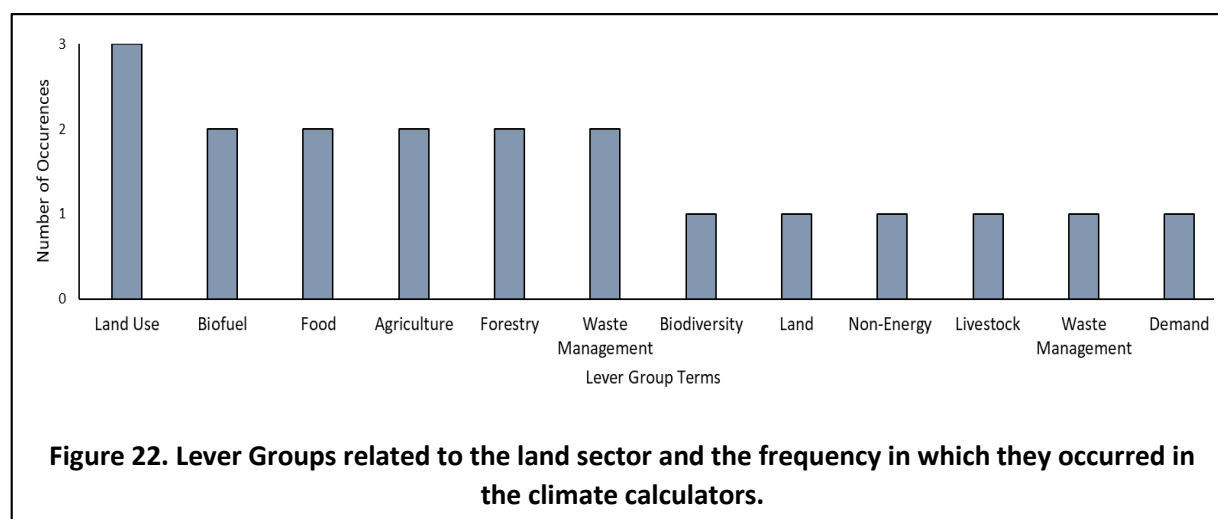
Figure 20. Examples of the two different categories that the lever inputs of the climate calculators were sorted into. Figure 20a. is a screenshot from the UK climate calculator, the McKay Carbon Calculator, where Levers were sorted into Lever Groups (e.g., “Farming Yield and Efficiency”, “Forestry”, “Land for Bioenergy” and “Waste Reduction” are all levers that were grouped under “Land use and biofuels”. Figure 20b is from the Bangladesh climate calculator, BD2050, where all the levers are listed out.

With the individual levers (whether grouped or listed) “Livestock Management” was the most frequently occurring (n=7). However, only 8 levers occurred in more than one calculators (Figure 21); there were 34 different lever names isolated within the land sector that only occurred once (i.e. only occurred in one calculator).



45% (n=10) of the calculators formatted the levers into lever groups, whilst 55% (n=12) did not. This is likely due to preference of UI, however is good to distinguish for this study as it helps mitigate the problems of comparing two different methods that are not exactly like for like.

Lever Groups had an occurrence rate between 1 and 3. “Land Use” was the most commonly occurring Lever Group, occurring in 3 different calculators (Figure 22).

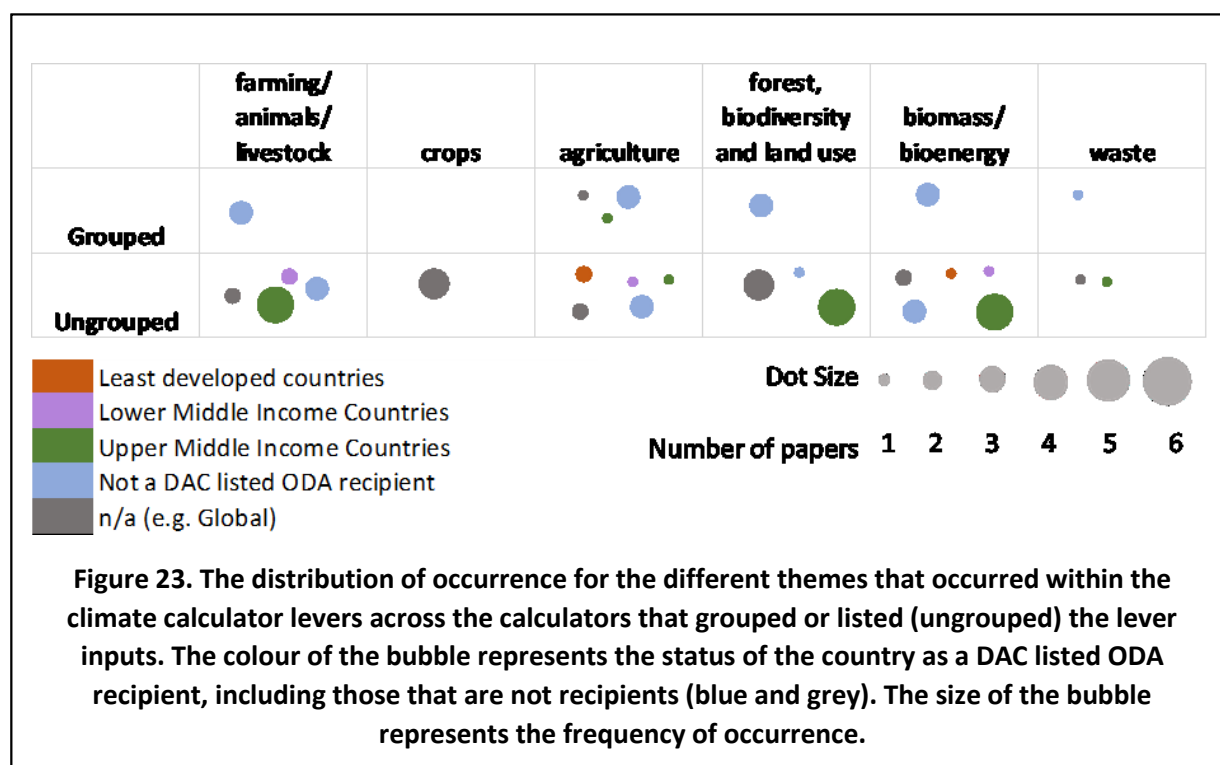


The 43 levers identified could be collated into 6 different themes, or collections (Table 15). This was done to present a common framework for analysing the two different types of lever formatting, and to understand the frequency of different styles of terminology use.

Table 15. The themes, or collections, that the 43 levers identified within the calculators could be sorted into

General Lever Collection	Lever Name
Farming/ Animals/ Livestock	farming yield and efficiency animal husbandry livestock (grains/residues fed) best livestock practices livestock management per capita meat consumption change in meat and milk consumption Livestock (pasture fed) climate smart livestock
Crops	climate smart crop production crop yields alternative protein source
Agriculture	irrigation and other agricultural practices Best agricultural practices bioenergy from agriculture agricultural practices agricultural Agriculture and 'others' Area set aside for nature... ...from agriculture and forestry
Forest, Biodiversity and Land Use	forestry Forestry practices commercial&protective reforestation reduced rate of deforestation. Carbon forestry land management surplus land (forest and bioenergy) land utilisation land-use efficiency land use
Biomass/ Bioenergy	forest management and biomass land for bioenergy dedicated land for biofuels biomass, biofuel and biogas production bioenergy capacity bioenergy bioenergy conversion bioenergy from marginal land biomass conversion rate CCS hierarchy for biomass end-uses
Waste	Wastes and residues waste reduction

All Least Developed, Lower Middle Income and all but one Upper Middle Income countries listed out their levers. All countries not listed on the DAC list of ODA recipients (global, EU and South East Europe calculators included), grouped the levers into lever groups (Figure 23).



Calculator Outputs

Of the 22 calculators reviewed, 68% did not include land within the calculator outputs (n= 15).

3 of the calculators had 1 land-based output, 3 had 2, and 1 (Bangladesh) had 4.

Of the type of outputs that were land based, there were three that appeared in more than one calculator (Table 16), with 'Other' graphs appearing only once.

Table 16. The type of output graph that included land-based information, and the frequency of occurrence within the climate calculators.

Graph type	Number of Calculators
Emission Reductions	2
Land Area Trade Off Graph	3
Livestock Population Type*1, Animal Product Demand *2	2
1(st) Additional 'Other' Graph	2
2(nd) Additional 'Other' Graph	2

"Land area trade off graph" was seen in 3 different calculators. An emissions reduction graph relevant to the land sector was seen in 2 calculators, as was a "livestock population" (Table 16). 4 other graphs were only seen once across the study. This is potentially because of the variability in how different calculators present data and prioritise certain aspects of land use and emissions.

Bangladesh was the only one with an additional graph that was related to food and included food security and demand. Bangladesh had two additional graphs, both of which were related to food and food security, underscoring the unique emphasis Bangladesh places on the intersection of food security and climate planning, reflecting its specific national priorities and challenges.

South Korea had two additional graphs both considered land use maps. This is interesting because it indicates a strong focus on spatial analysis and geographic representation of land use, which can be crucial for detailed planning and policy implementation.

These findings are important because they demonstrate how different countries tailor their climate calculators to reflect their unique priorities and challenges. The inclusion of specific graphs such as those related to food security in Bangladesh or land use maps in South Korea suggests a customised approach to climate planning that addresses distinct national concerns. Understanding these differences can inform better international collaboration and the sharing of best practices tailored to diverse contexts.

6.1.4. Discussion

This research evaluated the role that calculators play in reconciling the GHG emissions gap by investigating the way in which the land sector was represented within the climate calculators. Not only is land not consistently included within the climate calculators, but the way it is included is variable. This is consistent with the variable terminology use highlighted in chapters 4 and 5. The absence, or minimal inclusion of the land sector might be a result of political conflict, inertia or challenges that do not necessarily reflect the country's overall state of affairs regarding land use and policy. However, in practice, the codesign process of the climate calculators should reflect the prevailing state of knowledge and policy interactions at a national level of policy making. As such, the omission, or minimal inclusion of land indicates through what is chosen to be included and what is omitted, the relative priority, or tractability of novel land use policy in terms of climate management.

If a calculator includes land within the inputs, it is indicative that the country sees land-based actions (e.g. reforestation or sustainable agriculture) as important potential tools for achieving climate goals. This is representative of a proactive approach to utilising land management; increased detail in the land lever options reflects a nuanced understanding the potential specific and targeted interventions could provide. However, if land is not included, it could suggest that land is not a prioritised economic sector either in terms of emissions profile, or preference for alternate routes for climate mitigation from that country. Very generalised, or even absent levers for the land sector suggests limited drive to incorporate the land sector into the national strategy, potentially due to insufficient data, lack of technical expertise, doubt about effective implementation capacity, or lower prioritisation in policy frameworks.

Divergent Terminology May Reflect Different Strategic Phases or Priorities

The recurring themes of "General Public Use," "Explore a Low Carbon Future," and "Planning and/or Decision Making" across various calculators reflect a global recognition of the importance of public engagement and strategic planning in climate action (Garnett and Cooper, 2014; Reed *et al.*, 2017). Despite economic differences, these common themes suggest a shared understanding that effective climate action requires not only educating the public but also equipping decision-makers with the necessary tools for sustainable future planning. However, the specific terminology used in these calculators, such as "Net Zero," "Decarbonisation," and "Explore a Low Carbon Future," varies across countries, potentially reflecting differences in strategic phases or priorities. For instance, ODA recipient countries focusing on "Net Zero" may be in an earlier phase of their climate journey (Peñasco, 2023), while those emphasising decarbonisation might be pursuing more advanced, long-term objectives (Tu *et al.*, 2021). In more developed regions, such as non-DAC listed ODA recipients and Upper Middle-Income countries, climate calculators often emphasise broader goals like "education" and "decarbonisation". In contrast, lower-income countries and those receiving ODA support tend to focus on more immediate objectives, such as achieving "Net Zero." This indicates an evolution of the climate calculator design and purpose to best fit different demographic needs (Strapasson *et al.*, 2022). The difference between "Net Zero" and "Decarbonisation" might be small, but in this context likely elucidates to different strategic priorities and phases of climate action (Das and Ghosh, 2023).

This divergence in terminology is crucial when considering the role of climate calculators in bridging gaps in the current climate action system. Variations in language can point to variances in how different countries measure and report their climate actions, which could impact interpretation of progress. For instance, due to the similarity between "Net Zero" and "Decarbonisation" as terminologies, they might be easy to conflate (Das and Ghosh, 2023), causing misunderstandings about a country's actual climate objectives and progress. However, for climate calculators to provide

precise and equitable assessments, they must account for these differences in terminology and the underlying priorities they reflect. Understanding why certain terms are preferred in different contexts can shed light on each nation's specific strategies, helping to align global climate efforts and ensure that all countries can effectively work towards net-zero emissions (Moore *et al.*, 2021).

Moreover, the concept of "net zero" is inherently linked to the notion of balancing emissions with removals or sinks, which differs from "decarbonisation," a term that focuses exclusively on reducing emissions (Das and Ghosh, 2023). This distinction suggests that when a country prioritises "net zero," its policymakers might already be attuned to the broader necessity of enhancing carbon sinks alongside reducing emissions (Richter *et al.*, 2021). In contrast, a focus on "decarbonisation" might indicate a narrower scope centred only on cutting emissions, without an explicit emphasis on enhancing sinks. The concept of conditionality is vital in this context (Richter *et al.*, 2021). Even though there is a recognised difference between decarbonisation and net zero commitments, they are often used interchangeably, or underneath the same umbrella concept (Richter *et al.*, 2021; Das and Ghosh, 2023), making it difficult to draw conclusions from the results with high confidence. Despite this, it is still important to note that "Net Zero" commitments, without explicit timelines, conditions, or alignment with broader sustainability goals, can be ambiguous and potentially meaningless (Fankhauser *et al.*, 2021). The absence of a clear timeline or stated conditions undermines the effectiveness and credibility of these commitments, as it leaves the actual timeline for achieving net-zero emissions open-ended (Fankhauser *et al.*, 2021; Allen *et al.*, 2022). Analysing the presence or absence of conditionality in these commitments is crucial to understanding whether countries are merely setting aspirational goals or committing to concrete, time-bound actions will be key to assessing the true impact of their climate strategies. Consequently, while the results from current analyses provide valuable insights, they also highlight the need for a deeper exploration of how terminological differences, policy focus, and conditionality affect the global climate effort, with this potential difference in focus underscoring the need for further research to understand how these terminologies influence national strategies and their effectiveness.

Variation in Lever Input Formats Reflects Different UI Preferences

The split between calculators using grouped levers (45%) and ungrouped (55%) highlights the influence of user interface (UI) preference. This distinction in formatting can significantly impact how users interact with and interpret information, ultimately affecting the calculators' usability and effectiveness (Abu-Salma *et al.*, 2017; Wong *et al.*, 2020). The trend where Least Developed, Lower Middle Income, and most Upper Middle-Income countries list their levers individually, while non-DAC listed ODA recipient countries group their levers, suggests a potential link between a country's economic status and its approach to UI design. This may reflect varying levels of technological development, user preference, or resources available for tool design, with developed countries potentially favouring a holistic presentation of data, while less developed countries may opt for simplicity due to resource constraints (Zhai *et al.*, 2020).

The decision to leave levers ungrouped in climate calculators could stem from several plausible explanations, each with varying degrees of likelihood and implications. One possibility is that grouping levers introduces unnecessary complexity, particularly in scenarios where the added detail does not significantly enhance the tool's accuracy or utility (Zhai *et al.*, 2020; Richardson, 2022). In this case, simplifying the model by keeping levers ungrouped may be seen as a practical choice, particularly in contexts where users prioritise ease of use over granularity (Abu-Salma *et al.*, 2017). This approach might be more common in tools used by countries receiving Official Development Assistance (ODA), where resources for detailed modelling may be limited, and the primary goal is to provide broadly applicable insights rather than highly specific data.

Another possibility is that there is minimal evidence or practical benefit supporting the need for lever grouping. In this scenario, the decision not to group levers may reflect a lack of clear research or case studies demonstrating that grouped levers lead to more effective or actionable insights. For ODA recipients, this might be particularly relevant if the implementation of grouped levers does not align well with their specific economic or environmental contexts. Additionally, the difficulty of grouping levers, or a lack of awareness about the importance of such grouping, could play a role. Grouping levers requires a deep understanding of how different factors interact, which may be challenging without sufficient data or expertise (Wong-Parodi *et al.*, 2020). For countries with limited technical capacity or access to comprehensive datasets, the effort to group levers might outweigh the perceived benefits, leading to a preference for simpler, ungrouped inputs (Richardson, 2020). This decision, however, could undermine the calculator's effectiveness by overlooking potential synergies or conflicts between related variables, which are crucial for crafting well-rounded climate strategies.

Critically, the choice to group or ungroup levers in climate calculators is significant because it influences the accuracy and applicability of the resulting data. For countries not receiving ODA, where resources and expertise may be more readily available, grouped levers can offer more nuanced insights that better inform complex policy decisions. Conversely, the absence of grouped levers in ODA-recipient calculators could limit their effectiveness, potentially leading to oversimplified policies that fail to address the interconnected nature of climate-related challenges. Understanding the rationale behind these decisions is crucial for evaluating the robustness of climate calculators and ensuring that they serve as effective tools for all users, regardless of their economic status.

Land Use is a Common Focus but Lacks Consistent Representation Across Calculator Components

The frequent occurrence of "Land Use" as the most common Lever Group across three calculators highlights a shared recognition of its critical role in climate strategies. However, the fact that there are 34 unique lever names, with only eight levers appearing in more than one calculator, reveals considerable diversity in how different tools address and categorise issues within the land sector. The variability in the types and frequency of land-based graphs across calculators further suggests that countries prioritise different aspects of land use and emissions according to their unique national contexts. Including land sector outcomes in the outputs of the calculator, whether through graphs or tables, enhances the transparency of the pathways being explored for emissions reduction (Mabhaudhi *et al.*, 2023). By clearly presenting land-based data, these tools can improve public and stakeholder engagement, fostering trust in the decision support tools and the policies they inform (Strapasson *et al.*, 2017; Mabhaudhi *et al.*, 2023). Conversely, the absence of land sector data in the outputs may indicate gaps in monitoring and reporting capabilities or a lower emphasis on communicating the role of land in climate action plans. This omission can hinder the demonstration of the benefits of land-based measures, potentially reducing support and investment in these areas (Yates *et al.*, 2018). It could also suggest an attempt to avoid visualising less favourable outcomes, aligning the response more closely with political agendas rather than scientific accuracy (den Elzen *et al.*, 2013). This raises the question of whether such capacity for customisation, resulting in such omissions, has in practice limited calculator capacity to support land-sector decision making.

The inclusion of specific, unique graphs in the calculators from Bangladesh and South Korea highlights the critical role of tailoring climate tools to address the unique challenges and priorities of each country (Hoque *et al.*, 2020). For Bangladesh, the emphasis on graphs related to food security and demand reflects its pressing concerns around the intersection of food production and climate resilience, driven by the country's vulnerability to climate-induced food insecurity (Hoque *et al.*, 2020; Hossain *et al.*, 2020). Similarly, South Korea's focus on land use maps indicates a strong commitment to spatial planning and geographic analysis, crucial for managing land resources and implementing

effective climate policies. By customising these tools to reflect national priorities, countries can ensure that their climate strategies are not only more relevant but also more effective in addressing the specific issues they face. However, this variation complicates efforts to establish a standardised framework for climate modelling, underscoring the need for more unified approaches to ensure consistency and comprehensiveness in tackling land-related challenges (Mabhaudhi *et al.*, 2023).

Food and Diet Continue to Present Notable Gaps

The absence of food-related elements, and arguably behavioural changes in general, in most climate calculators is both notable and significant, highlighting a critical gap in how these tools assess and address climate change. The fact that only Bangladesh's climate calculator includes food, and only in the outputs rather than the inputs, suggests a widespread oversight in considering the crucial role of food systems in both contributing to and mitigating climate change. This omission is particularly concerning given the integral connection between food security and climate resilience, especially within the land sector (Fujimori *et al.*, 2022; Azmi *et al.*, 2023). By integrating food-related outputs, Bangladesh's approach underscores the importance of incorporating food systems into climate models to develop more holistic and effective climate strategies (Hoassain *et al.*, 2020). This gap points to a need for more inclusive tools that fully encompass the various factors influencing climate outcomes, particularly in regions where food production and security are closely linked to climate adaptation efforts.

Whilst this omission is reflected in chapter 4 and 5, the IPCC has highlighted the critical role of food systems in achieving sustainable land-use management and enhancing food security (IPCC, 2023), suggesting a prime opportunity for climate calculators to improve as DSTs. Factors such as food loss and waste reduction and dietary choices can significantly influence GHG emissions. Yet, despite this recognition, food remains largely excluded from climate calculators, suggesting a broader gap in the holistic assessment of climate actions. Several factors may contribute to this omission, including the complexity of food systems, which involve a wide range of activities from production to consumption, making them challenging to quantify within climate models (Crippa *et al.*, 2021; Durán-Díaz, 2023). Additionally, institutional silos might result in food policies being treated separately from climate policies, further contributing to their exclusion from climate calculators.

The consistent absence of food systems from most climate calculators likely reflects deeper structural issues within the traditional focus of these tools. Historically, climate calculators have concentrated on energy and industrial sectors, which offer more straightforward emission metrics (Strapasson *et al.*, 2020). In contrast, food systems, with their intricate social, economic, and environmental dimensions, do not easily fit into the conventional frameworks used by these calculators. This lack of integration risks underestimating the potential contributions of food system interventions to climate mitigation and adaptation efforts. Initiatives such as improving the diversity of food sources in public procurement, running awareness campaigns, and offering financial incentives can influence food demand and contribute to lower GHG emissions (Shabir *et al.*, 2023).

The relevance of this omission to the second aim of the thesis is significant. Understanding the role of climate calculators in bridging gaps within the current system is closely tied to how comprehensively these tools assess different sectors. The exclusion of food systems from climate calculators represents a substantial gap that must be addressed to achieve a more accurate and holistic understanding of land sector dynamics. Since food production and consumption are intrinsically linked to land use, their inclusion would provide a more complete and accurate view of how land sector activities impact climate change. Addressing this gap is essential for developing climate calculators that truly reflect the complexity of land sector affairs and contribute to more effective climate action.

6.2. Validation Study: Kenya's National Climate Calculator (KCERT)

In the previous chapter the terminology used in climate calculators can reflect alignment with national climate policies and commitments was explored. This alignment is crucial, as it indicates whether these tools are likely to support and reinforce existing strategies or goals within a country. Furthermore, this alignment can extend to international frameworks like the Paris Agreement, suggesting how countries might integrate global standards into their national context. When the terminology aligns, it reduces confusion, making it easier to compare and integrate data, align strategies, and ensure that calculators effectively inform decision-making (Gregory *et al.*, 2019; Pal *et al.*, 2020). This assumption is based on the idea that a shared language fosters clearer communication and better collaboration between different actors working toward similar goals. It assumes that users of climate calculators are likely familiar with the language of NDCs and academic literature. The language used in these calculators also serves as a marker of stakeholder engagement (Barletti *et al.*, 2020). When calculators incorporate inclusive and locally relevant terminology, it suggests that diverse stakeholders, including local communities and indigenous groups, have been considered in the policy-making process (Prell *et al.*, 2016). This is essential for ensuring that adaptation strategies are tailored to local needs and conditions, making the calculators more applicable and useful in specific national or regional contexts.

When it comes to calculator terminology and use, there are two angles that need to be considered. The first is that specific terms used in NDCs and academic papers have precise meanings that are critical for accurately modelling and assessing land sector activities. Therefore, calculators must use these terms to maintain precision and avoid misinterpretation. However, this assumes that the nuances in language are important for capturing the complexity of land sector dynamics, and that any deviation from these terms could lead to oversimplification or errors in analysis (Fall and Fall, 2001; Gregory *et al.*, 2019). The second, on the flip side of the first, is that rigid adherence to the language of NDCs and academic papers could stifle innovation in how land sector issues are conceptualised and addressed. Climate calculators might need the freedom to introduce new terms or frameworks that better capture emerging challenges or opportunities (Schreyer, 2011). Calculators might need to innovate rather than conform to traditional terminology, questioning whether existing language is always the best fit for the evolving needs of climate action. The assumption that calculators need to use similar language as NDCs and academic papers is supported by the need for consistency, alignment with policy frameworks, and terminological precision (Sanz *et al.*, 2017). However, it is also challenged by the diverse user base, the need for context-specific language, and the potential benefits of innovation and flexibility in terminology (Strapasson *et al.*, 2017). Together, these two perspectives highlight the complexity of designing effective climate calculators that balance standardisation with adaptability to diverse user needs and contexts.

Given the importance of terminology and its implications for policy alignment and stakeholder engagement, there is a clear need for a validation study. A validation study is a research process used to assess the accuracy, reliability, and relevance of a specific method, tool, or model (Santos *et al.*, 2020). Conducted to ensure that the methods, tools, or data used in the research are effective and appropriate for answering the research questions, a validation study here will help confirm that the assumptions drawn from previous research is generalisable. The analysis of the climate calculators alone cannot fully answer specific questions related to the alignment of these tools with local realities and international commitments. A validation study, involving country stakeholders or representatives in discussions about the language used in their climate calculators, allows the findings from the section 6.1. to be contextualised in practice (El Akremi *et al.*, 2018). By engaging directly with stakeholders, the study will ensure that there is a shared understanding between the developers of these calculators

and their potential users, and to highlight the exact nature of terminology use, validating the findings from the cataloguing of the calculators (Grimble *et al.*, 1995). It will help to identify discrepancies between the language used in the calculators and the perceived scope of the calculators within the land sector.

Surveying an in-country team that built one of the climate calculators about their perspective on how land is included in their tool, regardless of the specific terminologies used, can provide valuable insights that address some of the challenging assumptions and help refine the original assumption. By directly engaging with the in-country team, the survey can reveal how the language and structure of the calculator were designed to meet the needs of local users (Theodorou *et al.*, 2019). This insight can help challenge the assumption that a consistent language is always necessary, showing how flexibility in terminology can enhance accessibility and effectiveness for diverse audiences. The findings from the validation study can help rephrase the original assumption to better reflect the importance of balancing standardisation with adaptability. Instead of assuming that calculators need to use language similar to that in NDCs and academic papers to be effective, the revised assumption might be that calculators should aim for alignment where appropriate but remain flexible to incorporate locally relevant terminology and frameworks that address specific national or regional needs.

Based on the survey results, recommendations can be made to ensure that climate calculators are both locally relevant and aligned with international standards where necessary. This could include strategies for integrating context-specific terms with global frameworks, ensuring that calculators remain accessible and effective across different user groups while still contributing to broader climate goals. Any discrepancies highlighted can be addressed to enhance the coherence and effectiveness of climate policies, ensuring that the calculators are not only theoretically sound but also practically relevant. By engaging stakeholders and validating the findings, this research can significantly enhance the relevance, clarity, and utility of climate calculators (Burgha and Varvasovsky, 2000; Barletti *et al.*, 2020). This approach will support countries in setting and achieving their land-based mitigation and adaptation climate targets, ultimately contributing to more effective and locally tailored climate action. A validation study that engages stakeholders to discuss the language used in climate calculators can significantly enhance the relevance, clarity, and utility of these tools (Santos *et al.*, 2020). This process will help in reconciling policy gaps and supporting countries in setting and achieving their land-based mitigation and adaptation climate targets and aligns with the iterative theory-building process of this thesis.

6.2.1. Methods

Validation Approach

A survey is an appropriate method for a validation study in this context because it allows for broad engagement, captures both quantitative and qualitative data, and efficiently tests the assumptions underlying the design and language of climate calculators (Falk *et al.*, 2023). By directly involving those who built and use the calculators, a survey can provide critical insights into whether these tools effectively meet both local and global climate objectives, leading to more informed recommendations for future improvements (Braun *et al.*, 2021). Surveys allow for engaging a wide range of stakeholders, including the in-country team that built the climate calculator, policymakers, academics, and other users (Grant *et al.*, 2005). This can help gather diverse perspectives on how land is included in the calculators, reflecting the various priorities, experiences, and challenges across different regions and sectors.

Surveys can include questions that directly address the assumptions about language usage in the calculators (Braun *et al.*, 2021). By asking participants about their perceptions of terminology alignment with NDCs, academic literature, and local contexts, the survey can reveal whether these assumptions hold true or if alternative approaches might be more effective (Falk *et al.*, 2023). Additionally, surveys can be distributed to a large number of respondents relatively quickly and efficiently, especially when compared to more resource-intensive methods like interviews or focus groups (Grant *et al.*, 2005). This scalability is particularly beneficial when seeking validation across different regions or sectors (Abdollahpouri *et al.*, 2020). Surveys can be conducted anonymously, which might encourage more honest and candid feedback from participants. This can be particularly useful for identifying discrepancies or areas where the calculator might not be fully aligned with the needs or expectations of its users (Braun *et al.*, 2021). Whilst surveys might face challenges such as limited depth in responses compared to methods like interviews, which allow for more nuanced and detailed insights, this can be overcome by designing the survey to include a mix of closed-ended and open-ended questions, allowing participants to elaborate on their answers where necessary.

Country Selection

Kenya was the calculator team that was chosen to participate in this validation study, as they had a track record of high engagement with the programme and had previously worked with the author of this thesis, so contact links were already established. This aligned well with the time limitations this survey was conducted under and helped reduce the risk of limited data collection.

The Kenyan team have a clearly defined team structure, which would increase the ease of determining if there is a correlation between the answers provided and the role type of the respondent.

The Kenyan calculator, KCERT, started development in 2019 and was published in 2022, meaning that the justifications and mechanisms in which decisions were made for the development of the calculator are both recent and also done through the most up-to-date version of the programme's guidance (KCERT, 2024).

Additionally, this guaranteed that the team being utilised for this study had definitely and deliberately incorporated the land sector into the calculator, ensuring that the land specific questions would be relevant to the work and decisions they made.

Survey Development

The first step to survey development was to clearly define the primary question the survey aimed to answer (Boateng *et al.*, 2018). In this case, the primary question focused on understanding how in-country teams perceive the inclusion of land sector issues in their climate calculators. By pinpointing

this central query, the survey was structured to gather relevant data that could either validate or challenge the initial assumptions, ultimately guiding the direction of future recommendations.

Is the assumption that the different terminologies for the land sector references different things accurate?

Do the creators of the calculators view them as different things in practice?

The survey was developed on the software Qualtrics, a robust platform that offers a wide range of tools for designing, distributing, and analysing surveys.

The survey length could not be too long, as an overly lengthy survey might dissuade recipients from responding, leading to lower response rates and potentially biased results (Barrett and Stavins, 2003). At the same time, the survey needed to be detailed enough to gather all necessary information to answer the research questions effectively. To achieve this balance, each question was carefully considered for its relevance and contribution to the overall objective. Non-essential questions were eliminated, and the remaining questions were crafted to be clear, concise, and directly tied to the research goals (Barrett and Stavins, 2003). This approach helped ensure that the survey was engaging and manageable for participants, while still providing rich data for analysis.

The main questions that needed to be covered were (Appendix D):

1. Does KCERT include “AFOLU” and/or “LULUCF” (y/n)
2. What component of AFOLU/LULUCF does it include?
3. What is the purpose the calculator was made to fulfil?
4. Was the calculator designed to help with Kenya’s NDCs?
5. Do you think that there are economic sectors that the calculator has been particularly good at supporting creating interventions to achieve Kenya’s NDCs?
6. Do you think that the calculator has specifically helped support policy (and other interventions) development within the Land Sector? (please provide examples)
7. Do you think that the calculator help facilitate what policies should be conditional vs unconditional?
8. Do you think that the calculator reflects the current Land Sector dynamic in Kenya?

Stakeholder Identification and Engagement

The survey was distributed to known members of the Kenyan calculator team and snowballed to other individuals who participated, in any capacity, with the calculator development.

Stakeholder list and the attributes of these was analysed using the tool MAPTkit (Hoare *et al.*, 2022) to reflect upon the dynamic of the stakeholder list and acknowledge any biases that this might introduce to the survey responses.

Analysis and Limitation Mitigation

By following a structured approach, the data from the semi-qualitative survey can be effectively analysed to validate assumptions and synthesise findings from previous work conducted in this thesis, providing a comprehensive understanding of stakeholder perspectives. This structured approach ensures that the survey results are not just collected but systematically examined to draw meaningful insights that align with the broader research goals.

Analysis techniques included content analysis (see section 6.1.2.) and descriptive analysis (see section 5.2.4). Content analysis is particularly useful for interpreting the open-ended responses, allowing for the identification of recurring themes, patterns, and sentiments expressed by stakeholders (Gheyle

and Jacobs, 2017). This method helps to uncover the nuanced perspectives of respondents, especially in relation to how they perceive the inclusion of land sector issues in climate calculators and the alignment of terminology with national policies and academic standards.

Descriptive analysis, on the other hand, provides a quantitative summary of the data, offering insights into the distribution of responses and identifying trends across different respondent groups (Lawless *et al.*, 2010). This technique is crucial for understanding the overall direction of the data, such as the prevalence of certain opinions or the degree of agreement among participants on key issues.

These two analysis approaches support the survey approach by combining qualitative depth with quantitative breadth. Content analysis allows for a detailed exploration of stakeholder views, while descriptive analysis offers a broader overview of the survey data. Together, they provide a comprehensive analysis framework that not only validates the assumptions underlying the research but also integrates these findings with previous work, ensuring that the conclusions drawn are robust and well-supported by the evidence.

The Methods

A validation study using Kenya as a case study offers valuable insights into the assumptions surrounding language use in the land sector within climate calculators. By focusing on a specific geographical and socio-economic context, this study can assess how well these assumptions align with real-world practices (El Akremi *et al.*, 2018). Kenya, with its diverse land uses, serves as an ideal setting to examine the effectiveness of climate calculators' methodologies in accounting for regional variations in land use practices, carbon sequestration, and socio-economic factors. While the findings may be specific to Kenya and not entirely generalisable, the study remains essential for providing empirical evidence that can either support or challenge the assumptions made in this thesis. This localised approach can highlight discrepancies and areas for improvement (Moallemi *et al.*, 2020), leading to more accurate and context-specific insights that enhance the effectiveness of climate calculators.

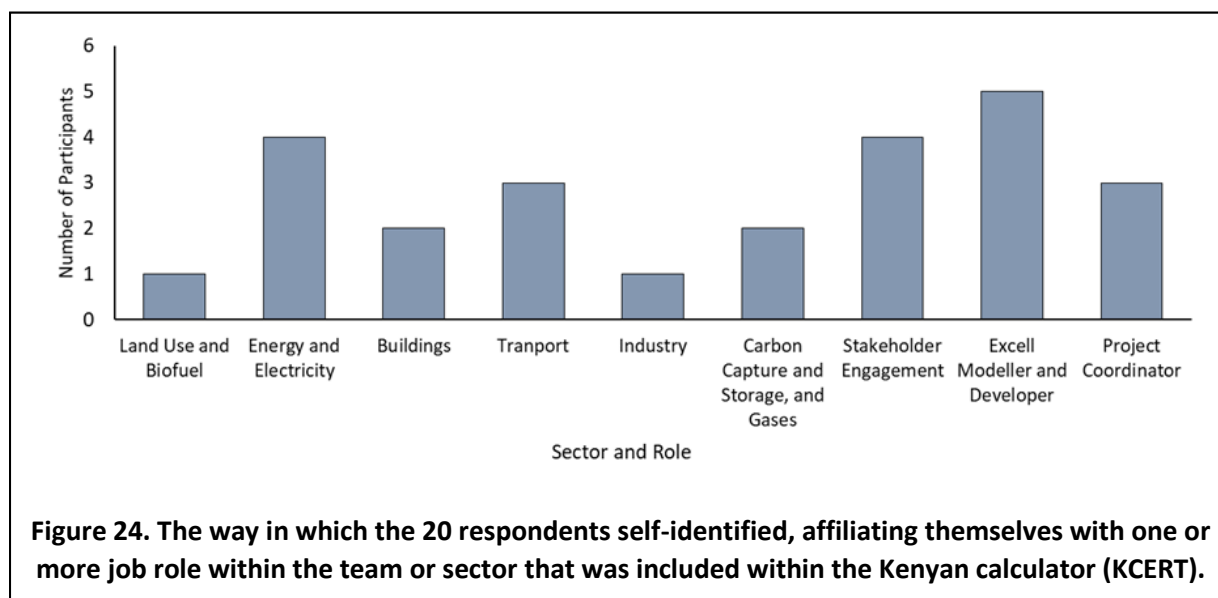
Although involving a more established calculator could have offered historical insights, the recent development of Kenya's calculator presents unique advantages. The fresh methodology and implementation ensure that the study reflects the latest standards and innovations, reducing the risk of outdated practices. Kenya's active collaboration with researchers also increases the likelihood of obtaining comprehensive and timely responses, contributing to a robust and reliable dataset (Desai, 2018). However, the study must account for potential biases introduced by focusing on a newly developed tool, as well as discrepancies in response rates across different stakeholder groups.

The demographic of the respondents was reasonably split across the different groups, although "Land Use and Biofuel" and "Industry" only had one individual. This means that while the majority of stakeholder groups are well-represented, the perspectives from these two specific sectors are limited (Hoare *et al.*, 2023). This is good because it ensures that a diverse range of insights and opinions are included in the analysis, enhancing the robustness of the findings. This can be improved by actively recruiting more participants from the underrepresented groups in future surveys, ensuring a more balanced and comprehensive representation (Hoare *et al.*, 2023). Overall, the survey still works because of the breadth of responses from other groups, providing a solid foundation for understanding the broader trends and issues within the calculator team.

6.2.2. Results

Demographic of respondents

20 individuals started the survey, although not every question got a 100% response rate. The respondents included sector leads, coordinators and different individuals from the Kenya team. The majority self-identified as “Excel modellers/developers”, part of “stakeholder engagement” or working in the “energy and electricity” sector (Figure 24).



Purpose of KCERT

47% (n=8) said the main purpose of the KCERT was to help with Kenya NDCs, 53% (n=9) said that was one of the reasons but not the main purpose.

71% (n=12) thought KCERT has, or will, help with developing any component of Kenya’s NDC. 6% (n=1) said no, and 24% (n=4) were unsure.

Some of the reasons that the participants gave for answering “yes” when offered the chance to elaborate were:

“Not sure if it was used, but i believe it has potential to support NDC policy decisions”

“it has the potenital to improve and identify new NDCs. However, I am not sure that it is in active use in developing NDCs”

While several respondents recognised the potential of the tool to support NDC policy decisions, there is uncertainty about its current active use in developing NDCs. This could be indicative of a gap between the tool’s capabilities and its actual application in policy-making processes. Other respondents noted the specific applications of the tool in areas like energy generation and industry, which are targeted for emission reductions in the NDCs. This indicates that the tool has been utilised in sector-specific contexts.

“Yes, in energy generation and in industry. Energy is one of the areas targeted for reduction of emissions in the NDCs”

“The Kcert data was used in making decision for intervention during the Kenya position in Aviation sector”

There is the idea that the tool's foundation in Excel allows for easy customisation, making it flexible for scenario analysis, especially after full adoption from stakeholders. The tool is viewed as a valuable reference for catalysing policy development and supporting conversations and actions aimed at achieving net-zero goals.

“Since it is based on Excel, it can be edited to feature various policies and predict outcomes this is crucial for scenario analysis and can inform the NDCs outcomes”

“Once it is fully adopted by the relevant stakeholders, it can be useful in calculating and reporting NDCs”

“KCERT is a good reference in catalysing policy development, and supports the conversation and actions geared towards the net-zero goal.”

These qualitative insights suggest that while there is recognition of the tool's potential and some evidence of its sector-specific applications, there is a need for broader adoption and integration into the NDC development process. Enhancing awareness, training, and stakeholder engagement could bridge the gap between potential and active use, maximising the tool's impact on policy decisions and climate goals.

KCERT influence on economic sectors

When asked “Which economic sectors has KCERT helped, or is most likely to help, in developing and supporting Kenya’s NDC?” the majority of respondents said, “Energy and Electricity” (n=15), followed by “Transport” (n=13) and “Industry” (n=11). “Land and Biofuel”, whilst being the 4th most selected, was not far behind (n=10) (Figure 25).

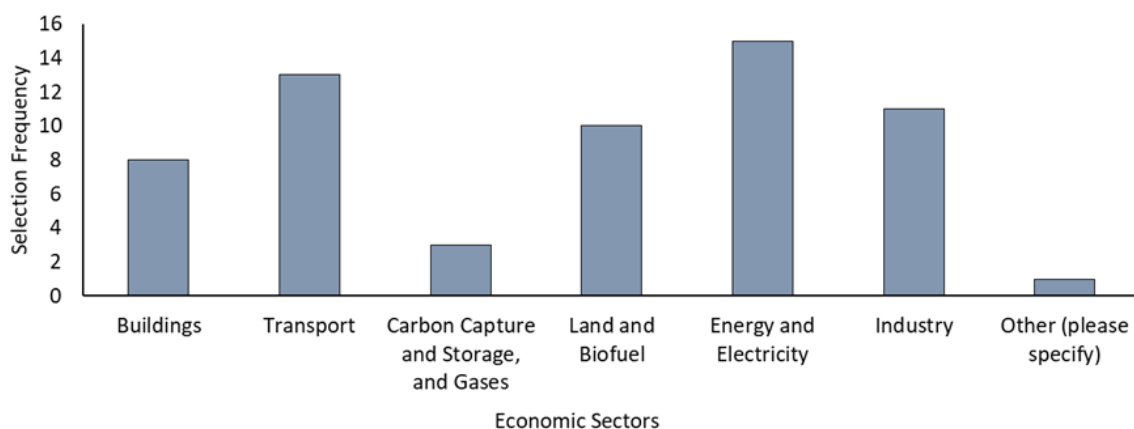


Figure 25. Selection frequency of the different economic sectors in response to the question “Which economic sectors has KCERT helped, or is most likely to help, in developing and supporting Kenya’s NDC?”

The “Other” response was answered: *“These sectors already have some activities dealing with sustainability”*.

This suggests that the sectors mentioned already have some level of infrastructure, policies, or initiatives in place aimed at sustainability. This could mean that they are more prepared and equipped to integrate KCERT's tools and recommendations into their existing frameworks, or it could mean that these sectors are already prioritized by the government and stakeholders for sustainability efforts.

KCERT influence on conditionality

Just under half the respondents (n=8) when asked about whether the Kenyan calculator has helped with differentiating between conditional and unconditional policies said “yes” (Table 20). Only 1 said “no”, whilst again just under half chose to either not to answer (n=2) or were unsure (n=6).

When asked the calculator supporting the land sector in Kenya’s NDC, again just under half said that “yes”, it has (n=8), whilst there was a slight increase in those saying “no” (n=2) and choosing not to answer (n=3) (Table 20).

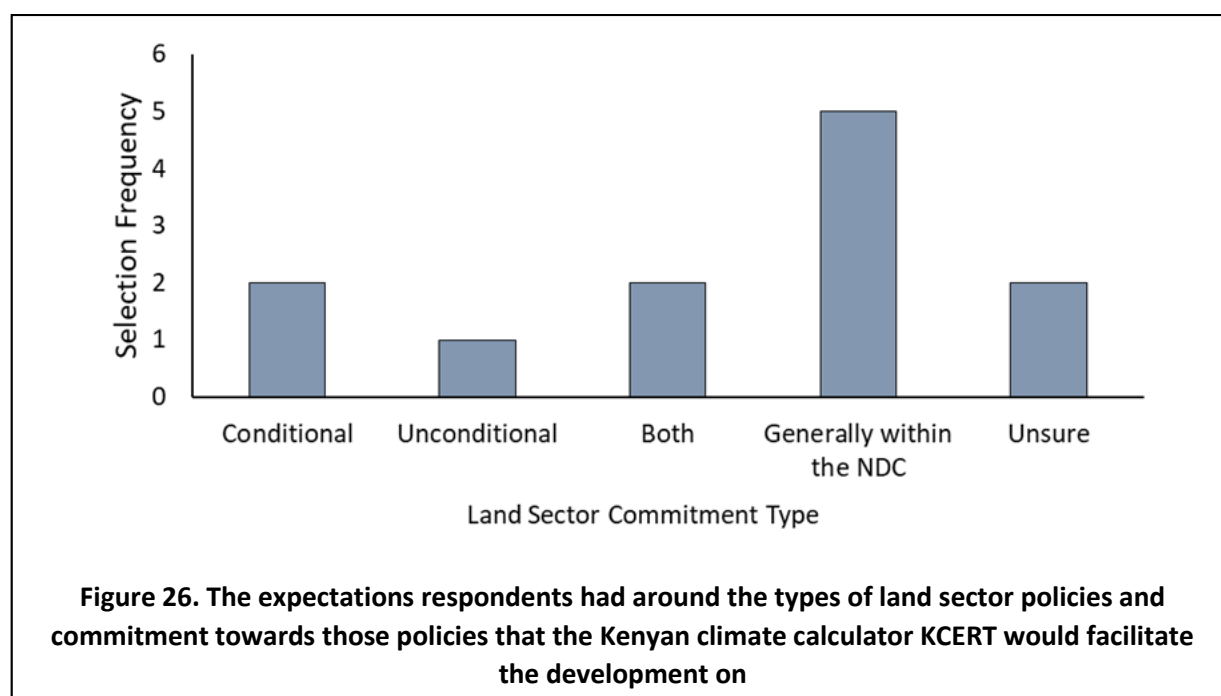
However, the respondents saying “yes” to if KCERT has help support other policies within the land sector dropped (n=4), with “no” and “unsure” responses increasing once more (n=4 and n=8 respectively) (Table 19).

Table 19. The responses to three questions around the influence the Kenyan climate calculator (KCERT) has had on supporting differentiating between conditional and unconditional policy options, as well as the support given to the land sector policies with Kenya’s NDC development, and other policy interventions.

Question	Yes	No	Unsure	Didn't Answer
Do you think KCERT has, or will, help with differentiating policies between <u>Conditional and Unconditional</u> with Kenya’s NDC?	8	1	6	2
Do you think that KCERT has, or will, specifically help developed <u>the Land sector</u> within Kenya’s NDC?	8	2	4	3
Do you think that KCERT has specifically helped support policy (and other interventions) development within the Land Sector?	4	4	8	

When asked *“Do you expect KCERT to help develop unconditional, or conditional, land sector commitments within Kenya’s NDC?”*, whilst some respondents (n=4) chose not to answer the question, the majority that did felt that the calculator would assist in some capacity (n=14), with most answering that they felt the calculator would help support the inclusion of land generally within the Kenyan NDC, rather than on land-specific conditional or unconditional targets (n=5) (Figure 23).

5 respondents felt that the calculator would be able to address land-specific conditional or unconditional targets, with 2 individuals saying “Conditional”, 2 saying “Both [conditional and unconditional]” and 1 saying only “Unconditional” (Figure 26).



Addressing land terminology use in KCERT

In order to address the assumptions held around the land sector inclusion, the participants were asked what land sector terminologies were included within the calculator.

When asked “Does KCERT include “AFOLU” (Agriculture, Forestry and Land Use), “LULUCF” (Land Use, Land Use Change and Forestry), both, or neither?”, a third of respondents (n=5) said “AFOLU” [blue], just under 2/3 said “Both” [green] (n=9) and the remaining said “LULUCF” [yellow] (n=1) (Figure 24).

If at this stage the respondent chose “neither”, then they were taken to the last question of the survey.

The three options that were chosen at this stage were “AFOLU [only]” (blue), “Both” (green) or “LULUCF [only]” (yellow). Each group were asked two following questions, with the group “Both [AFOLU and LULUCF]” having the question modified so that they could differentiate between the two, if they felt that one was included in one capacity, but not the other.

Each of these three answers led to slightly different question sets, in order to understand what components of AFOLU and/or LULUCF was included within KCERT.

For the question; “What components of AFOLU and LULUCF are included?”, “Other land uses” was the least selected answer.

There is a distinction between “Forestry (of AFOLU)” and “Forestry (of LULUCF)” to allow for respondents to differentiate between the two if they selected “Both” to the initial question.

For this question, “Forestry (of AFOLU)” and “Forestry (of LULUCF)” is to see if those that selected “Both” to the prior question consider there to be a difference to the concept that is ‘forestry’ within the terminology AFOLU vs LULUCF.

For the question; “Is LULUCF/AFOLU included in the inputs/outputs?” there are four categories. Those that answered that “Both” AFOLU and LULUCF are in KCERT, were able to respond whether AFOLU

and LULUCF was in the inputs/outputs of the calculator, and are differentiated through the opposing cross hatches in Figure 27.

None of the respondents said that land – in any format – was included in the outputs of KCERT (Figure 27).

The one respondent that answered “LULUCF” to the above question felt that LULUCF was only included in the inputs of the calculator.

Those that answered “AFOLU” and “Both [AFOLU and LULUCF]” felt that AFOLU and LULUCF were included within the inputs of the calculator (n=6, 2 from “AFOLU” saying AFOLU was in the inputs, 2 from “Both [AFOLU and LULUCF]” saying that AFOLU and LULUCF were in the inputs), or were in “Both [inputs and outputs]” (n=11, 3 from “AFOLU” saying AFOLU was in the both inputs and outputs, 4 from “Both [AFOLU and LULUCF]” saying that AFOLU and LULUCF were in inputs and outputs). This is potentially due to a disparity between user perceptions and the actual functionality of KCERT, indicating that while some users see comprehensive input integration, outputs related to land use are not being effectively communicated or utilised.

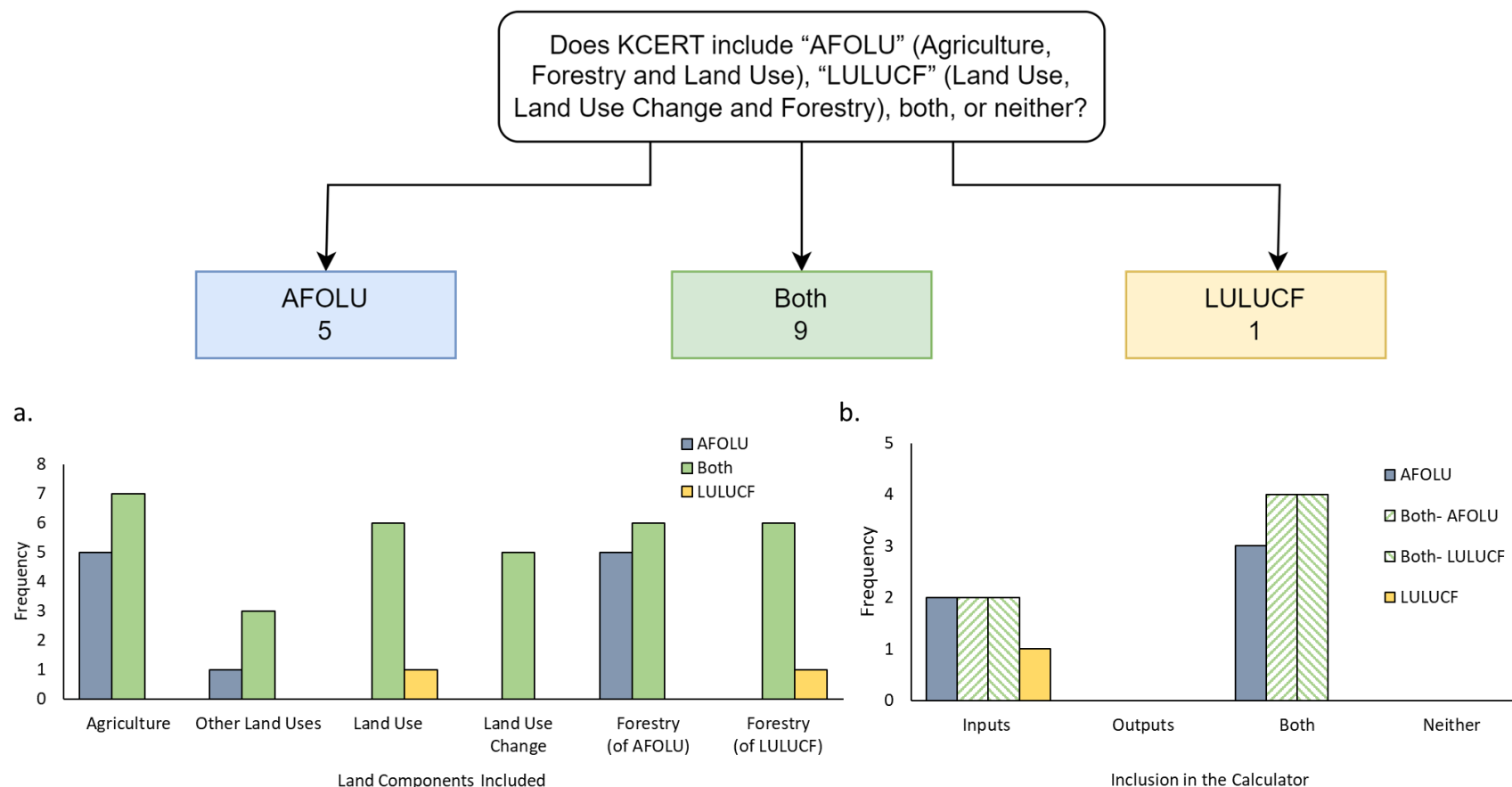


Figure 27. The breakdown of the way in which the survey respondents felt that land was included within the Kenyan calculator, KCERT. The three options that were chosen at this stage were “AFOLU [only]” (blue), “Both” (green) or “LULUCF [only]” (yellow). Each group were asked two following questions, with the group “Both [AFOLU and LULUCF]” having the question modified so that they could differentiate between the two, if they felt that one was included in one capacity, but not the other. Figure 24a. shows what land components the respondents feel are included within KCERT, breaking down the components of AFOLU and LULUCF respectively. Figure 24b. shows what parts of KCERT the respondents felt that AFOLU, LULUCF or Both were included in; Inputs, Outputs or Both [inputs and outputs].

The last question of the survey investigated how accurately the respondents felt KCERT reflected the Kenyan land sector. The respondents were given 5 options: “Highly Accurate”, “Quite Accurate”, “Somewhat Accurate”, “Minimally Accurate” and “Not at all Accurate”. None of the respondents selected the final two options, and most (n=7) responded “Quite Accurate” and “Somewhat Accurate” (n=5).

When asked to elaborate on why they answered the way they did, most cited that data availability was a significant limiting factor. This is interesting and important because it highlights the critical role that access to accurate and comprehensive data plays in developing and supporting effective sustainability initiatives. Without sufficient data, it becomes challenging to accurately measure, analyse, and implement strategies for reducing emissions and achieving NDC goals.

6.2.3. Discussion

This validation study critically examines the assumptions regarding language use in the land sector as presented in Chapters 5 and 6. It was presupposed that the calculators should mirror the NDCs terminology to accurately reflect its landscape and function as an effective decision-support tool. However, this assumption may not hold, given that the tools are designed and operated by humans, who may achieve successful outcomes without adhering to granular language distinctions. For example, the analysis reveals that certain concepts, although not explicitly named, were effectively captured within the calculators (Schreyer, 2011). The assumption that terminologies must be explicitly used to be included is challenged; for instance, the absence of the term "LULUCF" does not necessarily imply its exclusion. Instead, the use of constituent terms like "forestry" or "agriculture" might implicitly encompass broader categories like AFOLU or LULUCF (Roe *et al.*, 2019). The perception of inclusion by those who develop and use the calculators—if they believe these broader categories are reflected through their parts—supports the notion of their inclusion (Bremer *et al.*, 2019). Understanding developers' perspectives on how land is integrated into the calculators is crucial to assess whether these tools align with the intended representation of the land sector, ultimately determining their effectiveness in reflecting the national land sector landscape.

KCERT Aligns with NDCs, but stronger Land Sector Integration is Key for Balanced Climate Action

The survey shows that respondents come from a diverse range of sectors, with most identifying as "Excel modellers/developers," "stakeholder engagement," or "energy and electricity" professionals. However, when it comes to the land sector specifically, the responses indicate a mixed perception of KCERT's impact. While some respondents acknowledge the calculator's potential to support land-related policies, others are unsure or do not see its effectiveness in this area. The survey results provide insights into how well the KCERT (Kenya Climate Emissions Reduction Tool) aligns with Kenya's Nationally Determined Contributions (NDCs) and local land-use practices. A significant portion of respondents (47%) indicated that the main purpose of KCERT is to assist with Kenya's NDCs, while 71% believe that it has or will contribute to developing components of the NDCs. This suggests a general alignment with national climate policies, though the uncertainty expressed by some respondents (24% unsure, 6% saying "no") reveals a gap between the calculator's intended use and its perceived effectiveness. Most respondents believe the calculator has or will contribute to developing specific NDC components, highlighting the alignment between the KCERT and Kenya's NDCs, directly addressing the assumption that the calculator's language and functionality should align with national climate goals and practices. By reporting that a significant portion of respondents believe the tool contributes to the NDCs, the assumption that KCERT is intended to support national climate commitments can be confirmed. This suggests that the calculator must be adaptable to Kenya's evolving climate policy needs, ensuring it remains a valuable resource for policymakers (Strapasson *et al.*, 2020).

However, there is a notable perception that KCERT's impact is slightly more pronounced in sectors other than land use, such as energy, industry, or aviation ("Energy and Electricity" (n=15), "Transport" (n=13), "Industry" (n=11) and "Land and Biofuel" (n=10)). This indicates a potential gap in its application within the land sector. While this versatility is beneficial, integrating more robust land-sector-specific features could enhance its comprehensive support across all NDC areas. The land sector is often a more fragmented sector, involving millions of farmers, agricultural finance, forest law, land tenure issues, zoning schemes, cultural issues, etc. This increases the complexity to identify policy strategies via system dynamics models, whereas industrial sectors are more clearly identified with trends. As such, it may not just be an issue of the calculator itself but the specificity of this complex sector, even though the other sectors are also complex. This emphasis on energy aligns with

historical national policy and the design focus of earlier calculators like the UK's (My2050, 2011; Gross *et al.*, 2018). However, there is a clear need to diversify the calculator's outputs to provide meaningful insights into other critical sectors, particularly land use. Enhancing the calculator's capabilities to address AFOLU and LULUCF comprehensively will allow for more balanced NDCs that consider a broader range of environmental impacts (Fyson *et al.*, 2019; Luo *et al.*, 2024). This diversification is essential for a holistic approach to climate action, ensuring that all significant sectors are addressed in national policy planning. Acknowledging the strengths and limitations of the current calculators, this chapter advocates for improvements to create more versatile tools that reflect the diverse needs of national climate strategies, ultimately leading to more effective NDCs. Overall, KCERT's demonstrated utility in multiple sectors underscores its role in facilitating strategic decision-making and its continued importance in Kenya's climate strategy.

Improving Terminology and Output Features Will Reduce KCERT's Gaps and Ambiguities.

The confidence in the calculator for facilitation was not continued when the participants were asked if KCERT helped with conditionality within NDC development. There is a significant divide among users regarding KCERT's effectiveness in differentiating between conditional and unconditional NDC commitments, both generally and within the land sector. While some users find KCERT beneficial, others are either uncertain or do not perceive its value in this area. This divide highlights areas where KCERT is meeting user needs and areas requiring improvement (Poortinga *et al.*, 2019). Enhancing user training, improving the tool's interface to clarify these distinctions, and providing detailed documentation on using KCERT for conditional policy differentiation could address these gaps (Glaas *et al.*, 2017). Despite this divide, KCERT's demonstrated utility suggests it has the potential to become a more robust tool, fully supporting diverse users in NDC development and differentiation across various sectors, including the land sector. Conditionality was a concept that held less certainty within the participant's answers, with the majority of respondents opting to say that KCERT would help with including land within the calculator generally, rather than within a specific conditionality. This is important because the calculator usage for the land aligns reasonably well with the NDCs, it can be assumed that the calculator reflects the policy landscape well. However, if the calculators purpose is to assist with NDC development, but there is low confidence with how helpful the calculator is with determining conditionality then this is a potential gap in the calculator's utility, especially as conditionality it most prevalent in DAC listed ODA recipients, such as Kenya.

Additionally, there is a disparity in responses regarding whether KCERT includes elements of the land sector, with most saying the calculator included both LULUCF and AFOLU (n=9), then just AFOLU (n=5) and then just LULUCF (n=1). Interestingly, neither term is explicitly mentioned in KCERT, pointing to a level of individual interpretation among calculator developers regarding terminology use. The fact that only one respondent identified as an expert in the land sector suggests that the lack of expertise among other participants could affect the accuracy of their interpretations (Hoare *et al.*, 2023). However, since KCERT is designed for use by generalists and policymakers rather than specialists, all observations are valid. The consistent inclusion of forestry within both AFOLU and LULUCF frameworks highlights its significance (Luo *et al.*, 2024) but also suggests potential confusion if policies and NDCs do not specify which aspect of forestry they address (Forsell *et al.*, 2016). This ambiguity can lead to miscommunication in climate action plans. Therefore, enhancing clarity and specificity in definitions and reporting guidelines will strengthen the effectiveness of these frameworks and facilitate better communication among stakeholders (Pauw and Klein, 2020).

"Other land uses" was the least selected by those who chose (just) "AFOLU" and "Both" (AFOLU and LULUCF), indicating that forestry and agriculture respectively are the most predominant features of AFOLU. This means that when respondents consider both AFOLU (Agriculture, Forestry, and Other

Land Use) and LULUCF (Land Use, Land Use Change, and Forestry), they often see forestry as a significant and distinct component within each framework (Baumgartner, 2019). The consistent inclusion of forestry under both categories highlights its importance but also suggests a potential source of confusion if policies and NDCs do not clearly specify which aspect of forestry they are addressing (Forsell *et al.*, 2019). This ambiguity can lead to miscommunication and misunderstanding in the implementation and monitoring of climate action plans. This is interesting because it reveals the nuanced perception of forestry within different land use frameworks. While AFOLU encompasses a broader range of activities, including agriculture and other land uses, forestry remains a dominant and distinct feature. Similarly, in LULUCF, forestry is a critical component, but its role and implications might differ from its position in AFOLU (Roe *et al.*, 2021). This distinction is crucial for policymakers and stakeholders to understand and address appropriately. The current approach still works because it recognises the critical role of forestry in climate mitigation and adaptation. The inclusion of forestry in both AFOLU and LULUCF reflects its importance and ensures that it is accounted for in multiple contexts. However, enhancing clarity in definitions and reporting guidelines will strengthen the effectiveness of these frameworks and facilitate better communication and collaboration among stakeholders (Roe *et al.*, 2019; Barletti *et al.*, 2020; Luo *et al.*, 2024).

The calculator's inputs were perceived as effectively representing land-related factors; fewer respondents felt so for the outputs. This suggests a potential gap in how the calculator communicates the impact of land use parameters, despite their comprehensive consideration in the inputs (Guilhoto, 2021). Although the robust and thorough representation of land use in the inputs provides a solid foundation for accurate modelling and analysis, the outputs could be improved to better highlight and clarify the influence of these parameters (Burgman *et al.*, 2021). Enhancing the outputs with detailed breakdowns, visual aids, and clearer explanations would ensure that users can fully understand the results and make more informed decisions regarding land use in climate action planning (Cobb and Thompson, 2012). Respondents generally believe that land-related factors are well-represented in KCERT's inputs, although fewer feel this is reflected in the outputs. This suggests that while the calculator comprehensively considers various land use parameters, the results may not sufficiently highlight or communicate their impact (Forsell *et al.*, 2019). Enhancing the outputs to better reflect and communicate land use factors could include more detailed breakdowns of how these parameters influence final results, incorporating visual aids like charts or graphs, or providing clearer narratives within output summaries. Such improvements would help users better understand the results and make more informed decisions. The final survey question revealed that while respondents view KCERT as a reasonably accurate reflection of the Kenyan land sector, data availability is a significant limiting factor. This indicates that while the tool has a solid foundation, its accuracy could be improved with better data, providing a clear direction for future enhancements.

Overall

Despite the calculator analysis initially suggesting that AFOLU and LULUCF are included in a limited manner (see section 6.2.3), the respondents' feedback indicates that these components are incorporated in the calculator, aligning with national circumstances. This suggests that the calculator is more reflective of the land sector than chapter 6.1 indicates, playing a role in climate policy planning. However, the mixed responses regarding its effectiveness in addressing conditionality—an essential aspect of NDCs—suggest that while the tool is broadly successful, there may be gaps in its ability to fully support nuanced aspects of NDCs, like conditional commitments. This indicates that while the calculator is robust in its core functions, improvements may be needed to enhance its utility in more complex areas of policy development, such as conditionality. The findings suggest that while the initial hypothesis about the generalisability of the tool's success might hold in broader terms, there are

specific areas, like language consistency in addressing conditionality, that require further refinement to ensure comprehensive effectiveness across all components of NDC development.

This is especially true within the land sector context; the calculator does not directly reflect AFOLU and LULUCF within the NDC, but is included within the validation study suggests that it is not the terminology use that is inherently inconsistent, but the definition being allocated to those, pointing to inconsistencies in how terms are defined and applied. These inconsistencies might be the reason for critical omissions in key areas, such as the land sector's food systems. This suggests that the challenge may not lie in the language itself, but rather in the varying interpretations and definitions of key terms, which could undermine the tool's effectiveness in capturing all relevant aspects of the land sector.

6.3. Chapter Take Aways

The cataloguing of climate calculators and the subsequent validation study undertaken in this research were essential steps toward achieving the second aim of this thesis: "Understanding the role of climate calculators in reconciling the gaps in the current system." This objective was pursued by determining the accuracy of existing climate calculator structures in modelling the complexities of the current land sector. By systematically cataloguing the various climate calculators and conducting a thorough validation study, the research evaluated the extent to which these tools capture the intricacies of the land sector and their effectiveness in bridging the gaps in climate policy and implementation.

Sections 6.1 and 6.2 of the study highlight the complexity and variability in how climate calculators incorporate land sector elements, reflecting national priorities and the inherent challenges in standardising these tools across diverse contexts. The presence or absence of detailed land-related inputs in these calculators can be indicative of a country's strategic priorities or the difficulties faced in data collection and policy execution. For instance, when a calculator includes extensive land sector levers, it suggests that the country regards land management as a pivotal component of its climate strategy (Forsell *et al.*, 2019; Roe *et al.*, 2019). Conversely, the omission of these levers may point to either a lack of emphasis on the land sector or challenges in integrating land-related data into the national climate framework. This variability underscores that climate calculators are not merely technical tools; they also reflect the political and economic contexts that shape national climate policies.

A significant gap identified through the COP meetings is the underestimation of approximately one-third of emissions, largely due to the exclusion of food sector emissions in energy-related calculations (Bauck, 2023). This oversight indicates the need for more comprehensive climate calculators capable of fully capturing all emission sources. The treatment of food systems within these calculators is particularly concerning, as the consistent exclusion of food-related elements has significant implications for climate action. This exclusion suggests a broader issue in how these tools assess and address the interconnectedness of climate and food security, especially in regions where these links are critical (Amelung *et al.*, 2020).

Integrating food systems into climate calculators would provide a more comprehensive view of the land sector's role in climate change and enhance the effectiveness of national climate strategies (Azmi *et al.*, 2023). The ability of these calculators to accurately reflect existing systems is crucial in identifying and addressing policy gaps. When these tools effectively mirror the realities of the land sector and other emission sources, they offer valuable insights into discrepancies and areas needing policy intervention. This precision and comprehensiveness are essential for improving the alignment between climate policies and actual emission sources, ultimately leading to more effective and holistic climate action.

7. Key Informant Interviews

7.1. Introduction

Research has been conducted to evaluate the effectiveness of DSTs in shaping national policy, particularly in areas like environmental management, climate change, and energy planning (Mabhaudhi *et al.*, 2023). These tools are designed to integrate data from various sectors, enabling policymakers to forecast future scenarios and develop more resilient and sustainable strategies (Theodorou *et al.*, 2019). For example, the UK Climate Projections (UKCP) have been instrumental in informing national climate policies, illustrating the potential of DSTs to guide decision-making in complex and dynamic environments (Kendon *et al.*, 2023).

As awareness grows around the complexity of interactions between socio-cultural, economic, and biophysical system components, the sustainable management of natural resources has become an increasingly prominent focus of research (Matthies *et al.*, 2007). The role of DSTs in this context is crucial, as they provide a structured approach to understanding and addressing these multifaceted challenges. However, there is a need to further explore the specific influence these tools have had—and could have—on policy development (see chapter 3). This chapter aims to fill this gap by using key informant interviews to substantiate the research conducted so far and to specifically address the role of climate calculators in reconciling the gaps in the current system (Table 1, aim 2), with a focus on understanding how these tools have influenced policy and how they might be optimised to do so in the future (Table 1, Objective 2.2; Figure 3).

7.1.1. Overview and Research to Date

DSTs in land use planning and environmental management, such as Integrated Assessment Models (IAMs) and the Decision Support System for Agrotechnology Transfer (DSSAT), have found that these tools can be highly effective in helping countries achieve national targets related to climate change mitigation, biodiversity preservation, and agricultural sustainability (Czímber and Gálos, 2016; Jones *et al.*, 2017a; Strapasson *et al.*, 2020). For example, IAMs are valuable in understanding the long-term impacts of land management on carbon emissions and biodiversity, aiding in the formulation of policies that balance economic growth with environmental protection (Popp *et al.*, 2017; Jones *et al.*, 2017a). IAMs are instrumental in providing a comprehensive overview of potential future scenarios by integrating diverse data sources and projecting the environmental and economic outcomes of various policy choices (Jones *et al.*, 2017b; van Beek *et al.*, 2020). While they are limited in their ability to capture all local nuances and the dynamic nature of socio-economic systems, they are specialised at offering a broad framework for assessing trade-offs between different policy options (van Beek *et al.*, 2020). They have helped emphasise the importance of including local stakeholder inputs to improve the relevance and impact of these tools (van Beek *et al.*, 2020).

Similarly, DSSAT helps policymakers design agricultural strategies that account for climate variability, enhancing food security (Hoogenboom *et al.*, 2015; Jones *et al.*, 2017b). However, the capacity of these tools to help hit national targets is often limited by their complexity, particularly the integration of diverse and sometimes incompatible data sources, as well as the need for significant local customisation to reflect specific conditions and stakeholder needs (Hoogenboom *et al.*, 2015; Jones *et al.*, 2017a). DSSATs are powerful tools for simulating crop growth and yield under various scenarios (Hoogenboom *et al.*, 2015). While they are limited in their ease of use and the degree to which they require extensive data and expertise for accurate customisation, they are good at providing detailed, science-based insights into potential agricultural outcome, and have helped emphasise the

importance of data-driven decision-making in agriculture, highlighting the critical role of climate and soil conditions in determining crop productivity (Roman-Cuesta *et al.*, 2016).

Often DSTs focused on the land sector face the challenge of data integration and the need for localised adaptation. These tools often require comprehensive and high-quality data, which can be difficult to obtain consistently across different regions and sectors (Jones *et al.*, 2017b). Additionally, the effectiveness of these tools is closely linked to a country's adaptive capacity—its ability to adjust policies based on changing environmental and socio-economic conditions. Countries with robust institutions, strong governance, and a history of proactive climate policies are better positioned to leverage these tools effectively (Chan *et al.*, 2020). The challenges and advantages observed with DSTs in land use and agriculture mirror those found in tools designed for the energy sector, such as LEAP.

Studies on tools like the Long-range Energy Alternatives Planning System (LEAP) have generally found them to be highly effective in helping countries model energy demand and supply scenarios that can align with national targets for economic growth and environmental sustainability (Sadri *et al.*, 2014). LEAP, for example, has been instrumental in enabling countries to develop long-term energy strategies that take into account future energy needs, potential technology developments, and environmental goals such as reducing greenhouse gas emissions (Sadri *et al.*, 2014). These tools can simulate various policy interventions and their impacts on energy consumption, thereby allowing policymakers to make informed decisions that balance energy security with sustainability (Akpahou *et al.*, 2024). However, much like tools focusing on the land sector, effectiveness in helping countries hit national targets is often contingent on the accuracy and comprehensiveness of the input data, the assumptions made in the models, and the capacity of national institutions to implement the recommended policies.

Reliance on accurate and current data can present an increased challenge in many developing countries where data availability and quality are limited (Das and Ghosh, 2023). This links to adaptive capacity, as countries with more robust institutions and governance structures tend to be better equipped to use these tools effectively, adapting their policies in response to changing conditions (Shepsle, 2019). Furthermore, historical climate change and political factors can influence the utility of these tools, as entrenched interests, legacy infrastructures, and historical emissions patterns can all shape the feasibility and attractiveness of different policy options (Camacho, 2009; Ojo, 2024). Thus, while LEAP and similar tools are valuable for energy planning, their success often depends on broader governance, political will, and cross-sectoral integration (Sadri *et al.*, 2014; Akpahou *et al.*, 2024). Additionally, while these tools are powerful in modelling energy scenarios, they often struggle to fully integrate other economic sectors like land use, agriculture, and water, which are closely intertwined with energy policy. This lack of integration can lead to siloed decision-making that may not fully consider the trade-offs between sectors (Cobb and Thompson, 2012). While the sectors differ in specifics, the overarching issues of complexity, the need for contextualisation, and the influence of political and historical factors are common to both, underscoring the importance of a holistic and adaptive approach in using these tools for national policy development.

The sustainable management of environmental systems is increasingly complex as the interconnections between natural (ecological), economic, and human (socio-political–institutional) subsystems become more apparent (Simonovic, 1996; Matthies *et al.*, 2007). Research has evaluated how decision support tools (DSTs) facilitate cross-sectoral policy integration, particularly in combining data from sectors like agriculture, energy, and health to offer comprehensive insights for national policy. These studies generally indicate that DSTs are effective in merging diverse data sources, but they often struggle with a common challenge of local customisability. This challenge, shared by many other tools, limits their applicability in varying regional contexts.

While much of this research can be applied to current studies, there are still gaps that warrant further exploration. Specifically, these tools have not yet fully addressed the need for a comprehensive, global-level assessment, nor have they been thoroughly evaluated for their effectiveness from start to finish. It is crucial to examine their impacts quantitatively—through measurable outcomes such as emissions reduction, biodiversity preservation, and food security—and qualitatively, including user experiences, stakeholder engagement, and the adaptability of these tools in diverse contexts (Strapasson *et al.*, 2020). This examination is important because the effectiveness of tools depends not only on data accuracy but also on how relevant and usable they are perceived to be by their users. The successful implementation of policy hinges on this perceived relevance and usability. By integrating both quantitative and qualitative dimensions, we can gain a holistic understanding of how these tools function within complex, interconnected systems and optimise them to support sustainable policy development on a global scale.

7.1.2. Scope and Rationale

Key informant interviews can help with initial exploration and scoping of a study, or at the end, in a confirmatory manner (Shackelton *et al.*, 2022), providing in-depth, explanatory information on results from other research (Taylor and Blake, 2015; Shackelton *et al.*, 2022).

Key informant interviews are effective ways of achieving this because they provide direct access to the experiences, insights, and contextual knowledge of those who are deeply involved in the development and implementation of climate calculators (Bernard, 2017). Through these interviews, nuanced information that is often not captured in formal documentation or published studies can be gathered (McNamara, 2009). This method allows for the exploration of the practical challenges and successes encountered by users, the alignment of tool structures with local policies, and the rationale behind specific design choices (Bernard, 2009; Shackelton *et al.*, 2022). Engaging directly with experts elucidates on the implicit knowledge that drives the effective use of these tools, identify areas where improvements are needed, and better understand how these calculators function in diverse settings (Blake, 2015). This approach is particularly valuable for assessing the real-world applicability and impact of climate calculators, ensuring that they are not only scientifically robust but also relevant and usable in the contexts where they are needed most (for greater detail, see section 2.1.2.).

Talking to different experts in the climate calculator community, including country representatives and members of the UK supporting team, is crucial for several reasons when assessing the utility of climate calculators in bridging policy gaps in land-based commitments. Country representatives are experts who can provide detailed insights into how the climate calculators are used within their specific national contexts. They can explain how the terminologies and structures of the calculators align (or don't align) with local policies, practices, and priorities. Members of the supporting team can offer perspectives on the design, development, and intended flexibility of the calculators. They can explain the rationale behind certain terminologies and structures, which may not be fully evident in the documentation.

In terms of real-world implementation, country participants can share practical experiences, challenges, and successes in using the calculators for land-based commitments. This includes how the tools are integrated into policy-making and what barriers exist in their effective use. The UK supporting team/ key informants can provide insights into the technical aspects of the calculators, including any known issues, limitations, and potential areas for improvement based on user feedback. Engaging with experts can clarify how different terminologies are interpreted and used in various contexts. This helps ensure that the language within the calculators is universally understood and applied correctly.

Key Informant:

Someone who can provide detailed accounts/has long lasting knowledge of the calculator project. They are not affiliated exclusively to one of the calculators in the programme. They should be able to provide an opinion and a critical view on the programme as a whole, with the ability to discuss the original ideology behind the programme.

Country Calculator Participant:

Someone who can give a detailed snapshot of the calculator world at the time of their country's calculator development. Whilst they might have detailed knowledge of the calculator programme, they are also primarily affiliated to one country's calculator development. They are part of the calculator programme world because of their work within that country's climate calculator team.

Experts play a crucial role in providing feedback on the relevance and practicality of the measures included in climate calculators (Shackelton *et al.*, 2022). This is especially true for land use and management practices, which are highly localised and can vary significantly depending on regional conditions, socio-economic factors, and cultural practices (Barletti *et al.*, 2020). This input helps align the tools with real-world conditions and policy needs. Therefore, the expertise of those who understand these nuances is essential for creating accurate and effective climate calculators. Furthermore, the land sector's complexity, especially in relation to food systems and diet, is often underrepresented in climate models (Forsell *et al.*, 2019). This can lead to gaps in policy and action, which expert feedback can help to address, ensuring a more comprehensive understanding of the land sector's role in emissions and climate change mitigation. Engaging with experts also provides valuable real-world case studies and examples of how these calculators have been used to bridge policy gaps, offering concrete evidence of their utility and impact (Reed *et al.*, 2018). This practical application highlights their effectiveness in informing and shaping policy decisions, particularly within the land sector. By comparing expert insights with findings from this research, we can better understand where the calculators excel and where they may fall short, allowing for targeted improvements.

Talking to a diverse group of experts can help develop a holistic understanding of how different sectors and policies are integrated within the climate calculators (Stringer *et al.*, 2006). This can reveal synergies and conflicts that document analysis might miss. Engaging with experts from different disciplines (e.g., environmental science, economics, policy analysis) can provide a richer, more interdisciplinary perspective on the challenges and opportunities of using the calculators. Additionally, there could be different nuances to uncover depending on the timeframe in which they were part of the programme; whether they were part of early or more recent stages of development. Engaging with experts in the climate calculator community is essential for gaining a comprehensive understanding of the utility of these tools in bridging policy gaps related to land-based commitments. This approach helps clarify terminologies, align policies with practical realities, and gather real-world feedback that scoping reviews and document analysis cannot provide. By alleviating uncertainties and providing in-depth insights, expert engagement ensures that the calculators are effectively designed and used to meet national and international climate goals.

7.2. Methods

For key informant interviews, whilst they can appear informal, interviews that are presented with specific questions, a clear understanding of what is being sought, and an understanding of the individuals being interviewed, can capture information that cannot otherwise be obtained (Taylor and Blake, 2015). The technique for conducting the interviews is informed by interviewee's location; telephone interviews can be the least restrictive in terms of access but limits personable interaction between interviewer and interviewee (Taylor and Blake, 2015). In person meetings were not possible for this research; not only were the interviewees located in different areas globally, but COVID-19 placed restrictions on what travel, even within the UK, was feasible. As such, it was deemed appropriate for the interviews to be conducted in-person when possible and otherwise through video calls, which provide many of the same benefits of in-person that can be lost over the phone (Taylor and Blake, 2015).

7.2.1. Stakeholder Identification

Selecting relevant stakeholders for participatory processes can be challenging (Prell *et al.*, 2009). Before stakeholder identification, it is necessary to determine the problem or issue at hand that requires the study (Prell *et al.*, 2009); without a clear direction in this regard, the ambiguity around whom should be involved, and who is the most appropriate at identifying relevant issues, increases (Stringer *et al.*, 2006).

The three key techniques that this research further expanded upon is the use of expert identification, purposive sampling and snowball sampling.

Throughout project development, identification of stakeholders is to be expected; often the ones that are most well-known are the 'loudest' or the respective experts in that field or group. Identification of experts is a commonly used starting point for developing the full list of stakeholders (Burgman, 2014). By engaging with these experts in semi-structured interviews allows for the co-development of the stakeholder engagement process, as well as the subsequent identification of other stakeholders through the snowballing technique. Much like Prell *et al.* (2009), identified over 200 relevant organisations and groups of individuals to be stakeholders and then successfully snowballed other potential interviewees to gather their comprehensive list of stakeholders, this research used a combination of the above three techniques.

Expert identification, purposive sampling, and snowballing are complementary techniques (Naderifar *et al.*, 2017; Colson and Cooke, 2018). Expert identification involves consulting with individuals who have extensive knowledge of the area being studied; experts can provide valuable insights and recommendations on potential key informants, ensuring that the selection process starts with credible and well-informed choices (Colson and Cooke, 2018). This method leverages the expertise and networks of well-established individuals, which can enhance the reliability and relevance of the informants identified (Burgman, 2014).

Purposive sampling is a nonprobability technique ideal for research with limited time and resources (Etikan *et al.*, 2016). For this, participants are selected based on specific characteristics and qualities that align with the research objectives, ensuring that the selected stakeholders possess the necessary experience, knowledge, and perspectives relevant to the research topic. This requires the type of information that's needed to be identified first, and then for the qualities the interviewee would need to be defined next (Tongco, 2007). Whilst this method allows for a focused approach, the diversity and depth of information are prioritised over representativeness. The primary advantage of purposive sampling is its ability to yield rich, detailed data from highly relevant participants, though it can be limited by the researcher's subjective criteria and potential biases in selecting participants.

Snowball sampling is a complementary method to these as it uses the initial informants to identify further potential participants through their networks (Atkinson and Flint, 2001). After interviewing the first set of key informants identified through expert identification and purposive sampling, researchers ask these informants to recommend others who might also provide valuable insights. Snowball sampling helps in expanding the pool of informants by tapping into the social networks of the initial participants. This surveying approach, often used in healthcare studies, can be used to access vulnerable, minority or hard to reach populations (Naderifar *et al.*, 2017), and ensures that the sample grows in a manner that is naturally connected and contextually relevant (Atkinson and Flint). It may introduce biases, as the network connections may lead to a homogenous group of participants with similar perspectives, but this can be minimised by combining these three techniques. Expert identification provides a solid, knowledgeable starting point; purposive sampling ensures that participants are highly relevant to the research objectives; and snowball sampling expands the pool and diversity of informants in an organic manner. This combination enhances the breadth and depth of the data collected, ensuring a more comprehensive understanding of the research topic.

7.2.2. Question Design and Conduct

There are several routes for effective research question development (McNamara, 2009) and should be composed of: primarily open-ended questions, to allow interviewees to choose their own terminology; neutrally worded questions, avoiding emotive language; and questions that are clear and concise- if there are multiple parts to a question, asking them separately will keep the logical flow clearer (Turner, 2010). It is also up to the interviewer to ensure that questions during the interview are delivered in a way that keep the interviewee on track and promote focused responses (Creswell, 2007); this may come in the form of follow up questions if the response went off topic, or delivering the questions differently depending on the context of previous answers (Creswell, 2007; Turner, 2010).

Off the back of the other results chapters, there are several areas that the interviews need to cover. This includes questions around the climate calculator and policy development, the utility of the calculator around land sector support, and understanding how this links into the synthesis of ideas from chapters 5, 6 and 7.

Questions include (Appendix E);

- Has the programme helped with policy making?
- How has the calculator developed since inception (does this reflect the development of modern thinking around policies and the calculator use?)
- What role does land play within the calculator?
- What themes arise when talking about the utility of the calculator?
- Does the language that the interviewees use reflect the language use in the rest of the thesis?

The order of the questions, as well as the phrasing, was designed to maintain neutrality surrounding the topic and elicit more honest answers from participants (DeJonckheere and Vaughn, 2019). There is a risk with standardised questionnaires and structured interviews of limited depth; practicing note taking during the interview and asking clarifying questions is vital to achieving as much understanding and data from each interview as possible (Bernard, 2017). In addition to this, it has been shown conversational interviewing can produce more accurate data (Taylor and Blake, 2015). Therefore, time will be set aside at the start of each interview, dedicated for questions about anything the interviewee wanted to ask. Additionally, interviewees were not rushed during open ended questions and encouraged to elaborate on answers if they wanted to.

The interviews were designed to be conducted either in person or online, through the platform Teams. In person interviews would be recorded via a Dictaphone, whilst interviews conducted through Teams would be recorded using the Teams software. After completing the interview, the recordings would be transcribed and analysed through Nvivo (Nvivo, 2012).

7.2.3. Analysis and Limitation Mitigation

Nvivo

NVivo was used to analyse the informant interviews involving several steps. First, transcriptions of the interviews were imported into NVivo, allowing for efficient organisation and management of qualitative data. NVivo's coding features were used to tag segments of text with codes that represented different themes or concepts. NVivo's search and query tools helped identify patterns and relationships within the data (Dhakal, 2022). Thematic analysis in NVivo involves identifying, analysing, and reporting patterns (themes) within the catalogued data. The codes can be reviewed and refined to develop a detailed thematic map. This process is iterative and allowed deep engagement with the data (Dhakal, 2022).

Thematic Analysis

Thematic analysis is conducted by systematically identifying and analysing patterns within qualitative data (Clarke and Braun, 2017). This process begins with familiarisation of the data, then generation of codes to categorise relevant pieces of information. These codes are organised into broader themes by collating similar codes and examining their relationships. The themes are then reviewed and refined to ensure they accurately represent the data, followed by defining and naming each theme. These findings are interpreted in relation to the research questions and objectives, providing a coherent narrative that reflects the underlying patterns in the data (Clarke and Braun, 2017).

Content analysis

Content analysis (also see section 6.1.2) can be approached through either inductive or deductive coding (Elo and Kyngäs, 2008). Inductive coding involves developing codes and categories directly from the data without preconceived categories, making it data-driven (Elo and Kyngäs, 2008). Deductive coding starts with a predefined set of codes based on the existing work developed within this thesis (Elo and Kyngäs, 2008). Inductive coding is beneficial for discovering new insights and themes but can be more time-consuming and less focused. Deductive coding is efficient and aligned with existing frameworks but may overlook novel insights. To balance this, a hybrid approach was used, starting with a set of predefined codes and remaining open to new codes that emerge from the data (Elo and Kyngäs, 2008; Bardus *et al.*, 2016). This combination increased the likelihood of comprehensive coverage of the data while allowing for the discovery of unexpected themes (Table 18).

Table 18. Deductive codes that the subsets that were used within Nvivo

Purpose	Users	Sectors	Policy Making
Education	Policy Makers	Design	Generally
Dialogue	Government officials		
Policy creation	Schools		
	Universities	Importance	In the land sector
	Researchers		
		Land	

Importance Weighting

For questions regarding the purpose and users of the calculators, the frequency of the different purposes and users that the interviews mentioned was counted (Total References), as well as the number of interviews the different purposes and users were mentioned in (Number of Interviews) (see section 7.3.2, Table 19 and section 7.3.3., Table 20). For these data sets, two importance weightings were developed for the interviews (Gan *et al.*, 2017; Lowe *et al.*, 2018).

First, the Importance per Interviewee. This was calculated by dividing Total References (across all the interviews) by Number of Interviews (that mentioned each purpose or user type). This was calculated like this in order to understand the onus each interviewee that mentioned the purpose or user type placed on the different types. For instance, ‘user type A’ could have been mentioned a total of 9 times across all interviews (9 Total References), but the analysis of this would be different if ‘user type A’ was mentioned by just one participant, or by 9 participants (1 or 9 Number of Interviews). The Importance per Interviewee weighting helps differentiate between the two.

Secondly, the Importance across Interviews. This was calculated using the following formula:

$$\left(\frac{\frac{\text{Number of Interviews}}{\text{Total References}}}{(\text{SUM}(\text{Number of Interviews}) + \text{SUM}(\text{Total Reference}))} \right) * 100$$

This was calculated like this in order to understand the overall onus placed on the purpose or user type. For instance, “purpose type A” might have been mentioned in 2 interviews, a total of 8 times, giving it an Importance per Interviewee weighting of 4.0. “Purpose type B” might have been mentioned in 9 interviews, a total of 29 times, giving it and Importance per Interviewee weighting of 3.2. Looking at these, it would appear that “purpose type A” holds more significance than “purpose type B”, but this does not account for the increased number of interviewees that referenced it, nor that there was a significant larger number of mentions overall. Using the Importance across Interviews weighting formula, “purpose type A” has a weighting of 6.2 and “purpose type B” has a weighting of 23.2, helping better reflect the onus placed on the different purpose or user types across number of interviewee and total mentions.

The benefits of these two methods are that they provide a nuanced understanding of the significance placed on different purposes and user types by both individual interviewees and across the entire interview sample (Gan *et al.*, 2017). The Importance per Interviewee weighting helps highlight how much emphasis each interviewee places on a particular purpose or user type, allowing for the identification of strongly held views even if they are only expressed by a few participants. Meanwhile, the Importance across Interviews weighting gives a broader perspective on the overall significance of a purpose or user type, taking into account the frequency of mentions across all interviews and providing a more comprehensive view of the data.

The drawbacks of these two methods are that they may introduce complexity in interpretation, particularly when the weightings provide conflicting insights (Gan *et al.*, 2017). For instance, a purpose or user type with a high Importance per Interviewee weighting but low Importance across Interviews might suggest strong individual opinions that are not widely shared, potentially complicating the analysis. Additionally, these methods rely heavily on the accuracy and consistency of coding during the analysis, which could introduce bias if not carefully managed (Clarke and Braun, 2017). These drawbacks are counterbalanced by the complementary nature of the two methods. While one approach emphasises the depth of emphasis within individual interviews, the other accounts for breadth across the sample. Together, they provide a more balanced and thorough analysis, ensuring

that both concentrated and widespread perspectives are adequately captured and understood in the context of the research (Lowe *et al.*, 2018).

The Methods

Key informant interviews, while valuable for obtaining in-depth insights, can be limited in certain aspects. Firstly, the small sample size of only 12 interviewees for this research could limit the breadth and diversity of perspectives that have been captured. With only one person representing some of the stakeholder groups, there is a risk that the views expressed may not fully represent the broader opinions and experiences of that group (Abdollahpouri *et al.*, 2017; Hoare *et al.*, 2023). This can lead to biased or incomplete understandings of the issues at hand (Prell *et al.*, 2016). Moreover, with smaller numbers of respondents, it can be challenging to confidently identify whether there are gaps in the stakeholder list, and that all relevant viewpoints have been included (Hoare *et al.*, 2023). The selection process may inadvertently exclude critical voices, particularly those from marginalised or less prominent groups, resulting in gaps in the data (Hoare *et al.*, 2023). Additionally, the subjective nature of key informant interviews means that the data collected can be influenced by the personal biases and experiences of the interviewees (Barriball and While, 1994; Shackelton *et al.*, 2022). This can affect the reliability of the information and may lead to an overemphasis on certain issues while underrepresenting others. Furthermore, the interpretation of the interview data by the researcher can introduce additional biases, as the analysis may be influenced by the researcher's own perspectives and preconceptions.

However, the way the interviews were conducted mitigated some of these issues by employing a structured and systematic approach to selection and questioning (Shackelton *et al.*, 2022). By carefully choosing interviewees based on their expertise and roles within their respective stakeholder groups, the study ensured that the most knowledgeable and relevant individuals were included (Bernard, 2017). Additionally, the use of standardised interview protocols helped to minimise interviewer bias and ensure consistency across all interviews. This approach included asking each participant the same core set of questions, which facilitated comparability and comprehensive coverage of key topics (DeJonckheere and Vaughn, 2019). Moreover, conducting in-depth interviews allowed for the exploration of complex issues and the elicitation of detailed responses, providing a richer understanding of the topics discussed (Taylor and Blake, 2015). The inclusion of follow-up questions enabled interviewers to clarify ambiguities and probe deeper into important areas, ensuring that critical insights were not overlooked (Taylor and Blake, 2015). Furthermore, deliberation of overall recommendations with chapters 4, 5 and 6 helps corroborate and contextualise the findings from the interviews, enhancing their overall reliability and validity.

7.3. Results and Discussion

This chapter aimed to contextualise the land sector on a global scale by developing an understanding of the influence calculators have had and could have on policy development, within and around the land sector. Specifically, this chapter undertook a set of key informant interviews to gain expert stakeholder knowledge on the way the perceived capacity of climate calculators to represent and support policy creation and development within the land sector, gaining insight into the strengths and weaknesses of the programme.

This results and discussion section follows the structure of evaluating participant demographic and perspectives (section 7.3.1), the differences between intended design use and perceived use (section 7.3.2), the different users of the calculators and the inference taken from this of its uses (section 7.3.3), the balance of standardising sector inclusion and allowing for localised specificity (section 7.3.4), the nexus and importance of energy and land sector interactions within the calculators (section 7.3.5), and the themes that arose across the interviews (section 7.3.6).

7.3.1. Diverse Participant Perspectives: Balancing Objectivity and Insight

The composition and perspectives of the study's participants, and how these factors influence the findings, showed that the diversity of viewpoints is crucial for a balanced evaluation, while also revealing potential biases due to the disproportionate representation of certain roles (Reed *et al.*, 2009). The diversity of participants and the representation of roles highlight the potential biases and strengths within the sample, while the emphasis on the land sector demonstrates how these participant perspectives shape the discussion of critical issues. Overall, the demographic of this study provides a comprehensive understanding of how participant characteristics impact the study's conclusions (Reed *et al.*, 2009).

Diversity of Participants

12 key informant interviews were conducted, ranging between 45 and 120 minutes in length, determined by the participants' desire to elaborate on questions. 66% (n=8) of the participants worked in the public sector during their time with the calculator programme, 25% (n=3) worked in the

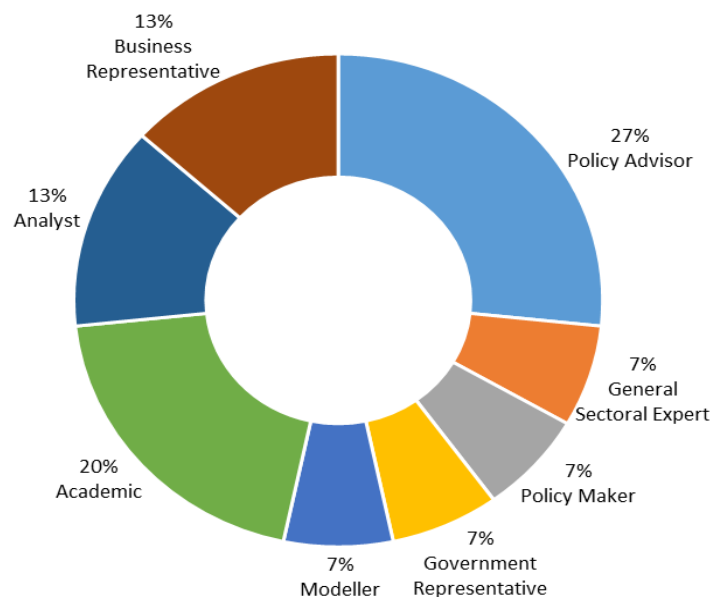


Figure 28. The percentage representation of the different roles each interviewee self-identified as. One interviewee could identify with multiple roles.

private sector, whilst 1 individual was in both (Figure 28). Although it was initially desired to have a larger number of participants, the group of 12 interviewees still provides comprehensive coverage of the necessary perspectives. The participants included a diverse mix of academics, policy advisors, and sector specialists, encompassing individuals who were involved in the programme's creation, those currently working with it, and those familiar with the programme but not deeply enmeshed in its design and rollout (Figure 28).

This diversity is crucial because it introduces a balance between objectivity and in-depth knowledge (Reed, 2008). Those less involved in the programme are likely to be less biased (Pirozzi, 2019) because they are not as deeply invested in the programme's outcomes or processes. This means their feedback might reflect a more neutral and potentially critical perspective on the programme's strengths and weaknesses. This is important because objective feedback can highlight issues or challenges that might be overlooked by those more closely connected to the programme (Pirozzi, 2019). However, the value of including participants who were or are currently involved in the programme cannot be understated. Their direct experience offers insights that are deeply informed by their understanding of the programme's intricacies, which allows them to provide detailed, nuanced feedback that others might not be able to offer (McNamara, 2009; Reed *et al.*, 2018). This duality in participant perspectives allows both a variety of viewpoints and a more comprehensive and accurate evaluation of the programme. The objective feedback from less involved participants can serve as a check against the potential positive bias of those deeply enmeshed in the programme. Conversely, the insights from involved participants can add context to and possibly explain the reasoning behind certain decisions or outcomes that might appear problematic to those less familiar with the programme's operational challenges.

The integration of these diverse perspectives ensures that the evaluation is both thorough and balanced. Without the inclusion of less involved participants, the evaluation might skew overly positive, missing critical areas for improvement (Hoare *et al.*, 2023). Conversely, without the insights of those with direct experience, the evaluation might lack depth, failing to recognise the complexities and constraints that shape the programme's operations. The diversity of participants enhances the evaluation, providing a realistic and actionable assessment of the programme (Reed, 2008; Hoare *et al.*, 2023). By acknowledging and critically analysing the potential biases and strengths that each group brings to the table, the evaluation becomes a more effective tool for guiding future decisions and improvements in the programme.

Representation of Roles

Proportionately, it may seem that there is significant over representation of roles such as “Policy Advisor” at 27% (n=4), and potential underrepresentation of other groups such as “Policy Maker”, or “Modeller” at 7% (n=1) each. Given that there were only 12 participants, these percentages represent a seemingly large subset of the sample, but when considering the actual numbers, the disparity is less pronounced. This difference becomes more apparent when the influence that each role might have on the findings is considered. For example, the perspectives of Policy Advisors could dominate the narrative due to their larger representation, potentially skewing the results towards their viewpoints (Begg, 2018). On the other hand, the underrepresentation of Policy Makers could lead to an underappreciation of the practical, on-the ground challenges that these individuals face when implementing policies (Begg, 2018). This disproportionate representation matters because it can influence the overall conclusions drawn from the study. If certain roles, like Policy Advisors, are overrepresented, their specific concerns and priorities might overshadow those of underrepresented roles, such as Policy Makers. This could result in a skewed understanding of the issues, where the evaluation may lean towards a higher-level perspective, potentially missing critical insights related to

policy execution and real-world application (Reed *et al.*, 2017). Additionally, the dual affiliation of one participant as both a Policy Advisor and an Academic further complicates the analysis. While this dual role might enrich the insights provided by that individual, it also introduces a potential bias in how data is interpreted and presented. The overlap of roles could mean that certain concepts are more frequently mentioned or receive more emphasis, not necessarily because they are more important, but because the participant's dual perspective reinforces them (Gan *et al.*, 2017).

To mitigate these potential biases, it is important not just to count how many participants express a certain viewpoint but also to consider how often particular concepts are mentioned across all interviews. This approach helps to standardise the results, ensuring that the findings reflect the importance of certain themes rather than just the influence of a more vocal or overrepresented group (see section 7.3.2.). This helps mitigate the bias because it shifts the focus from the number of participants to the weight of the concepts themselves (Gan *et al.*, 2017). By analysing how often particular themes are mentioned, regardless of the participant's role, the study can identify which issues are central to the programme's evaluation. This approach reduces the risk of overemphasising the perspectives of an overrepresented group, such as Policy Advisors, whose viewpoints might otherwise dominate simply due to their numbers (Lowe *et al.*, 2018). Moreover, considering the frequency of concept mentions allows for a more nuanced understanding of the data. It highlights recurring themes that might be critical but underrepresented in terms of the number of participants discussing them (Gan *et al.*, 2017). By standardising results in this way, the study can better account for potential biases introduced by the sample's composition, leading to more reliable and actionable findings.

Emphasis on the Land Sector

Eleven of the twelve participants referred to the 'Land Sector' in some form, often without being prompted by the questions, and before the final set of questions specifically focused on the land sector. The way the Land Sector was brought up varied widely, with some participants mentioning it in passing, while others discussing it in depth. Various components of the land sector were covered, including forestry, agriculture, biofuel, and land use. One of the participants who mentioned the land sector did so in passing, without electing to provide a clear link to the question being asked and the land sector, suggesting a pervasive relevance of the topic in their thinking, even when it was not directly solicited (Maurer *et al.*, 2022). 10 participants mentioned land in a manner to highlight its importance, its complexity or a specific component that they felt was of note to the question. Specifically, three different interviewees mentioned biofuel and/or agriculture in a manner that denoted its importance to national policy, the calculator programme or to the reduction of global GHG emissions. This dynamic is reflective of the importance that the land sector plays; it is an integral part of a nation's system, but also reflective of the inherent complexity of tackling the land sector (Baumgartner, 2019; Barletti *et al.*, 2020). There are many ways to approach it in terms of national policy, and many arguments about the prioritisation of the different components; the way the land sector was present within these interviews reflects that (Barletti *et al.*, 2020).

The frequent and varied mentions of the land sector among participants indicate that it is a key area of concern and interest, even in the absence of direct questioning (Maurer *et al.*, 2022). This suggests that the land sector is perceived as integral to the broader policy and environmental landscape, influencing a range of outcomes from national policy to global climate goals. The participants' spontaneous references to the land sector highlight its critical role in the programme, suggesting that any evaluation of the programme would be incomplete without a thorough examination of this sector (Clarke and Braun, 2017; Maurer *et al.*, 2022). Furthermore, the diversity in how the land sector was discussed—ranging from brief mentions to detailed analysis—reflects the multifaceted challenges it

presents. The varied approaches to discussing the land sector indicate that it is not a siloed entity but a complex system with many interrelated components, each with its own set of challenges and priorities (Barletti *et al.*, 2019; Sovacool, 2023). This complexity underscores the difficulty in formulating policies that adequately address all aspects of the land sector, from agriculture and forestry to biofuels and land use.

The repeated emphasis on the land sector, particularly on components like biofuel and agriculture, suggests that these areas are seen as pivotal in achieving national and global environmental objectives (Daioglou *et al.*, 2020). However, the fact that there are "many ways to approach it in terms of national policy points to the potential for disagreement or conflict in prioritising these components. Different stakeholders may have differing views on what aspects of the land sector should be emphasised (see section 7.2.4.), which could lead to challenges in achieving a coherent and effective policy approach. The pervasive and varied references to the land sector among the participants highlight its critical importance and the complexity of addressing its challenges (Plank *et al.*, 2021; Sovacool, 2023). This insight is crucial for policymakers and programme evaluators, as it underscores the need for a nuanced and multifaceted approach to land sector issues. **Ignoring or oversimplifying the role of the land sector could undermine the effectiveness of national policies and global climate strategies**, making it a central focus for any comprehensive evaluation of the programme (van den Ende *et al.*, 2023).

7.3.2. Design Intention and Perceived Needs Misalignment Inhibits Achieving Broader Goals

Diverse Purposes of Climate Calculators

The interviewees identified a wide range of purposes for climate calculators, with no single purpose universally agreed upon. While some purposes were mentioned frequently, such as "Dialogue Creation," others like "Net zero" and "Policy prioritisation" were referenced only once, suggesting they may be secondary benefits rather than primary objectives. When asked "What is the purpose of the climate calculators?", the 12 interviewees presented 12 different purposes, indicating a broad range of recognised purposes for climate calculators. Some of these purposes were referenced throughout the whole process multiple times (Table 19). The interviewees were not provided a list from which to choose from, to not bias the results, or limit them to one purpose. This approach, while intended to capture a more authentic range of responses, introduces subjective analysis when coding the different interviews within Nvivo (Nvivo, 2012). However, whilst this technique mightn't have been as successful with a larger interview pool (Bernard, 2017), the coding process was done through specific use of words, and for both the purpose of the calculator (Table 19) and the users of the calculator

Table 19. The number of interviews that each purpose was mentioned in, and the number of times the 12 interviewees referenced the purpose throughout the interview process overall.

Purpose	Number of Interviews	Total References	Importance per Interviewee	Importance across Interviews
create dialogue	9	29	3.2	23.2
educate general public	8	14	1.8	13.4
carbon budgets	6	10	1.7	9.8
Explore options	5	10	2.0	9.1
ndcs	5	8	1.6	7.9
Policy creation	5	10	2.0	9.1
country dependent	5	8	1.6	7.9
accountability	4	4	1.0	4.9
train officials	4	6	1.5	6.1
promote engagement	2	8	4.0	6.1
Net zero	1	1	1.0	1.2
Policy prioritisation	1	1	1.0	1.2

(Table 19, see section 7.3.3.) saw that the way in which the interviewees responded falling into the categories identified.

“Net zero” and “Policy prioritisation” was brought up once; the reduced emphasis placed on these, suggests they might be secondary benefits rather than primary objectives of climate calculators; whilst this is indicated by the results, the programme has roots in supporting policy design (Strapasson *et al.*, 2020), so this may suggest a shift in how the calculators are perceived or used. Additionally, this raises a critical question: if such significant goals like “Net zero” are seen as secondary, are the calculators aligned with the most urgent climate action priorities? Whilst some of the older calculators (such as the Global Calculator) may predate the programme’s goal to present net zero pathways, this is still an important question to broach to the programme as a whole, and more recent calculators. “Promoting engagement”, whilst only mentioned within 2 interviews, was mentioned 8 a total of times across these two interviews, indicating that the importance that different interviewees put onto the different purposes varied. This variability hints at a potential lack of consensus on what these calculators should prioritise, aligning with results from chapter 6 (see section 6.1.3.), and could dilute effectiveness in driving cohesive climate strategies (van Swol *et al.*, 2022).

There are several purposes that are mentioned within 33-50% (n=4–6) indicating that whilst they are potentially key purposes of the calculators, they are not the primary, or most prevalent reasons. “Policy creation”, “Explore options”, “NDCs” and “Country dependent” were all mentioned in 5 different interviews (<50%) but were mentioned 8-10 times total indicating that whilst these purposes are not necessarily primary reasons, when they are mentioned, they tend to be discussed in reasonable detail (Fereday and Muir-Cochrane, 2006). Even though the importance weighting across all the interviews for these was ~ half of that for creating dialogue (Table 19), this pattern suggests that while these purposes are not universally recognised as the primary roles of the calculators, they hold substantial importance in specific contexts (Herold *et al.*, 2018; Jernnäs *et al.*, 2019; Forsell *et al.*, 2019). This variability in perceived importance suggests that while the calculators are valuable, their impact may be inconsistent, depending on how and where they are used. If these calculators are to be effective in global climate strategies, they need to be more than just adaptable—**they must be capable of addressing core, universally acknowledged objectives without compromising on other essential functions.**

Interestingly, when comparing these interview-based findings with results from Chapter 6.1.3 (Figure 18), which assessed the calculators' stated purposes, there are some notable differences. The most prevalent reasons provided by the calculators themselves were “Planning/Decision Making,” “Exploring a low carbon future,” and “General Public Use.” These functions align closely with strategic and practical applications, emphasising the calculators' role in shaping future scenarios and engaging the public. In contrast, the interviewees, who are users and stakeholders related to the calculators, highlighted “Dialogue Creation” more prominently. This suggests a gap between the calculators' intended functions and how they are perceived and utilised by their users. The calculators' designers might prioritise technical and educational functions, while users place higher value on their ability to foster dialogue and collaboration (Capano and Howlett, 2020; Strapasson *et al.*, 2022). **This discrepancy indicates that while calculators are seen as versatile tools, there might be a misalignment between their design intentions and the actual needs or perceptions of their users.** Understanding and addressing this gap is crucial to enhancing the effectiveness of these tools in achieving their broader goals.

Significance of “Dialogue Creation”

“Dialogue Creation” was the most frequently mentioned purpose, appearing in 9 out of 12 interviews and discussed in detail, with the greatest importance weighting per interviewee and across the

interviews in their entirety (Table 19), indicating that climate calculators are not just technical tools but are also seen as instruments for facilitating broader conversations and collaborations among stakeholders, and collaborations around climate issues (Strapasson *et al.*, 2020). This aspect of dialogue creation implies that these calculators can act as a bridge between stakeholders (e.g. policymakers, researchers, general public), facilitating increased participatory approaches to climate action (Cradock-Henry *et al.*, 2020; Hinson *et al.*, 2022). Increased dialogue, can help align different perspectives, identify common goals, and drive collective efforts towards sustainable solutions (Garnett and Cooper, 2014). The emphasis on dialogue signals a shift to recognising them as pivotal in shaping the social dynamics of climate policy. This shift is significant because it acknowledges that effective climate action depends not just on accurate data, but on the collective engagement and alignment of diverse stakeholders (Fagiewicz *et al.*, 2021). Increased dialogue can help align different perspectives, identify common goals, and drive collective efforts toward sustainable solutions (Garnett and Cooper, 2014; Fagiewicz *et al.*, 2021).

This emphasis on dialogue also highlights the potential of these tools to enhance transparency and accountability in climate policy-making, as well as to build a shared understanding and commitment to addressing climate change (Pauw and Klein, 2020; Strapasson *et al.*, 2022). By fostering dialogue, climate calculators can make the policy-making process more inclusive and reflective of a wider range of voices. This could lead to more robust and widely supported climate policies, as stakeholders who feel heard and involved are more likely to commit to the outcomes. “Educate general public” was brought up nearly as much (n=8), but with nearly half the numbers of mentions overall (n=14). This suggests that, generally, there was a consensus that “Dialogue Creation” and “Educate general public” are core reasons for the calculator program to exist. However, the greater emphasis on dialogue suggests that stakeholders believe creating a platform for discussion is more impactful than simply disseminating information. This prioritisation of dialogue over education could indicate a recognition that passive knowledge transfer is insufficient for driving meaningful climate action; instead, **active engagement and discourse are necessary to mobilise change** (Barletti *et al.*, 2020; Fagiewicz *et al.*, 2021).

It is important to understand the goals that these calculators are designed to achieve, as knowing these purposes can help with the evaluation of the effectiveness of them meeting these goals, and the broader goal of facilitating decision making. This understanding is crucial for refining the tools to ensure they are not only meeting their intended functions but are also adaptable enough to address emerging challenges and opportunities in climate action (Cobb and Thompson, 2012; Garnett and Cooper, 2014). These tools can reflect the political landscape of a nation and highlight gaps in current policies, such as the omission of critical areas like food and diet from national climate strategies (Strapasson *et al.*, 2020). If climate calculators merely mirror existing political priorities without challenging them, they risk perpetuating the status quo and missing opportunities to push for more comprehensive and forward-thinking climate policies (Nightingale *et al.*, 2022). This could undermine their potential as instruments of innovation and progress.

Challenging such gaps would lend climate calculators the capacity to serve as a bridge between scientific data, public awareness, and policy formulation, ensuring that all vital sectors are considered in climate change mitigation and adaptation. By addressing these gaps, climate calculators could become catalysts for more holistic and effective climate strategies that account for the full spectrum of factors influencing climate outcomes. While NDCs are frequently cited as successes, specific examples illustrating their impact are often lacking, which can obscure the real-world effectiveness of these instruments (Winkler, 2019). Additionally, there is a general consensus that the core purpose behind the calculators has remained consistent over time, emphasising their role in integrating

comprehensive data into actionable policies. Addressing these gaps could enhance the practical utility of climate calculators, providing clearer, evidence-based insights that inform both public understanding and policy development, thereby improving overall climate strategy effectiveness.

The diversity of identified purposes suggests that climate calculators are versatile tools, which is consistent with their role in strategic planning and decision-making. The emphasis on "Dialogue Creation" aligns with this versatility, as fostering dialogue can enhance the effectiveness of strategic planning by ensuring that various stakeholders' perspectives are considered. Together, these findings suggest that climate calculators are comprehensive tools that serve multiple, interconnected purposes in climate policy and action. The integration of dialogue into strategic planning not only strengthens the calculators' utility but also ensures that the policies developed are more resilient and reflective of a broader consensus (Garnett and Cooper, 2014; Pal *et al.*, 2020). Together, these findings suggest that climate calculators are comprehensive tools that serve multiple, interconnected purposes in climate policy and action. This multifaceted role **underscores the importance of ensuring these tools are designed and used in ways that fully leverage their potential, aligning technical capabilities with the social and political dimensions of climate action.**

7.3.3. Perceived Users Indicate Predilection for Dual Use Shaping Policy and Educating Public

When asked "Who are the main users of the calculators?", the 12 interviewees presented 12 different users, indicating a broad range of recognised users for climate calculators (Table 20). The most frequently mentioned users, "Gov Officials" (government officials), "Policy makers" and "public" were all included in 75% of interviews (n=9). Government officials, policymakers, and the public were the most frequently mentioned user groups (Table 20), with "Gov Officials" being the predominant group, referenced 21 times across interviews. This is interesting because it underscores the multifunctional role that climate calculators play in both shaping policy and educating the public. Whilst not all the participants are affiliated with a specific calculator, and so will be working off of the ethos of the programme rather than the specific users they have seen interacting with the calculator, the interviewees less certain in their answers often caveated by stating that the users they were mentioning were ones they were aware of as active users, and felt that there were likely more they were unaware of. Therefore, prominence of government officials and policymakers highlights the critical function of these tools in informing and guiding climate-related decisions and strategies at the governmental level (Strapasson *et al.*, 2020). Simultaneously, the significant mention of the public emphasises the importance of these calculators in raising awareness and fostering engagement among citizens (Begg, 2018). This dual focus suggests that for climate calculators to be most effective, they need to be designed with both high-level policy needs and broader public accessibility in mind, ensuring they can cater to a wide range of users and facilitate comprehensive climate action. This finding underscores the significant role these calculators play in informing and guiding climate-related decisions and strategies at the governmental level. The frequent mention of both policymakers and the public also highlights the dual functionality of climate calculators in shaping policy and educating citizens (Begg, 2018; Theodorou *et al.*, 2019). This suggests that these tools are crucial not only for high-level decision-making but also for raising awareness and fostering public engagement on climate issues.

The other user groups were mentioned in 33% or less of the interviews (n≤4) and mentioned significantly less frequently than the top three. The only user that is a slight outlier to this trend is "Universities", which was mentioned in 25% (n=3) of the interviews but mentioned a total of 8 times. Compared to the number of interviews, this indicates a greater length of detail of this user group within these interviews. This pattern suggests that while these users are not universally recognised as the primary users of the calculators, they hold substantial importance in specific contexts, or to

specific interviewees, potentially the participants that self-identified as academics. Overall, this suggests that the roles of universities are acknowledged but perhaps not as critical as those of the general public and policymakers (Clarke and Braun, 2017). The moderate emphasis on researchers and educators highlights their roles in leveraging these tools for scientific analysis and educational purposes, suggesting opportunities for targeted enhancements to support their needs (O’Neil *et al.*, 2009; Strapasson *et al.*, 2022). The relatively lower emphasis on businesses, NGOs, and media suggests that while these groups are recognised as potential users, their engagement with climate calculators may be more specialised or situational (Clarke and Braun, 2017). This is interesting because understanding the specific contexts in which less frequently mentioned user groups find value can help in identifying untapped potential and new avenues for expanding the use and effectiveness of climate calculators.

Table 20. The number of interviews that each User (of the calculator) was mentioned in, and the number of times the 12 interviewees referenced that these were the users of the calculator throughout the interview process overall.

Users	Number of Interviews	Total References	Importance per Interviewee	Importance across Interviews
Gov Officials	9	21	2.3	25.2
Policymakers	9	14	1.6	19.3
Public	9	14	1.6	19.3
NGOs	4	5	1.3	7.6
Businesses	3	3	1.0	5.0
Engineers/sector experts	3	5	1.7	6.7
Universities	3	8	2.7	9.2
Analysts	2	2	1.0	3.4
External users	1	2	2.0	2.5
Pressure Groups	1	1	1.0	1.7

The less frequent mention of other user groups, like universities and NGOs, indicates potential areas where the calculators could be further developed to better serve these sectors, potentially expanding their impact and utility. However, the predominant focus on government officials and policymakers aligns with the climate calculators’ critical role in policy-making, while the emphasis on public engagement complements this by ensuring that the broader population is also informed and involved in climate action (Graham *et al.*, 2023). The recognition of other user groups, though less frequent, does not contradict this but rather highlights additional, context-specific uses that can be targeted for further enhancement. Together, these points suggest a coherent understanding of the calculators as versatile tools that need to be both broadly accessible and contextually adaptable to maximise their effectiveness in climate action.

7.3.4. The Trade-off Between Standardisation of Development and Context-Specific Design

When prompted across the course of the interview to discuss the sectors present within the climate calculators, there were three concepts that developed; all sectors should be included, case by case and some should take precedence (see section 7.3.4.)

All sectors should be included

When asked about what sectors should be included within the calculators, 7 of the interviewees said some variation of “all of them”, stating that you required “*basically [the] whole economy*” (Interview 112), and “*if you missed one out, you wouldn’t have the whole picture*” (Interview 1012). This suggests that a comprehensive approach is necessary when designing climate calculators, as omitting any

sector could lead to an incomplete and potentially misleading understanding of the overall climate impact (Lamb *et al.*, 2021). Including all sectors ensures that climate calculators provide accurate, holistic insights into the economic and environmental dynamics at play. By capturing the full scope of the economy, these tools can better inform policymakers, businesses, and the public about where interventions are most needed (Stern, 2008; Månsson, 2015). The quotes highlight a fundamental understanding that the economy and environmental systems are interconnected and that excluding any sector could lead to an incomplete or skewed picture of a nation's GHG emission portfolio and climate impact. Leaving out sectors can result in significant gaps in data and analysis, ultimately undermining the effectiveness of the calculators in guiding policy decisions (IPCC, 2018; IPCC, 2023).

This sentiment is emphasised further by the statement *“At one level, yes, they are all important as each other, because the moment you start excluding sectors, you lose the power of forcing everything into a common analytical framework.”* (Interview 1212). Understanding the interconnectedness of different sectors is crucial for developing effective and sustainable climate strategies. Without a comprehensive view, key areas might be overlooked, leading to ineffective or counterproductive climate actions (Faldutoi and Rochai, 2020; IPCC, 2023). The holistic inclusion of all sectors ensures that the calculators provide a robust, integrated framework for evaluating emissions, identifying reduction opportunities, and formulating policies that are truly reflective of the entire economy's climate dynamics (Lamb *et al.*, 2021).

A comprehensive approach is crucial because climate change is a complex, multifaceted issue that affects and is affected by a wide range of activities and sectors. By electing to evaluate all sectors under a common analytical framework it becomes possible to understand the trade-offs, synergies, and interactions between different sectors (Bowen *et al.*, 2017; Palomo *et al.*, 2019). For instance, reducing emissions in one sector might inadvertently increase emissions in another if not properly managed (Bowen *et al.*, 2017; Danish *et al.*, 2019). Therefore, including all sectors allows for a more nuanced understanding and ensures that climate policies are balanced and effective across the board (Jernnäs *et al.*, 2019). This inclusiveness also enhances the credibility and utility of the calculators, as stakeholders can trust that the analyses are thorough and encompass all relevant factors.

Case by Case

It was not just when asked about what sectors should be included within the calculators that interviewees relayed the sentiment that the calculators not only should be, but are best designed when fully on a case-by-case basis. This was an overarching sentiment throughout the interviews that was either stated directly, or caveated alongside answers, indicating that *“it's very context dependent”* (Interview 912). Whilst the international calculator programme presents a standardised approach and template to calculator development, there is no one size fits all approach to calculator design and specifications. This raises important questions about the adaptability and effectiveness of global climate initiatives when applied to diverse national contexts. The emphasis on context-specific design suggests that standardisation, while useful for creating a common framework, may not fully capture the unique environmental, economic, and social dynamics of individual nations (Beck and Oomen, 2021).

This has significant implications for the success of climate calculators in driving effective policy. If calculators are not tailored to the specific circumstances of a country—such as its energy mix, industrial base, and cultural practices—there's a risk that the policies they inform may be incomplete or ineffective (Anderson *et al.*, 2020). For example, as one interviewee noted, *“If there's anything that burns coal in the nation, that should be included, and even the burns gas in the nation, it should be included in the burns oil in the nation.”* (Interview 212). Excluding any significant source of emissions, like coal or gas, could lead to an underestimation of a nation's environmental impact (Audi *et al.*, 2020;

Fünfgeld, 2020). This oversight could result in less effective or misguided mitigation strategies, ultimately undermining global efforts to combat climate change. The broader implication is that climate calculators, and by extension, climate policies, must strike a balance between the benefits of standardisation and the necessity of contextual relevance (Harenda *et al.*, 2018; Pawlak and Kołodziejczak, 2020). The ability to customise these tools to reflect local realities could be crucial in ensuring that they contribute to meaningful and actionable climate strategies. In other words, **the effectiveness of climate calculators—and the policies they influence—hinges on their capacity to be both globally informed and locally adapted**, ensuring that all relevant factors are considered in the pursuit of sustainable development.

When exploring the notion of case-by-case, the concept that arose was that to determine the ‘most important sectors’ was for the developers to *“just carry on down that list of what the biggest emitters are. I mean, I think that that that's the way it needs to be and then prioritised.”* (Interview 1112). This advocates for the potential to prioritise sectors depending on the magnitude of emissions. This would ensure that efforts directed towards the most significant contributors to emissions first, thereby maximising the impact of mitigation strategies. The approach of listing and prioritising emitters aligns with practical resource management, allowing for a structured and efficient pathway to reducing overall emissions, but not with the programme ethos of presenting a holistic and non-policy prescriptive approach to decision support (Van Beek *et al.*, 2022). This tension between practicality and inclusivity raises important questions about how to best balance efficiency with the need for comprehensive, context-sensitive solutions. The critical issue here is the potential trade-off between efficiency and comprehensiveness in climate policy. While prioritising high-emission sectors could lead to quicker, more measurable results, there is a risk that such an approach might overlook or undervalue sectors that, although smaller contributors to emissions, are still vital to a country’s overall environmental and economic health (Akash *et al.*, 2017; Hossain *et al.*, 2020). For instance, focusing solely on energy and transport might neglect sectors like agriculture or forestry, which are crucial in certain national contexts and play a significant role in long-term sustainability (Sadri *et al.*, 2014; Palomo *et al.*, 2019).

The idea of universal versus context-specific priorities further complicates this balance. It acknowledges that while certain sectors like energy and transport are universally important, the relative significance of other sectors varies greatly depending on the country. *“I would argue that there are things like energy supply and demand transport that are kind of as important in all countries and then obviously in some countries they'll have a massive forestry sector and others they won't at all.”* (Interview 912). While energy supply, demand, and transport are critical areas for emissions reduction universally, other factors such as forestry may vary significantly in importance from one country to another (Baumgartner, 2019; Alusiola *et al.*, 2021). This highlights the necessity for flexibility and customisation in developing environmental policies and interventions. Recognising that each country has unique characteristics and sectors that contribute differently to their overall emissions enables more tailored and effective strategies, reinforcing the need for both a broad and nuanced approach to environmental management (Ashley and Boyd, 2006; Rusmayandi *et al.*, 2023). It can be assumed that whilst a standardised framework for emissions reduction can provide a foundational guide, the successful implementation of such a framework relies heavily on its adaptability to specific national contexts (Abbass *et al.*, 2022). This dual approach of comprehensive inclusivity and prioritised, context-sensitive strategies allows for a more accurate and impactful response to global environmental challenges (Amelung *et al.*, 2020; Fawzy *et al.*, 2020). However, despite the recognition of the need for flexibility and adaptation, there remains a strong argument among some interviewees that certain sectors are so critical that they must always be included in climate calculators.

7.3.5. The Nexus of Energy and Land Use is Central to Sustainable Climate Policy

The emphasis on universally impactful sectors is practical, given their significant contributions to emissions and the feasibility of large-scale interventions (Byer *et al.*, 2018). However, this focus may overshadow other crucial but potentially less accessible or more complex areas, such as agriculture, forestry, and specific industrial processes, which can vary in importance depending on the regional context (Baumgartner, 2019; Malhi *et al.*, 2020). Additionally, while these sectors are pivotal, the challenges in addressing them—such as infrastructural changes, policy shifts, and economic considerations—are complex and require multifaceted approaches. This can be seen in this study; where some interviewees stated that they were all important, or there could be variation seen on a case by case basis, this was not a sentiment that extended across the rest of the participants. For others, whilst there was no common consensus on a sector(s) that ‘should always’ be included, nor on which sectors held the most important role in upholding the functionality of the calculator, there were several that did dominate the topic of conversation.

Electricity, transport and energy were three sectors that were frequently cited as core components of the calculators. *“The most important and then maybe industry or transport. [...] I think it is probably electricity supply.”* (Interview 912) and *“I feel like the obvious ones that should be included would be transportation ... Electricity...The built environment.... Umm, industry....And then land use.”* (Interview 712) are clear examples where the significance of sectors such as electricity, transport, and energy were brought to the forefront of the conversation, highlighting the perceived importance of these sectors within the policy creation and climate change mitigation landscape. The implication is that many interviewees view these sectors as critical drivers of emissions and, therefore, essential components of any comprehensive climate calculator. From this emphasis, we can assume that participants believe addressing these sectors can yield the most substantial improvements in environmental outcomes, because they are major contributors to greenhouse gas emissions and have significant potential for reductions through technological advancements and policy interventions (Den Elzen *et al.*, 2013; Shobande *et al.*, 2024). Electricity, transport, and energy are universally relevant and heavily intertwined with economic and social activities, making them key targets for any mitigation efforts. This focus also implies an acknowledgment of the interconnected nature of these sectors, where improvements in one can lead to positive ripple effects in others, such as the transition to electric vehicles reducing emissions from both transportation and electricity generation if powered by renewable energy sources (Schwanen *et al.*, 2011).

While the focus on electricity, transport, and energy sectors is significant and reflects their critical role in emissions reduction, it is essential to maintain a broad and adaptable perspective on the role different sectors play within the calculator. This ensures that other sectors are not neglected and that the tools remain relevant and effective across diverse contexts. Additionally, there was a distinction made between sectors that were most *important* (aka, highest emitters), and those that should always be *included*.

The distinction between sectors deemed most important and those that should always be included in environmental calculators reflects a nuanced understanding of their varying impacts and roles in emissions reduction. One interviewee stated *“I'd probably say transport just because it's something that is [so integral]”* (Interview 812), relating to the need for integrated transport into all regions' physical infrastructure, whilst another stated, *“I think the key one, the non-negotiable, is energy consumption”* (Interviewee 1012), following the idea that sectors like electricity, transport, and energy are often highlighted as most important due to their significant and direct contributions to emissions, making them key targets for impactful mitigation strategies (Akash *et al.*, 2017; Crippa *et al.*, 2021). Energy and transport, alongside land, were the top three mentioned sectors. (Energy broadly, and then more specifically as electricity, CCS and nuclear) (Table 21).

Table 21. Sectors the participants referenced within the interviews

Sectors	Number of Interviews	Total References	Importance per Interviewee	Importance across Interviews
Land	12	62	5.2	46.0
Energy	11	40	3.6	31.7
Transport	6	10	1.7	9.9
CCS	5	7	1.4	7.5
Industry	3	3	1.0	3.7
Heat	1	1	1.0	1.2

Considering energy was mentioned in 92% (n=11) (Table 21) of the interviews, evidences the importance of the sector and its representation within the climate calculators. Whilst transport was the third most mentioned sector, it was only brought up in half the interviews, with an importance weighting across the interviews of less than a third of energy and land (Table 21). This helps emphasise the importance places on energy and the land sector within the interviews, and how deeply intertwined these components are respectively with the climate calculator history and with other sectors (Gomez-Echeverri, 2018; Filipović *et al.*, 2022). The size and complexity of the land sector, encompassing diverse activities from agriculture to forestry, make it a critical component of any comprehensive emissions analysis. Unlike more singularly focused sectors, the land sector's multifaceted impact and interactions necessitate its consistent inclusion to ensure accurate and effective environmental management (Liu *et al.*, 2020b). Interview 1012 not only stated the utmost importance of energy, but also land; *“And yes, land use as a sector should always be in the calculator and [is] the key.”* (Interview 1012), sentiments that were echoed through the entire interview process, for almost all the interviewees (Table 21).

Energy

The prominence of the energy sector within the interviews could reflect the significance of the sector due to its central role in both economic development and climate change mitigation, making it a primary focus for many countries (Durán-Díaz, 2023; Akpahou *et al.*, 2024). Historically, energy independence has been a critical goal for countries due to the critical nature of energy in powering industries, homes, and transportation systems (Ahmad and Zhang, 2020). As countries strive to balance energy needs with environmental responsibilities, the sector has become a focal point for policies aimed at reducing carbon footprints and transitioning to more sustainable energy sources. It is suggested within the interviews that countries with climate calculators sometimes do have split focus and priorities, sometimes at the detriment of the overall goal of the climate calculator programme; *“More focused on energy independence, rather than achieving greenhouse gas emission targets.”* (Interview 1112). This highlights a potential conflict between national priorities and global

climate goals. If countries prioritise energy independence over reducing GHG emissions, they may delay or undermine the effectiveness of climate calculators in achieving meaningful reductions in global emissions (Stoddard *et al.*, 2021). This could result in missed opportunities for collaboration and innovation in renewable energy and emissions reduction strategies, ultimately slowing progress towards global climate targets. The tension between these priorities underscores the need for integrated approaches that can reconcile energy independence with sustainable development and climate mitigation.

Additionally, the development of a successful energy sector is crucial for the overall growth of a country (Ahmad and Zhang, 2020). Historically, the energy sector has underpinned industrialisation and economic expansion (Jones *et al.*, 2023). In more recent times, it has also become integral to sustainable development (Stoddard *et al.*, 2021). The push for sustainability has highlighted the necessity of integrating technologies such as carbon capture and storage (CCS), nuclear energy, and renewable sources like wind and solar power. This progress of energy development and provision is *“one of the big takeaways of the global calculator and the UK calculator is that you have to have a scale of either CCS, nuclear or sort of wind and solar”* (Interview 112), and can be a marker of success for climate mitigation; *“When you get done well, you've got to have renewable energy.”* (Interview 412). This underscores the critical role of the energy sector in achieving climate goals. The integration of advanced technologies like CCS and renewable energy is not just an option but a necessity for any meaningful progress in reducing global carbon emissions (Dods *et al.*, 2021). Failing to scale these technologies could result in continued reliance on fossil fuels, thereby exacerbating climate change and hindering efforts to meet international climate agreements such as the Paris Agreement. Moreover, the successful transition to sustainable energy sources can serve as a model for other sectors, demonstrating that economic growth and environmental responsibility can go hand in hand (Murshed *et al.*, 2021; Filipović *et al.*, 2022).

This focus on the energy sector also illustrates the broader challenge of balancing immediate national interests with long-term global sustainability goals. While energy independence and economic growth are immediate concerns for many countries, there is a need to ensure that these priorities do not overshadow the urgent need for climate action. The challenge lies in aligning short-term national interests with long-term global commitments, particularly in a sector as pivotal as energy (Faldutoi and Rochai, 2020). The energy sector is fundamental to national development and sustainability, historically underpinning industrialisation and more recently driving sustainable growth through technologies like CCS, nuclear, wind, and solar power (Herold and Böttcher, 2018; Dods *et al.* 2021). It is also a prime study in how the adaptive capacity of a country can impact how a sector has developed over history and the focus a country puts on it now. This adaptive capacity reflects a nation's ability to evolve its energy strategies in response to changing environmental, economic, and technological conditions, which is crucial for meeting both national and global climate objectives.

Land and Agriculture

The interconnectedness of energy with land further underscores the complexity of sustainable development. Land use is integral to energy production, particularly with renewable sources such as wind and solar, which require significant space for infrastructure (Duguma *et al.*, 2014; Filipović *et al.*, 2022). Therefore, whilst the climate calculators have origins as energy calculators, *“it adds value to include the land use because it is actually a big emission sector.”* (Interview 112). This highlights the necessity of considering land use in any comprehensive climate strategy. Excluding land from the equation could result in an incomplete understanding of emissions; including land use ensures that the calculators reflect the full spectrum of emissions, enabling more accurate and effective climate action (Strapasson *et al.*, 2017).

Additionally, bioenergy production competes with food production for land resources (Karlsson and Röö, 2019; Reid *et al.*, 2020). This interdependency necessitates careful planning and management to optimise land use while supporting energy needs and environmental conservation (Reid *et al.*, 2020). In fact, land was often cited as the sector that would make the calculator function redundant if removed; *“land use is so crucial in terms of getting to net zero [so I would] say land use is the one that would make [the calculator] redundant, if we take that out.”* (Interview 712). This emphasises that land use is not just another sector within the climate calculators but a foundational element that supports the entire framework (Roe *et al.*, 2019). The successful integration of energy and land use policies is essential for achieving comprehensive sustainability goals, reflecting the intricate balance required to meet both human and environmental needs (Fyson and Jeffery, 2019; Fanzo *et al.*, 2021). Without this integration, efforts to reach net zero could be significantly hampered, as key areas of emissions would remain unaddressed.

The land sector was mentioned in all interviews (Table 21), due to specific questions about it, however it has the highest reference rate outside of this and was mentioned by 11 out of 12 of the interviewees before the land-specific questions came up. The interviewees recognised it as a large source of GHG emissions, potentially seeing land as a problem and not necessarily part of the solution, with the frequent mention of land underscoring its role in bioenergy production and the need to balance energy crops with food production (Karlsson and Röö, 2019; Reid *et al.*, 2020). This confluence of energy and land use issues reflects the complex interplay of factors that must be managed to achieve climate goals, illustrating the comprehensive approach required for effective climate mitigation strategies (Filipović *et al.*, 2022). This further demonstrates that land use is not merely a peripheral concern but a central issue in the broader context of climate policy. The constant tension between using land for energy production versus food production exemplifies the broader challenge of balancing competing interests in the pursuit of sustainability (Danish *et al.*, 2020).

Not only is the land sector a topic of discussion due to the sectors interconnections with other sectors, but also because of the intrinsic challenges associated with such a large and complex sector. Agricultural emissions present a particularly difficult challenge; *“You know, one of the big and hard problems to solve is agricultural emissions, which really comes down to, you know, that land use component.”* (Interview 1212). This is important because agricultural emissions are among the most stubborn sources of GHGs, often linked to deeply entrenched practices and significant economic interests (Kamyab *et al.*, 2024). The challenge of reducing these emissions underscores the need for innovative and context-sensitive approaches within the climate calculators. Addressing land use in agriculture requires not only technological solutions but also policy shifts and potentially significant changes in land management practices (Solecka, 2019; Kamyab *et al.*, 2024).

Understanding the critical role of land in climate strategies is essential for designing policies that are both effective and equitable. The way land is considered in the climate calculator programme reflects the political landscape and serves as an indicator of broader environmental and policy trends. Land use can act as an indicator in the context of climate strategy, providing insights into the effectiveness and priorities of national policies (Gan *et al.*, 2017). Omissions from the land sector in discussions or policies might occur for various reasons, yet these omissions are often deliberate, reflecting the difficulties and sensitivities involved in managing land use (van den Ende *et al.*, 2023). The attention given to land in the programme underscores its significance and the need for integrated approaches to tackle the multifaceted challenges it presents. This focus not only highlights the importance of land use but also raises critical questions about how well current policies align with the realities of achieving sustainable development and net-zero goals.

7.3.6. Thematic Analysis

Throughout the interviews there were common concepts and themes that the interviewees kept drawing back to. These are concepts that were not asked directly but were offered by the participants to contextualise their other answers (see section 7.2.3.) (Lowe *et al.*, 2018). Whilst the role of the land sector within the calculators was a core concept the interviews were designed to draw out, the concept that the land sector is integral to linking the other sectors together was a theme that emerged across the interviews.

Effective Policy-Making Through Cross-Sector Land Use Integration

“One way you need to include land and land use is as a constraint or as a resource that all the other sectors.” (Interview 1212). This idea suggests that land and land use play a fundamental role in the interconnectedness of various sectors. For instance, agricultural practices can affect water quality and availability, while urban expansion can encroach on natural habitats, reducing biodiversity (Andersson *et al.*, 2022; Durán-Díaz, 2023). Land serves as a critical factor in determining the feasibility and sustainability of activities in other sectors. Integrating land use considerations into broader strategies ensures that sector-specific actions are coherent and synergistic, thereby enhancing overall sustainability and resource efficiency (Liu *et al.*, 2020b). Ultimately land is a globally limited resource that can act as a constraint to other sectors. This highlights that neglecting land constraints can lead to inefficient use of resources and missed opportunities for holistic solutions. Effective management of land use is crucial for ensuring that other sectors can operate sustainably without exacerbating environmental problems or depleting essential resources (Roe *et al.*, 2019; Smith *et al.*, 2020).

This is an exceptionally important concept when considering the way that land is incorporated and integrated within the climate calculators. Ineffective inclusion of land and its relationships with other sectors can undermine the quality of GHG emission and climate policies derived from these tools (Baumgartner, 2019). Land plays a pivotal role in carbon sequestration, agricultural productivity, water management, and habitat conservation, all of which are interdependent with energy, industry, and urban development sectors (Nabuurs *et al.*, 2022). If land use is not accurately represented, it could lead to flawed projections and strategies, potentially overlooking critical trade-offs and synergies. For instance, failing to account for land's role in carbon sequestration might result in underestimating its potential to mitigate emissions, while ignoring land use constraints could lead to unsustainable agricultural or urban expansion plans (Palomo *et al.*, 2019). Thus, incorporating a comprehensive and accurate depiction of land within climate calculators is crucial to formulating robust, holistic, and effective climate policies. Ultimately, land links all the other sectors together, reinforcing the importance of evaluating the utility of these decision support tools in facilitating climate mitigation and adaptation within the land sector.

However, land is complicated. This was stated explicitly by several participants, with the complexity arising from diverse land use—agriculture, forestry, urban development, and conservation—as well as from the dynamic interactions between these uses and the ecological, economic, and social systems they impact (Nabuurs *et al.*, 2022). These multifaceted interactions can lead to difficulties with data sharing because each land use category involves distinct stakeholders, data types, and measurement methods, which may not be easily integrated or standardised (Mercer and Burke, 2023). For instance, agricultural data might be collected at the local level with a focus on productivity, while forestry data could prioritise carbon sequestration at a regional or national level (Singh *et al.*, 2016). The varying priorities, data formats, and levels of access among stakeholders can create barriers to effective data sharing, complicating efforts to achieve a unified approach to land management and climate mitigation. With *“Some countries will just be more willing to share their data and to be potentially criticized.”* (Interview 812), a disparity in data transparency and accessibility exists. This disparity can

result in significant gaps and inconsistencies in the data available for climate calculators, making it challenging to develop comprehensive and accurate models (Yates *et al.*, 2018). These data gaps can lead to incomplete or skewed assessments of land use impacts, undermining the effectiveness of climate calculators and making it difficult to implement informed and equitable climate policies. Addressing data sharing challenges is crucial for enhancing the accuracy and reliability of climate models and ensuring that policies are based on the best available information.

Additionally, there are elements to calculator development that are difficult to understand, and more so overcome, giving rise to critical reflection on the climate calculators and the quality of work already built. *"We didn't understand very well at the time when we built the first calculator, we didn't understand the levers."* (Interview 1212). This indicates the potential lack of deep understanding of the complex mechanisms driving land use and its impacts on climate systems. Moreover, critical aspects such as soil carbon, which one interviewee mentioned is *"often neglected in the calculators,"* (Interview 312), underscores the intricacies and gaps in current models. The challenge is not merely technical but conceptual, requiring a more nuanced grasp of the multifactorial relationships at play.

While this might be because of limited resources or knowledge within the calculator team (Mezei and Sarlin, 2016), or limitations in the design of the initial approach (Creswell, 2007), there are other reasons to consider: land is a politically sensitive sector. Land use decisions are deeply embedded in political and social contexts, influenced by policies, regulations, and governance structures. These political dimensions can affect data transparency, the prioritisation of certain land uses over others, and the implementation of climate policies (Seymour and Busch, 2016; Bowen *et al.*, 2017). *"Some of the tensions and difficulties with land use change, particularly and afforestation."* (Interview 1112) support this, implying that understanding and integrating land within climate calculators necessitate not only technical expertise but also a keen awareness of the political landscape. The political nature of land use can create biases and barriers that complicate efforts to achieve accurate and equitable climate solutions, necessitating a broader, more integrative approach to climate modelling and policy development (Beck and Ooman, 2021). The political sensitivities surrounding land use can lead to biases and incomplete data, making it challenging to develop fair and effective climate policies. Addressing these political dimensions is essential for creating climate calculators that reflect a comprehensive understanding of land use and its impacts.

This reflects the broader conflicts and tensions inherent in balancing economic interests with environmental conservation. Palm oil plantations, for instance, are economically lucrative but often come at the cost of deforestation and biodiversity loss. *"But then if you look at Malaysia, there's huge controversy around the rainforest versus palm oil plantations, et cetera"* (Interview 412), underscoring the complex dynamics of land use policies and their ecological impacts. These controversies are critical because they directly affect the effectiveness and credibility of climate policies (Grassi *et al.*, 2017). Mismanagement or oversimplification of such issues in climate calculators can lead to flawed strategies that fail to address the root causes of environmental degradation, thus undermining efforts to mitigate climate change and preserve vital ecosystems (Grassi *et al.*, 2017). Addressing these controversies in climate calculators is crucial for developing policies that genuinely address both environmental and socio-economic challenges, ensuring that climate strategies are both effective and equitable.

This tension between economic gain and environmental preservation is not unique to palm oil or afforestation; it also extends deeply into the agricultural sector, where similar conflicts arise over the balance between economic interests and the need for sustainable practices (Zomer *et al.*, 2008, Alusiola *et al.*, 2021). There is a lack of confidence in the political will to engage in the social conversations necessary to implement change; *"But as far as I know government doesn't want to get*

into it with farmers." (Interview 512). This reluctance could stem from the significant political and economic influence wielded by the agricultural sector. Farmers often form a substantial and vocal constituency, making it politically sensitive for governments to impose stringent regulations or changes that might be perceived as detrimental to their livelihoods (Rickards *et al.*, 2014). This is important because it highlights the challenges in implementing effective climate policies that require substantial changes in agricultural practices. The sector is a major contributor to GHG emissions, yet political resistance can hinder progress towards more sustainable practices. Addressing these controversies is crucial for developing comprehensive climate strategies that balance environmental goals with the economic and social realities of the agricultural community. Navigating these political sensitivities is essential for creating climate policies that are both practical and effective, ensuring that necessary changes are implemented without causing undue harm to vulnerable sectors.

Agriculture is a source of political uncertainty, to the point where *"politically, it can be forgotten or not considered part of it"* (Interview 112), which can often lead to it being avoided all together. This highlights how land use issues can be side-lined in political discourse. The avoidance of land use issues can lead to gaps in climate policies and undermine efforts to address critical environmental challenges (Roe *et al.*, 2019; Nabuurs *et al.*, 2022). Especially in developing countries where land rights and enforcement issues can be complex, political avoidance can prevent meaningful progress on climate goals (Boateng *et al.*, 2017; Dsa and Ghosh, 2023), although it is important to recognise how different developing countries, or LMIC, can be and thus the approach to and history of land tenure is differing (Stoddard *et al.*, 2021). This is especially true though in developing countries where land right issues and enforcement can be difficult; this was explicitly mentioned by several interviewees. The complexity and contentious nature of land use make it a politically sensitive topic, leading politicians to potentially avoid it to prevent alienating key voter groups. *"So I think (land/land use) politically it's somewhat of an easy win. But in reality, it's the hardest one to get right"* (Interview 112); the improvement of the land sector, within the calculators and broadly, is not a straight forward matter.

Building Trust in Climate Tools Amidst Political Uncertainty

This political will that has been seen impacting the inclusion of the land sector within the calculators, can be extended further into the other main theme that arose through the interviews; the calculator relies on 'buy in', for the initial development, for the tool to be believable and for the tool to have continued use. Broadly speaking, this highlights the intersection of technology, psychology, and user engagement in tool adoption (Chung *et al.*, 2021). The success of the calculator is not solely dependent on its technical accuracy or functionality, but also on the perception and trust of its users (Abdollahpouri *et al.*, 2020; Chung *et al.*, 2021). This phenomenon underscores the importance of user-centred design and the need for continuous feedback and improvement. Individuals can make an impact on the utility of the calculator.

The initial development of the calculator often hinges on the enthusiasm and commitment of key advocates. These early proponents, driven by passion and a belief in the tool's potential, are essential for sparking the momentum needed for development; *"either you've got to have somebody that really buys into the character's approach, or you're in a country where they just don't have the modelling."* (Interview 112). However, this interviewee highlighted that the departure of these key champions can lead to stagnation or even a decline in the project's progress; *"[...] if somebody leaves, the senior person who's like the sponsor for it, if they leave, then the support could go."* (Interview 112), emphasising that the project's inception and longevity depend on these individuals' dedication. This scenario illustrates the precarious nature of such initiatives, where the absence of continuous, passionate advocacy can result in minimal development and a loss of relevance (Gislason *et al.*, 2021).

The sustainability of the calculator is thus heavily reliant on the presence of dedicated champions who can navigate the political and organisational landscapes to maintain support and momentum.

The development and sustainability of the calculator are also subject to the varying talents and efforts of the individuals involved, with the calculators *“sometimes hav[ing] very arbitrary amounts of effort put into them based on the talents of the individuals involved.”* (Interview 212). This variability highlights the need for committed and skilled advocates who genuinely believe in the tool's approach and objectives. In environments lacking such advocates or infrastructure for proper modelling, initiative development and implementation can suffer (Gislason *et al.*, 2021). Whilst this study does not look at decision support tools specifically, it highlights how project and place-based communication is heavily impacted by the presence, or absence, of climate champions. Whilst this is different to the climate calculators as there is a core UK team to support the main programme, individual country calculators require internal advocacy to produce, reflecting a complex intersection of users, support tools and governments (Chung *et al.*, 2021). This balance underscores the importance of continuous strategic backing and the risk that without it, the calculator may fail. In the land sector, where accurate data and modelling are crucial for policy-making, the tool's effectiveness directly impacts planning and implementation processes. Therefore, the loss of key advocates can undermine the effectiveness of policies and land-use planning, highlighting the need for sustained, dedicated support (Gislason *et al.*, 2021).

Buy-in is essential not just for developing the calculator but also for ensuring its continued use and effectiveness. Trust in the calculator is built on the belief that data is presented fairly and accurately, which requires transparency and thoroughness (Voinov *et al.*, 2018). However, this also raises the potential for conflict, as stakeholders may be upset if their priorities are not fully represented. The challenge lies in balancing comprehensive data inclusion with user satisfaction, ensuring that the tool remains credible and useful (Voinov *et al.*, 2018; Abdollahpouri *et al.*, 2020). Sustained use of the tool relies on passionate champions who understand its potential and can advocate for its integration into policy-making, playing a crucial role in aligning the tool with broader policy goals and navigating the political landscape (Gislason *et al.*, 2021). This engagement is crucial because initial scepticism or outright hostility, particularly if the tool does not align with established economic models, can hinder its acceptance and utility; *“There was a lot of sort of scepticism and sort of outright hostility because it wasn't, and it wasn't an economic model.”* (Interview 1212). **The success of the calculator is therefore as much about strategic advocacy and alignment as it is about the tool's technical merits**, highlighting the complex interplay between technology, politics, and human behaviour in addressing climate change. Additionally, *“it's kind of a case of timing as well and making sure that like the people that you're talking to who are working on the calculator that are also working on these other bits of policies.”* (Interview 912), to ensure cohesive and comprehensive implementation. This highlights that successful adoption and continued use are as much about strategic advocacy and alignment as they are about the tool's technical merits.

Different elements of how land is complex, and the challenges associated with addressing climate change, could be seen throughout the interviews. There is potential conflict between maintaining high standards of living and meeting climate change targets, especially when considering *“the behavioural stuff isn't as well represented as it could be given the evidence we've got.”* (Interview 412), despite substantial evidence supporting their importance regarding the representation of behavioural factors in climate models. This gap highlights a critical challenge in climate policy: **while the technical aspects of emissions and environmental impacts are well-documented, the ways in which human behaviour influences these factors are often overlooked**. There are multifaceted and often conflicting priorities involved in climate policy, illustrating the tension between economic development and environmental

sustainability. This narrative reflects the diverse motivations and resistance to change among different stakeholders, tying into land and food systems by emphasising the critical role of agricultural practices in climate strategies and the need for comprehensive approaches that consider behavioural, economic, and environmental factors.

7.4. Discussion Continued

There are several key points derived from these interviews that bring new insights to the discussions in previous chapters, particularly when considering the interplay between technology, land use, and decarbonisation strategies. The interviews shed light on the complexities surrounding the integration of negative emissions technologies within the energy sector (see section 7.2.5.). This integration is essential for achieving the goals of carbon capture and storage (CCS) and other emissions reduction methods. However, the interviews also emphasise the critical role that the land sector plays in this process, highlighting the competition for land use between energy technologies and natural climate solutions. This competition underscores the importance of strategic land use planning in achieving decarbonisation objectives and balancing them with other essential land functions.

One key element from the interviews is that there is a balance to be struck between emissions reductions and land use, a balance that is at the heart of achieving net-zero goals. This balance between energy and land use is highlighted by both energy technology and natural-based solutions (NBS), with each playing a significant role in the overall strategy of decarbonisation. While the interviews reaffirm the significance of this balance, they also reveal a nuanced understanding of the differing terminologies used in chapter 6, particularly the distinction between decarbonisation and net zero. Decarbonisation is primarily concerned with the removal of emissions, whereas net zero involves a more comprehensive approach that balances emissions reductions with the enhancement of carbon sinks (see section 1.1.6, IPCC definitions). Despite this critical distinction, as seen in chapter 6 the calculator programme does not explicitly differentiate between these concepts, potentially leading to confusion or oversimplification in the application of climate strategies.

Interestingly, the interviewees demonstrate a more refined understanding of these concepts, often differentiating between decarbonisation and net zero in ways that the calculator programme does not. This raises important questions about the role of human interpretation in the use and understanding of climate tools. The interviews suggest that human behaviour, interpretation, and divergent perspectives play a significant role in how these tools are perceived and utilised (see section 7.3.1, 7.3.2 and 7.3.3). This theme is central to the chapter, highlighting the duality between the intended design of the calculators and their perceived uses by different stakeholders. The discrepancies between the designed uses and perceived uses of these tools could lead to varied outcomes in climate policy and action, emphasising the need for greater alignment between the tool's objectives and user understanding.

7.4.1. Answering the aim

The cataloguing of the calculators and validation study was designed to help answer the second aim of this thesis, *“Understand the role of climate calculators in reconciling the gaps in the current system”*, by focusing on the objective *“Develop an understanding of the influence calculators have had and could have on policy development”*. By exploring the diverse participant perspectives (7.3.1), the chapter illuminates how different stakeholders perceive and interact with these calculators, highlighting both their strengths and limitations in achieving broader climate goals. This perspective is essential for identifying where the design intentions of these calculators may not align with the perceived needs of users (see section 7.3.2). Such misalignments can significantly inhibit the broader impact these tools are intended to have on policy development, which is particularly concerning when considering that the initial framework of these calculators was heavily influenced by the UK's approach (UK Govt, 2013; UK Govt, 2023). This framework could introduce inherent biases, potentially skewing the design and functionality of calculators to reflect certain priorities over others, limiting their adaptability to the diverse needs and circumstances of different countries.

One key assumption to challenge from the programme's perspective is that all countries prioritise their NDCs in the same way the UK did (Leinaweave and Thomson, 2021). However, as countries have gained flexibility to develop climate calculators tailored to their specific needs, the initial biases rooted in the UK's approach could still persist, potentially making the tools less effective in capturing the unique dynamics of various sectors, including land use and agriculture. This is significant because these biases might result in calculators that do not fully align with the specific environmental, economic, and social contexts of all nations, thereby reducing their effectiveness and relevance in addressing global climate challenges comprehensively. This limitation could hinder the potential of calculators to drive tailored and impactful policy decisions, particularly in sectors like land use, where local context is crucial (Harenda *et al.*, 2018). The potential use of the calculator extends beyond its immediate application as a policy tool; it fosters international cooperation by engaging countries in a shared programme (Strapasson *et al.*, 2020; Strapasson *et al.*, 2022). Whilst all studies published specifically about the climate calculator programme and affiliated calculators are written by a small group of authors (Strapasson *et al.*, 2017; Strapasson *et al.*, 2020; Strapasson *et al.*, 2022), which could introduce bias, the programme itself has had to go through several stages of review and iterative design, including critique, making it less likely that commentary about the programme is biased. Additionally, the programme, the calculators and the research on these have all been heavily international, collaborative and transparent processes, which increases robustness (Anderies *et al.*, 2013). This collaborative aspect is significant as it promotes the exchange of knowledge and best practices, which is crucial for enhancing the global response to climate change, as well as ensuring local context is fairly represented.

The discussions on the nexus of energy and land use (7.2.5) further emphasise the importance of cross-sector integration in developing sustainable climate policies. By linking energy technologies with land use considerations, the chapter demonstrates how interconnected these sectors are and the necessity of considering these links in policy-making. This integration is crucial for creating policies that are not only effective in reducing emissions but also sustainable in the long term (Faldutoi and Rochai, 2020). However, current calculators often do not fully capture the complexities of behaviour, diet, and food systems, limiting their potential to drive holistic climate action (see chapter 6). Enhancing these tools to incorporate more comprehensive factors will enable them to address a broader range of issues and support more effective and inclusive policy development, ensuring that they reflect not only current land sector dynamics but also anticipate and guide future climate strategies.

Finally, the chapter's focus on building trust in climate tools amidst political uncertainty underscores the importance of credibility and transparency in the development and use of these calculators. Trust is a fundamental component of effective policy-making, and without it, even the most well-designed tools may fail to achieve their intended impact (Abu-Salma *et al.*, 2017). This is particularly important given the varied perceptions and expectations highlighted in the interviews, which suggest that human behaviour, interpretation, and divergent perspectives play a significant role in how these calculators are utilised (Chung *et al.*, 2021). This theme of duality—comparing the designed uses and perceived uses of the calculators—underscores the complex interplay between technology, politics, and human behaviour in addressing climate change. Looking to the future, it is crucial to consider how climate calculators can be improved to better meet the gaps identified in this thesis, ensuring that they not only guide current policy but also adapt to evolving challenges in climate strategy.

8. Discussion

This thesis has investigated the climate calculator's capacity to bridge the emissions gap (seen where current efforts are insufficient to hit global warming limits of 1.5°C, let alone 2°C (Anderson *et al.*, 2020; UNEP, 2017)) and assessed successes and identified areas for improvement to enhance the climate calculators role as a decision support tool (DST) and their effectiveness in the area of helping identify material interventions to minimise the emissions gap. By examining national policies enacted since the Paris Agreement, this research evaluated how the calculators reflect the land sector of various countries and their effectiveness in advancing climate policies. The goal is to understand how these tools can better support sustainable land use and environmental conservation efforts using the intra-design component of the climate calculators as a probe to investigate a country's capacity and willingness to view the land sector as a tool for mitigation.

A key objective of DST developers is to enhance multi-stakeholder and whole-system decision analysis and participatory processes (Brunner and Weibel, 2017; Hinson *et al.*, 2022). These tools facilitate structured decision-making, robust decision-making, and analytic-deliberative processes. These approaches are designed to yield sustainability policies and projects of superior 'decision quality' compared to those developed without such methodologies (Janssen *et al.*, 2017; Zhai *et al.*, 2020). A DST is considered successful if it meets criteria or possesses characteristics that improve decision quality (Wong-Parodi *et al.*, 2020), but defining 'decision quality' consistently remains challenging across various domains, including the land sector. However, a robust definition of 'decision quality' remains elusive and difficult to bound across various domains. Despite the potential benefits of using DSTs, systematic and comprehensive management of uncertainty and risk remains a significant challenge (Shepherd *et al.*, 2018). Although DSTs aim to tackle systematic and comprehensive management of uncertainty and risk, the persistent gap in achieving land-based commitments highlights the difficulty in consistently attaining and measuring high decision quality, as no single framework can address the full spectrum of conservation planning and decision challenges (Schwartz *et al.*, 2018).

In the land sector, decision quality encompasses several critical attributes, including the integration of diverse stakeholder perspectives, the use of robust and transparent decision-making frameworks, and alignment with sustainability goals (McElwee *et al.*, 2020). High decision quality involves processes that ensure inclusivity, engaging landowners, local communities, environmental groups, and governmental bodies (Zamarioli *et al.*, 2020). This inclusivity means that decisions better reflect a broad range of interests and expertise, leading to balanced and equitable outcomes. Additionally, robust decision-making frameworks, such as structured decision-making or robust decision-making, provide systematic and repeatable methodologies that enhance the credibility and reliability of decisions (Kusters *et al.*, 2020). Furthermore, decision quality in the land sector necessitates rigorous data analysis and evidence-based approaches that consider long-term environmental, economic, and social impacts. Effective decisions are transparent, with clear documentation and communication of the criteria and rationale behind choices, fostering trust and accountability among stakeholders (McElwee *et al.*, 2020). Sustainability is a core element, ensuring that land use decisions promote conservation, biodiversity, and resilience to climate change. Thus, high decision quality in the land sector not only addresses immediate needs but also contributes to the enduring health and vitality of the land and its ecosystems.

Despite numerous pledges and initiatives, achieving land-based commitments remains a challenge. Many regions continue to experience deforestation, habitat loss, and unsustainable land use practices, undermining global goals for conservation and climate change mitigation (Roe *et al.*, 2019; Nabuurs

et al., 2022). There is a lack of in-depth understanding of the problem and potential technological and behavioural solutions at the national scale, leading to inadequate implementation and the perpetuation of the gap between commitments and actual progress (Grassi *et al.*, 2021; Nabuurs *et al.*, 2022). Socio-economic pressures and competing land-use demands exacerbate these challenges, making it difficult to balance development needs with environmental sustainability across multiple trade-offs and synergies. To bridge this gap, there must be a renewed focus on robust policy enforcement, better knowledge on what does and doesn't work in terms of land management and provision of food security at the appropriate spatial and temporal scales, and enhanced collaboration across all sectors involved in land stewardship.

This thesis investigated the 'The utility of Climate Calculators as climate policy decision support tools in bridging the global land sector emissions gap', using an iterative theory-building framework, allowing for continuous iteration of research design enabling the later stage chapters to be informed by early stage ones. The discussion is structured in the following way:

1. The energy-land nexus presents challenges for integrated approaches despite historic tackling of energy solutions
2. Land use for food production is the major driver of LU and LUC and global GHG emissions.
3. Including a dynamic food system model in Decision Support Tools is crucial, as shown by the global calculator, for timely technology and policy interventions.
4. At the National and subnational level however, no calculators include food systems
5. There are key barriers to the inclusion of food system dynamics in climate mitigation and adaptation that this work has identified, including:
 - a. Language inconsistencies
 - b. Reporting inconsistencies
 - c. Increased need to recognise the duality of DSTs

Key takeaway:

A comprehensive approach is one that acknowledges the shortcomings of current efforts and strives to understand why these gaps exist. It aims to integrate the missing components of the land sector, such as the food system, into future DSTs and policies. This approach involves overcoming the current difficulties within the land sector that inhibit the creation of better policies. By addressing these challenges, we can develop more effective and holistic strategies for sustainable land management and conservation.

8.1. The Energy-Land Nexus Presents Challenges for Integrated Approaches Despite Historic Tackling of Energy Solutions

The energy sector has been the dominant, near exclusive, focus of national and international climate policy to date, as shown by the literature review (chapter 1) and in the results chapters; NDC analysis (chapter 4), systematic map (chapter 5), climate calculator analysis (chapter 6) and key informant interviews (chapter 7).

The energy sector has dominated climate policy analyses and international agreements, as shown by the literature review (chapter 1) and within all four of the results chapters; NDC analysis (chapter 4), systematic map (chapter 5), climate calculator analysis (chapter 6) and key informant interviews (chapter 7). These chapters consistently highlight the significant attention and resources devoted to the energy sector, showcasing a robust framework for understanding and addressing energy-related climate challenges. This comprehensive approach contrasts sharply with the treatment of the land sector, which often lacks the same level of detail and commitment in climate policies and tools.

Historically, the energy sector has been the primary focus of climate calculators within programs and national and international climate policy (Ahmad and Zhang, 2020). This focus stems from the energy sector being a major contributor to GHG emissions, making it a critical target for climate mitigation efforts, as well as the sector's relatively straightforward metrics (Ortega-Ruiz *et al.*, 2022). Established technologies for measuring and reducing emissions make the energy sector an attractive area for policymakers and technologists (Lyu and Liu, 2021). For example, the widespread adoption of renewable energy sources like solar and wind power, alongside advancements in energy efficiency, exemplifies how the energy sector has been prioritised. These technologies not only reduce emissions but also provide clear and measurable benefits, which can be easily integrated into climate models and calculators (Olabi and Abdelkareem, 2022). However, it is important to recognise that while these technological advancements are promising, they also present challenges such as high initial costs, the need for substantial infrastructure investments, and the issue of managing electronic waste (Fawzy *et al.*, 2020; Olabi and Abdelkareem, 2022). Additionally, the benefits of these technologies are not uniformly distributed, often favouring developed countries over developing ones, thus exacerbating global inequalities.

The energy system, despite its advancements, remains challenging enough that when considered alongside the needs of the land sector, there must be serious reflection on the current approach. The land sector presents unique complexities that are not as easily addressed by technological solutions alone (Droli *et al.*, 2019). Issues such as land use change, deforestation, and soil degradation require integrated approaches that consider social, economic, and environmental factors. Despite substantive overlaps between the energy and land sectors, the energy sector's focus on technological solutions may not translate directly to the land sector, where policies must balance multiple, often competing, interests and long-term ecological impacts (Bowen *et al.*, 2017; Gomez-Echeverri, 2018; Filipović *et al.*, 2022). Whilst the energy sector provides valuable lessons and frameworks for climate action, it also highlights the need for a more nuanced and integrated approach to the land sector. This historic lack of focus on the land sector and lack of willingness to address its complexities has been echoed in the recent developments of the national climate calculators in this area. Reasons for this include the complexity and variability of land use practices, the close coupling of land, food and culture, the diverse socio-economic contexts, and the historical focus on industrial and energy-related emissions (Smith *et al.*, 2020).

Chapter 7 assessed the land sector as a significant constraint to other sectors, including energy. For example, the expansion of renewable energy projects, such as large-scale solar farms or bioenergy

production, can compete with agricultural land, leading to confusion and even direct conflict over land use priorities. The resulting strain food production systems, exacerbates land degradation and increases pressure on already vulnerable ecosystems (Muscat *et al.*, 2020; Smith *et al.*, 2020). This underscores the interconnectedness of the energy and land sectors and the necessity of developing policies that can reconcile these competing demands. The interplay between energy and land use is particularly evident when considering the competing demands on land for food production, bioenergy, and conservation, the interface of which can reduce the land available for food production, thereby exacerbating food security issues (Fujimori *et al.*, 2022; Azmi *et al.*, 2023). These trade-offs highlight the need for integrated approaches that consider both sectors simultaneously, rather than in isolation. The energy sector's success in developing and implementing climate solutions offers valuable insights, but it also underscores the limitations of a siloed approach. Addressing the energy-land nexus requires a broader perspective that includes socio-economic factors, land tenure systems, the rights of indigenous and local communities, through to dietary choice and nutritional health, all of which play crucial roles in land management (Filipović *et al.*, 2022).

The pressures of feeding a growing global population, coupled with demands for bioenergy and conservation, create a complex landscape with inevitable trade-offs (Muscat *et al.*, 2020). These competing priorities make developing cohesive policies that address both energy and land sector goals challenging. Therefore, understanding the energy-land nexus is not just about bridging the gap between these two sectors; it is also about recognising the central role of food production in shaping land use patterns and, consequently, the effectiveness of climate mitigation strategies.

8.2. Food Production is a Major Driver of Land Use, Land Use Change and Global GHG Emissions

Land sector is represented in most national calculators but the acknowledgement that land use for food production is the major driver of LU and LUC and global GHG emissions is not

The interplay between food production and land use is central to understanding global environmental change, yet its significance is often underrepresented in climate policy and tools. The land sector is present within the international conversation around climate change, but it requires substantive and material improvements as evidenced by the insufficient efforts to limit global warming. Food production is the primary driver of land use and land use change (LUC), processes that are directly linked to significant greenhouse gas (GHG) emissions (Forsell *et al.*, 2016; Tacconi and Muttaqin, 2019b). The Intergovernmental Panel on Climate Change (IPCC) reports indicate that greenhouse gas emissions reached their highest levels in 2023, underscoring the urgent need for more effective land-based climate strategies (IPCC, 2023). This trend highlights the failure to implement adequate land sector policies and actions that can contribute to the global goal of reducing emissions and mitigating climate change. The current state of affairs suggests that while the land sector is acknowledged, the actions taken are far from sufficient to make a meaningful impact. This omission poses serious challenges to the effectiveness of climate mitigation strategies, as it obscures one of the most substantial contributors to global emissions.

Food production exerts a profound influence on land use decisions, dictating the conversion of natural landscapes into agricultural land and driving LUC at a global scale (Bauck, 2023). For instance, deforestation in the Amazon Basin is largely driven by the expansion of soy and cattle farming, which not only transforms forests into farmland but also releases vast amounts of stored carbon into the atmosphere (Haddad *et al.*, 2024). Similarly, the conversion of grasslands and wetlands into arable land for crops like palm oil and rice leads to significant alterations in land cover and ecosystem services, with far-reaching implications for biodiversity and climate stability (Shi *et al.*, 2024).

These changes in land use are not just about the physical transformation of landscapes; they represent a shift in the ecological balance that can have cascading effects on climate systems. The conversion of forests to agricultural land, for example, reduces the planet's capacity to sequester carbon, while the cultivation of crops on previously untouched land can lead to soil degradation and reduced water retention, exacerbating the impacts of climate change (Smith *et al.*, 2019). The way land is represented in language use and conditionality has been heavily variable, as shown in the NDC analysis (see chapter 4), systematic map (see chapter 5), and calculator cataloguing results chapters (see chapter 6). These inconsistencies in terminology and conditions attached to commitments create significant barriers to achieving cohesive and effective climate policies. The critical point here is that food production is not merely a sector that needs to be accounted for; it is a driving force behind the land use decisions that shape the global carbon cycle and, by extension, the climate itself. Failing to adequately address the impacts of food production on land use, broader climate goals are undermined by allowing one of the most potent sources of emissions and environmental degradation to continue unchecked (Smith *et al.*, 2019; Nabuurs *et al.*, 2022).

The contribution of food production to global GHG emissions is substantial and multifaceted. Agricultural activities, including livestock farming, rice cultivation, and synthetic fertiliser use, are significant sources of CH₄ and N₂O, two potent greenhouse gases (see section 1.2.). These emissions are not just by-products of food production; they are integral to the processes that sustain global agriculture (Jones *et al.*, 2023). Underestimating the role of food production in contributing to GHG emissions, risks creating climate policies that are blind to one of the largest and most complex sources of emissions (Pawlak and Kołodziejczak, 2020). Without targeted strategies to mitigate these emissions, efforts to reduce global GHG levels will fall short, and the ambitious targets set by international agreements like the Paris Accord will be unattainable (Anderson *et al.*, 2020).

The IPCC's AR6 report has highlighted the critical importance of the food sector and the significant gap in its inclusion within current policies (IPCC, 2024). The food sector's contributions to emissions, through practices like agriculture and livestock management, are substantial. However, despite this recognition, food and diet are not included in any climate calculators or many policies. (see chapters 4 and 5). This omission reflects a significant oversight, considering the intertwined nature of food systems with land use and climate change. Understanding the scale and sources of these emissions is crucial for crafting effective climate policies. For instance, efforts to reduce emissions from the energy sector are critical, but if these efforts are not matched by equally robust strategies in the agricultural sector, the overall impact on global GHG levels will be insufficient (Anderson *et al.*, 2020). This imbalance in policy focus highlights a significant gap in current climate strategies, where the emphasis on energy overshadows the equally urgent need to address emissions from food production.

In conclusion, food production is a central driver of land use, land use change, and global GHG emissions, yet it remains inadequately addressed in climate policy and tools. Climate calculators reflect the state of each nation's land sector landscape, but this reflection alone is not sufficient to support policy creation that will guide us toward the 2°C pathway, let alone the more ambitious 1.5°C target (Anderson *et al.*, 2020; UNEP, 2017). While these tools provide valuable insights into national land use practices and potential areas for improvement, they lack the capacity to drive the necessary policy changes. To meet global climate targets, it is essential that we develop a more comprehensive approach that acknowledges and addresses the full impact of food production on the environment. Effective policy creation requires not only accurate data but also a commitment to integrating this data into actionable and enforceable strategies (Das and Ghosh, 2023). This will require not only better data and models but also a shift in policy focus to ensure that food production is given the attention it deserves in the global effort to combat climate change.

8.3. Dynamic Modelling of Food Systems for Effective Climate Action

The global calculator demonstrated the importance of including a dynamic representation of the food system in the Decision Support Tools to help develop appropriate and timely technological and behavioural interventions and policies

The Global Calculator allows users to model the impacts of various lifestyle, technological, and policy choices on global emissions, energy use, land use, and food production (Strapasson *et al.*, 2020). By integrating a wide range of data, including energy consumption, agricultural practices, and land use changes, the Global Calculator provides a comprehensive view of how different sectors interact and contribute to overall emissions. The significance of the Global Calculator lies in its ability to simulate the complex interconnections between different sectors, including the often-overlooked food system (Strapasson *et al.*, 2020). By incorporating food production, dietary patterns, and land use changes into its models, the calculator highlights the substantial impact of food systems on global emissions. The global calculator demonstrated the importance of including the food system by revealing how deeply interconnected food production, consumption, and land use are with global GHG emissions and environmental sustainability. By integrating data on agricultural practices, dietary patterns, and land use changes, the calculator was able to show that food systems contribute significantly to emissions—comparable to, or even exceeding, those from energy systems (Strapasson *et al.*, 2020). This integration allowed for a more accurate assessment of the overall impact of human activities on climate change, highlighting that any effective climate policy must address food systems alongside energy, transportation, and industry.

The global calculator is not the only study that has highlighted the importance of including the food system in climate modelling (IPCC, 2018; Roe *et al.*, 2021). However, it uniquely emphasises the intricate connections between food systems, land use, and GHG emissions in ways that other models might overlook. For instance, while other studies might focus primarily on the direct emissions from agricultural activities or the carbon footprint of food production (Jägermeyr *et al.*, 2021; Shabir *et al.*, 2023), the Global Calculator goes further by integrating these factors into a broader context. It examines how shifts in dietary patterns, changes in agricultural practices, and land use dynamics interact with one another, influencing both local and global environmental outcomes. This broader, integrated perspective adds depth to the ongoing discussion about food systems and climate change, particularly by demonstrating how interventions in the food sector can have cascading effects across the entire climate system (Strapasson *et al.*, 2020).

This is significant because it underscores the need for a holistic approach to climate action. Traditional models and decision-support tools often focus primarily on energy and industrial emissions, overlooking the substantial role that food systems play in driving land use change, deforestation, and methane emissions from agriculture (Grêt-Regamey *et al.*, 2017). By failing to include food systems, policymakers might miss key opportunities for mitigation and adaptation, potentially leading to policies that are less effective or even counterproductive (Smith *et al.*, 2019). The global calculator's findings emphasise that comprehensive climate strategies must include interventions targeting food production and consumption, such as promoting sustainable agricultural practices, reducing food waste, and encouraging dietary shifts toward less resource-intensive foods. This broader perspective is crucial for achieving the deep emissions reductions required to meet global climate targets and for fostering sustainable development across all sectors.

The global calculator highlighted the critical need for including a dynamic representation of the food system within DSTs. This inclusion is essential for developing appropriate and timely technological and behavioural interventions and policies. By integrating a more comprehensive model of food systems,

the global calculator showcased how food production, consumption patterns, and land use are intricately connected to greenhouse gas emissions and environmental sustainability. Without such a dynamic representation, DSTs risk oversimplifying the complex interactions between food systems and climate change, potentially leading to policies that are misaligned with the realities on the ground (Doherty *et al.*, 2023). For instance, food production's impact on land use and emissions is not static; it fluctuates with changes in diet, agricultural practices, and economic conditions (Prudhomme *et al.*, 2020; Oberlack *et al.*, 2021). Therefore, a more nuanced approach that accounts for these variables is necessary to develop interventions that can effectively address both current and future challenges in food systems and their environmental impacts. However, food systems are influenced by a vast array of factors, including socio-economic conditions, cultural preferences, and technological advancements, all of which are challenging to model accurately (Crippa *et al.*, 2021; Doherty *et al.*, 2021). Critics might argue that the complexity of these systems could lead to uncertainties in the outputs of the calculator, making it difficult to develop concrete policies based on its findings. Furthermore, the dynamic nature of food systems means that the results from such tools could quickly become outdated, requiring constant updates and recalibrations to maintain their relevance (Fanzo *et al.*, 2021).

Despite this, the inclusion of a dynamic representation of the food system remains crucial. While no model can perfectly capture the intricacies of global food systems, the global calculator's findings underscore the importance of striving for as accurate and comprehensive a representation as possible (Tubiello *et al.*, 2021). The potential uncertainties should be viewed not as a reason to dismiss the findings but as an inherent aspect of working with complex systems. By continuously refining these models and integrating the latest data, DSTs can still provide valuable insights that inform more effective and adaptable policy interventions. Ultimately, the inclusion of a dynamic food system representation enhances the robustness of DSTs, making them better equipped to support policies that address the interlinked challenges of food security, land use, and climate change (Durán-Díaz, 2023). Without such representation, it is harder to identify how the integration of food systems into such holistic models is crucial in bringing attention to the need for comprehensive climate policies that go beyond energy and industrial sectors. The Global Calculator thus serves as a valuable resource for developing more holistic and effective climate strategies, emphasising the importance of including all major sources of emissions in policy discussions and decision-making processes.

8.4. At the National and Subnational Level Calculators Omit Food Systems

What's missing- from NDCs, from the calculators- is food.

The omission of food and diet from most climate calculators and policies represents a significant gap in addressing the full scope of environmental challenges. Food production and consumption patterns are major drivers of land use change, deforestation, and GHG emissions, yet these factors are often overlooked in national and subnational climate action plans (Siegal and Lima, 2020). Food accounts for approximately 30% of global GHG emissions and has substantial overlap with land use (see section 1.2.). However, most climate calculators and frameworks focus primarily on energy and industrial emissions, missing the critical role of food systems (see chapter 6). This exclusion leads to an incomplete picture of a country's climate impact and mitigation potential, which undermines efforts to create effective and holistic strategies. Given the significant contribution of food systems to global GHG emissions, it is essential that these aspects be incorporated into climate policies and calculators. Without this integration, national strategies may fail to align with global climate goals, reducing the efficacy of monitoring, reporting, and ultimately, action on climate change.

What's missing in current climate calculators and policies is the critical inclusion of food systems. While the calculators have proven effective in other sectors, as evidenced by the results from previous chapters, they have not adequately addressed the complexities of food. This omission is particularly concerning because food systems are deeply intertwined with land and energy sectors, making it difficult to isolate them into distinct categories (Gerber *et al.*, 2013). The exclusion of food systems from these tools not only reflects a broader challenge of addressing sectors that overlap significantly, but it also risks the creation of policies that are disconnected from the realities of how these sectors interact (Filipović *et al.*, 2022). This interconnectedness complicates policy formulation and the creation of effective calculators, as shown by the key informant interviews that underscore the complexity of food systems and their significant overlap with other sectors.

Furthermore, food systems are not only tightly woven into land and energy sectors but also deeply embedded in human and cultural contexts, adding another layer of complexity to their inclusion in climate policies (Von Braun *et al.*, 2021). Unlike the more technical and industrial nature of the energy sector, food involves everyday human behaviours and cultural practices, which vary widely across regions (Von Braun *et al.*, 2021). This human dimension makes it challenging to develop universal strategies that can be effectively applied across different contexts (Zurek *et al.*, 2022). The omission of food from climate policy and calculators is a significant oversight with far-reaching implications, as it not only underestimates a major source of emissions but also misses opportunities for holistic environmental stewardship (Wezel *et al.*, 2020). Ignoring the food sector in climate models can lead to incomplete or misguided policies that do not address the full spectrum of climate change drivers. Moreover, the sensitivity surrounding food as a fundamental human right and its direct impact on human well-being further complicates political discussions and policy decisions (Muluneh, 2021). Policymakers must navigate the delicate balance between ensuring food security and promoting sustainable agricultural practices, a task that is often fraught with political and social resistance.

In a broader sense, the reluctance to integrate food systems into climate calculators reflects the political and economic complexities tied to the agricultural sector (Crumpler *et al.*, 2019). This reluctance can perpetuate unsustainable practices and delay necessary transitions to more sustainable food systems. By not addressing food production's environmental impacts, policymakers risk failing to meet climate targets and exacerbating food security issues. Integrating food into climate calculators and policies is crucial for developing comprehensive strategies that encompass all major sources of emissions, promote sustainable land use, and ensure food security while mitigating climate change. This integration is not just about enhancing the accuracy of climate models, but also about aligning climate action with broader sustainability goals, ensuring a more resilient and equitable future. Without this, efforts to combat climate change remain incomplete, potentially undermining the very goals they aim to achieve.

8.5. Barriers to Integrating Food Systems in Climate Policy: Addressing Language and Reporting Challenges

This work identifies key barriers to the inclusion of food systems dynamics in climate mitigation and adaptation including: language inconsistencies, reporting inconsistencies and the increased need to recognise the duality of DST

Key metrics, data presentation and language are inconsistently presented within land sector representation, across different nations. Various methods, such as different approaches to Nationally Determined Contributions (NDCs) and studies by den Elzen *et al* (2014), evidence this, and are key reasons that indicate why the development of successful land sector policy creation is being inhibited. These are all factors that need to be considered when not just addressing the climate crisis, but the way in which we should be acting in the face of an imminent crisis (Gills and Morgan, 2022).

8.5.1. Language Inconsistencies

Language inconsistencies, specifically erroneous application of terminology, is a key reason that indicates why recent and current land sector policy creation is inhibited and unsuccessful.

Language plays a significant role in understanding interests and land-based concepts, especially when the language differences are being presented by different actors (Otchere-Darko and Ovadia, 2020); in this case, different countries. Whilst this is seen more with state actors and local communities and localised land-based examples, conceptually this can be scaled up to a global level to reflect the importance of shared values and interpretations of land-based language.

Language evolves over time, and part of this is the development and use of new terminologies that better represent the desired meaning (Füssel and Klein, 2006). While AFOLU serves a specific purpose in the context of climate change mitigation and adaptation, its usage may shift over time as new concepts and terminologies emerge. This is why evaluating the land terminologies used is important, so as not to continue aggregating the land sector under the term “AFOLU” and not questioning whether all definitions of this are the same. After all, studies have highlighted that AFOLU, as an aggregate, contains a lot of uncertainty (Lee and Sanz, 2017). Perpetuating this uncertainty can be avoided by clarifying land terminology meanings and standardised protocol such as those in the national GHG inventory. Overall, whilst AFOLU provides a comprehensive framework for addressing land-based contributions to climate change, its adoption varies depending on factors such as complexity, familiarity, alternative terminologies, regional differences, and the evolving nature of language and discourse

On a global scale the land sector is hard to standardise; standardised language ensures that terms and concepts have clear and precise definitions, reducing ambiguity and misunderstanding among policymakers, stakeholders, and the public (Ho *et al.*, 2015). This facilitates international cooperation and assessment of the effectiveness of climate change mitigation and adaptation efforts (Carattini *et al.*, 2021). Conflicting language definitions, and the values these present, can lead to the instance of those in a more influential or powerful position delegitimising local level interpretations and values attributed to land.

Land is part of a complex interdependent system; introducing language issues increases complexity and incommensurability in decision-making. The question needs to be asked if these terminologies are referencing the same concepts, or if despite all coming under a land-based banner that they are not reducible together, making comparison complex (O'Neill, 2002). The alignment of standards is a complex task, which among others includes the development of vocabularies used or implied by the standards that are going to be aligned.

The importance of this is not just isolated to the land sector, but to broader efforts towards emissions reductions; another critical language issue in climate policy is the conflation between "decarbonisation" and "net zero". While both terms are often used interchangeably, they have distinct meanings. Decarbonisation refers to the reduction of carbon emissions, whereas net zero encompasses the balance between emissions produced and emissions removed from the atmosphere (IPCC, 2022). This distinction is crucial, as policies aimed at decarbonisation may focus solely on reducing emissions, potentially neglecting the need for carbon removal strategies essential to achieving net zero. The failure to clearly differentiate these terms can lead to policies that are less effective in achieving long-term climate goals.

Such inconsistencies in terminology and the lack of clear definitions in international agreements make it challenging to establish common goals and hold countries accountable. For instance, the varying terminology in NDCs complicates the creation of cohesive strategies to combat climate change. Precise language is essential for drafting legally binding commitments, and without it, agreements may contain ambiguities that undermine their effectiveness. This issue is particularly pertinent given the global nature of climate change and the need for coordinated international action. It can be seen in other studies that multiple meanings for terminologies has sparked discussion on whether the variation is a strength that facilitates more voices participating in discussions (Garmendia *et al.*, 2016; Mell and Clement, 2020; Matsler *et al.*, 2021) and allowing for locally appropriate application and solutions (Fletcher *et al.*, 2015), or a barrier to progress that introduces uncertainty around the relevancy of goals and specific actions required to meet them (Matsler *et al.*, 2021). Whilst Matsler *et al.* (2021) looks at a much more localised terminology, it emphasises reasons that inconsistency is detrimental to decision-making that are particularly pertinent to the land sector as a whole; depending on how a term is defined, it changes the association with other concepts that people place on it. Without some level of uniformity, it becomes difficult to compare information across different countries and regions, especially when comparing data.

Challenges already inherent with data collection within the land sector, such as data integrity and accuracy, are made worse by a lack of agreement on definitions and reporting standards (Grubert *et al.*, 2020). It was shown by Grubert *et al.* (2020) that relatively minor changes to definitions of key words, such as 'water consumption' can drastically change the end report on the volume of water consumed, with no change to the underlying data. This is true within the land sector, as shown by den Elzen *et al.* (2014). Quantitative impacts of imprecise units and data integrity are more difficult to estimate, but this work demonstrates that minor changes to reporting standards in these realms can substantially improve certainty. This might suggest that ambiguity in language use allows for those writing the NDCs to cherry pick language to present the land data in the most beneficial way to them possible.

This ambiguity and the potential for selective interpretation of data are particularly problematic when considering the inclusion of complex systems like food production in climate policies. The inclusion of food systems in climate calculators, such as the Global Calculator, marks a significant shift in how climate action is approached. Initially, these tools focused primarily on direct emissions from energy and industrial activities, neglecting the substantial impact of food production and consumption on GHG emissions and land use (UK Govt, 2013; Strapasson *et al.*, 2020). The need to incorporate food systems arose from the recognition that they are major drivers of environmental change, contributing to deforestation, land degradation, and significant portions of global emissions. This addition underscores the importance of creating comprehensive climate tools that address all major sources of GHGs, not just those directly tied to energy use. However, this inclusion also introduces complexity, as food systems are deeply intertwined with cultural practices, land use, and local economies, making

them challenging to standardise and manage within global climate frameworks (Von Braun *et al.*, 2021).

The complexity of integrating food systems into climate calculators is further compounded by the variations in how different regions and countries approach land use and food-related emissions. For instance, Kenya's KCERT model categorises land under "land, bioenergy, and waste," while the UK's MacKay Carbon Calculator uses the term "land use and biofuels" (UK Govt, 2023; KCERT, 2024). The Global Calculator takes a more detailed approach by distinguishing between "land and food" on the supply side and "diet" on the demand side. These differences reflect not only linguistic variations but also the distinct cultural, economic, and policy priorities of each region. In countries where food security is a primary concern, integrating food systems into climate calculators becomes even more complex, as policymakers must balance the need for climate mitigation with the imperative to ensure adequate and equitable food access (Bauck, 2023). This tension between local priorities and global climate goals highlights the need for flexible yet precise terminology that can accommodate diverse contexts without sacrificing the accuracy and utility of climate tools.

The importance of clear and consistent language in land use and food system policies cannot be overstated, especially in light of alarming trends such as rising malnutrition rates reported by the FAO. It is projected that nearly 600 million people will be chronically undernourished by the end of the decade, with global hunger having risen sharply from 2019 and 2021 to stay steady for three years at affecting 9.1% of the population (FAO, 2024). These figures underscore the critical role that land use plays in ensuring food security and addressing hunger. However, inconsistencies in language and reporting within the land sector have been significant barriers to effective policy-making and implementation. Without standardised terminology, it becomes difficult to develop coordinated strategies that can effectively address these urgent issues. The variations in how food and land use are represented in climate calculators across different countries not only hinder the creation of effective climate mitigation policies but also exacerbate global challenges like food insecurity. To overcome these barriers, there is an urgent need for standardized, yet adaptable, language that ensures clarity and comparability across regions while respecting local contexts and priorities.

In conclusion, the inconsistent application of terminology within the land sector significantly hinders the creation of effective climate policies. Addressing these language inconsistencies, including the conflation between terms like decarbonization and net zero, is crucial for enhancing the clarity, comparability, and effectiveness of climate action. Standardised yet adaptable language is essential for ensuring that policies are inclusive, transparent, and capable of driving meaningful progress towards global climate goals. Without this, efforts to combat climate change will remain fragmented and less effective, undermining the global response to one of the most pressing challenges of our time.

8.5.2. Reporting Inconsistencies

Inconsistent language in climate agreements exacerbates challenges in data collection and reporting within the land sector, leading to significant discrepancies in data interpretation and undermining the accuracy of climate assessments (Abrahams, 2020). This lack of consistency not only complicates the comparison of data across different countries but also affects the integrity and accuracy of climate assessments. As a result, policymakers may be working with incomplete or misleading information, which can lead to ineffective or misguided climate strategies. The inconsistent language and varying emphasis on land sectors within national commitments (NDCs) highlight the need for standardised and comprehensive reporting guidelines to improve clarity and ensure all critical aspects of land use are addressed.

The ambiguity surrounding conditional and unconditional commitments in NDCs further complicates the effectiveness of land-based climate policies. Clear distinctions between these commitments are

essential for assessing the feasibility and robustness of national pledges, yet many NDCs remain vague, particularly in how they address land use and decarbonisation (Will, 2020; Zaman, 2022; Elliot, 2023). This lack of clarity hinders transparent monitoring and accountability, making it difficult to track progress and hold countries responsible for their actions (Elliot, 2023). The disparity between wealthier nations and less developed countries (LDCs) in specifying conditionality also underscores the need for equitable support mechanisms. LDCs often rely on international assistance to fulfil their commitments, making clear and transparent conditionality crucial for fostering trust and ensuring that all nations can contribute effectively to global climate goals (Will, 2020; Elliot, 2023).

The variability in how countries specify conditionality in their NDCs reveals significant disparities in how climate commitments are approached and communicated (Will, 2020). Interestingly, most countries that did not specify conditionality were not recipients of Official Development Assistance (ODA) (see Chapter 4). This suggests that wealthier nations or those with greater resources might be more confident in their ability to meet commitments independently, or conversely, may not see the need to clarify conditions due to assumed self-sufficiency. For less developed countries, clear specification of conditionality is crucial, as their commitments often rely on international support and funding. Wealthier nations, less reliant on external funding, may be more confident in meeting their commitments independently, while LDCs often need to explicitly state their reliance on international support. This disparity highlights the importance of aligning international policies and support mechanisms to ensure all countries can meet their climate commitments. For LDCs, the clear specification of conditionality is not just a matter of transparency but a critical component of their ability to participate effectively in global climate strategies (Pauw *et al.*, 2020). Ensuring that these countries have the necessary resources and capacity to fulfil their commitments is essential for creating a more inclusive and effective global climate policy.

The inclusion of AFOLU in the climate discourse has introduced additional challenges in compliance and reporting (Verschuuren, 2022). As countries are at different stages of integrating AFOLU into their NDCs, the lack of standardised metrics and language complicates monitoring and comparing progress. This inconsistency creates gaps in reporting and accountability, making it difficult to accurately assess global progress and ensure all parties meet their commitments (Jalón, 2022; Vershuuren, 2022). Furthermore, the varying capacity of countries to adopt new terms and frameworks exacerbates these issues. Nations with limited resources may struggle to implement and report on climate actions effectively, creating an uneven playing field that undermines collective global efforts (Elliot, 2023). Addressing these capacity disparities and standardising metrics for AFOLU are essential steps toward cohesive and effective climate action in the land sector.

The current level of AFOLU commitments in many NDCs is not adequately supported by corresponding policies, which undermines their potential effectiveness (Droli *et al.*, 2019). While countries have made pledges related to agriculture, forestry, and other land uses, these commitments often lack the policy frameworks necessary to implement and sustain them (Forsell *et al.*, 2016; Luo *et al.*, 2024). This gap is especially pronounced when considering the distinction between conditional and unconditional commitments. Conditional commitments, which depend on external support or resources, are particularly vulnerable to underachievement if the requisite international assistance is not forthcoming (Taibi *et al.*, 2020). This issue is further complicated by the fact that not all countries possess the land capacity for nature-based solutions (NBS) or the financial resources to implement them effectively (Morri and Santolini, 2021). Decarbonisation efforts are closely linked to these land-based strategies and made more difficult to implement when terminology and reporting is inconsistent or erroneous. However, without robust policies to back these commitments, especially in nations where the land sector plays a critical role in climate mitigation, achieving net-zero targets

becomes increasingly difficult (Hall *et al.*, 2012; Hasan *et al.*, 2020). This highlights the need for integrated policies that align national land-based commitments with the global decarbonisation agenda, ensuring that both conditional and unconditional pledges are realistic and actionable.

It is important to review the language used and the conditionality of land-based commitments because it is these that the calculators are designed to help design or improve. It is important to be able to reflect the relationship a country has with the land sector through the conditionality of its land-based commitments as this shows the countries capacity and preferred area of land-based mitigation. The calculators should not feedback what a country wants to hear (like the FAO omitting the potential of dietary shifts in reducing GHG emissions) but rather presenting an unbiased, tailored set of decision-pathways that help achieve the lowest GHG emission trajectories as possible. Knowing conditionality and distribution of that conditionality across the globe and land terminologies can help this thesis review what kind of response the climate calculators have taken to this and whether they have directly mirrored language use or if the way the land sector has been included is reflective of other priorities (e.g. data set availability, creator bias etc) (see more in chapter 7).

Climate calculators are designed to assist in the development and improvement of national climate strategies, including those related to the land sector. However, these tools must provide unbiased, tailored decision pathways that reflect the true potential for reducing GHG emissions, rather than simply reinforcing existing national preferences or biases. Understanding the conditionality of land-based commitments and the distribution of these commitments globally can help refine climate calculators, ensuring they present the most effective strategies for achieving low-emission trajectories. By accurately reflecting the relationship between a country's land sector and its climate commitments, climate calculators can play a crucial role in shaping effective and equitable climate policies.

8.5.3. Increased need to recognise the duality of the climate calculators as DSTs

In the evolving landscape of global climate policy, the tools and frameworks used to guide action must be both robust and adaptable. As countries work to meet their climate commitments, particularly within the land sector, the variability in language, data interpretation, and conditional commitments presents significant challenges. These inconsistencies not only complicate the process of tracking and comparing national efforts but also undermine the effectiveness of international agreements. As climate calculators become increasingly central to shaping national strategies, there is a critical need to balance standardisation with flexibility, ensuring that DSTs such as the Calculators are both scientifically rigorous and contextually relevant.

Developing countries, particularly those in the global south, often have higher conditional commitments due to their dependence on international finance, technology transfer, and capacity-building support. Additionally, this design helps reflect fair responsibility; the Global North is historically the biggest driver of anthropogenic climate change, yet the Global South faces the majority of the consequences (Rajamani, 2000; Anderson *et al.*, 2020). In contrast, countries in the global north are typically able to make more unconditional commitments, leveraging their greater resources and technological capabilities. This disparity **highlights the fact that strategies effective in the global north may not be feasible in the global south** due to differing socioeconomic conditions, resource availability, and capacity constraints. Therefore, a one-size-fits-all approach to climate calculators and policy tools is insufficient. Instead, tailored approaches that consider regional differences are essential for the global success of climate commitments and policies (Photiadou *et al.*, 2021). Given these regional disparities, it is clear that the path forward requires a nuanced approach to both policy formulation and the development of impactful DSTs such as the climate calculators. Ensuring that

these tools are adaptable enough to reflect local realities while maintaining a consistent global framework is a delicate but necessary balance to strike. This approach not only supports the diverse needs of different regions but also strengthens the overall coherence of international climate efforts.

Standardising language across international climate agreements and tools like climate calculators can indeed reduce ambiguity and enhance transparency (Otchere-Darko and Ovadia, 2020). However, this must be balanced with the need for flexibility, especially in sectors deeply intertwined with local practices and values, such as the food sector (Moallemi *et al.*, 2020). Overly rigid standardisation risks marginalising certain communities and oversimplifying complex issues, while excessive flexibility can lead to inconsistencies that hinder meaningful comparisons, game playing and disjointed action (Amelung *et al.*, 2020; Bjørn *et al.*, 2022). Achieving this balance is critical to ensuring that climate calculators remain effective in diverse contexts while promoting a unified global effort against climate change. The successful integration of standardisation and flexibility is particularly crucial in sectors where localised knowledge and practices play a significant role. In these areas, climate calculators must be designed not only to accommodate global standards but also to reflect the unique characteristics of local ecosystems and economies. Without this dual focus, the tools risk becoming either too generic or too fragmented to drive meaningful change on a global scale.

The dual nature of climate calculators as both analytical tools for policymakers and human-centred tools for broader public engagement underscores the complexity of this challenge. While these calculators are vital in informing government officials and shaping policy, they must also be accessible and adaptable to the general population to ensure widespread involvement in climate action. The pursuit of improved language and reporting standards should be conducted with this duality in mind. Any adjustments made to these tools must recognise that they serve not only as precise, data-driven instruments but also as platforms for fostering public understanding and participation. This dual function is essential for maximising their effectiveness and ensuring that climate action is both technically sound and socially inclusive.

8.6. Thesis Recommendations

A good DST enables policymakers to pinpoint where new knowledge is needed, identify barriers to the implementation of effective policies, and recognise synergies and trade-offs associated with proposed interventions (Mabhaudhi *et al.*, 2023). These tools are critical for assessing the materiality of interventions and ensuring that policies are based on a comprehensive understanding of the challenges at hand. However, to remain effective, DSTs must evolve to reflect shifts in both scientific understanding and the political landscape (Theodorou *et al.*, 2019).

If a DST mirrors existing policy gaps—such as the omission of crucial areas like food and diet from national climate strategies—it risks reinforcing these oversights rather than challenging them. Addressing these gaps is essential for DSTs to function as more than just reflections of current political priorities; they must also be instruments for advancing novel approaches to climate action (Mabhaudhi *et al.*, 2023). By bridging scientific data, public awareness, and policy formulation, DSTs can ensure that all vital sectors are considered in climate change mitigation and adaptation efforts.

8.6.1. Standardise Language Use and Increase Clarity on Terminology Definitions

Due to the human element of language interpretation and application, it is important when developing the components of not only the climate calculators but surrounding climate mitigation policies to ensure that terminology use is standardised as much as possible (Fall and Fall, 2001; Schreyer, 2011). Standardisation helps promote global unity and comparability. To allow for local design and context, it is likely that this standardisation will most likely come in the form of increased clarity on terminology definitions and the appropriate application of them.

One of the primary areas for this standardisation should be the terms "decarbonisation" and "net zero." These terms, while often used interchangeably, have distinct meanings that can lead to different interpretations and applications in climate strategies (IPCC, 2024). Increasing clarity within both policies and the climate calculators ensures that policymakers, researchers, and practitioners are aligned in their understanding and implementation of climate actions, thereby reducing ambiguities and improving the capacity to report on land sector commitments (e.g. conditionalities). Additionally, there should be a concerted effort to standardise the recognition and application of terms within national greenhouse gas (GHG) inventory definitions, particularly concerning AFOLU and LULUCF (Lamb *et al.*, 2019; Minx *et al.*, 2021). These sectors play a critical role in both emissions and carbon sequestration, yet their constituent parts are often inconsistently applied in policy due to varying definitions and accounting methods across countries. By increasing the transparency in for how AFOLU and LULUCF are applied and avoiding erroneous application of the definitions, countries can more accurately account for the land sector's impact on their overall GHG emissions (Nabuurs *et al.*, 2022). This consistency not only improves the reliability of national inventories but also enhances the comparability of efforts across different regions, facilitating a more coordinated global approach to addressing climate change.

This clarity ensures that all stakeholders, from policymakers to practitioners, have a common understanding of critical concepts, reducing misinterpretations and misapplications of climate strategies (Amelung *et al.*, 2020). By establishing clear definitions and their proper applications, regions can develop localised policies that align with global standards, thereby supporting a unified approach to climate action. The push for standardisation could lead to oversimplification or rigidity, potentially stifling the flexibility needed to address region-specific challenges (Bjørn *et al.*, 2022). In contexts where local practices and interpretations are crucial, strict standardisation might hinder the effective implementation of policies. Additionally, achieving consensus on terminology and definitions across diverse cultural, social, and economic contexts can be a complex and time-consuming process,

requiring extensive collaboration and negotiation among international stakeholders. **However, standardisation of terminologies does not mean enforcing all countries to include all sections of the land sector regardless of local context or capacity, but rather to apply existing terminology accurately according to national GHG guidelines, as well as being transparent about how the components of the land sector being included exist within the wider contextual framework that AFOLU and LULUCF provide.**

International climate institutions, regional policymakers, and national climate research bodies could work collaboratively to establish a unified standard for data reporting and emissions modelling. Such an initiative would likely be created by global experts and supported or led by unified government, public and private sector representatives. It would also be an opportune moment for the UK Government to re-establish itself as a global leader in climate change mitigation efforts; after all previous ground-breaking efforts have resulted in successful global initiatives, such as with the 2050 climate calculator programme.

Implementing standardised terminology within climate calculators and policies will likely improve the alignment of national efforts with global climate targets. Clear and consistent definitions enable more accurate reporting and comparison of emissions reductions across countries, ensuring that all regions are working towards the same goals (Matsler *et al.*, 2021). This harmonisation supports the integrity of international climate agreements by providing a reliable basis for tracking progress and enforcing commitments. Moreover, standardised terminology facilitates better communication and collaboration among countries, enhancing the overall effectiveness of global climate strategies and fostering a more coordinated response to climate change (Abu-Salma *et al.*, 2017; Gislason *et al.*, 2021).

8.6.2. Incorporation of Behavioural Insights

The climate calculators should integrate more behavioural science into climate calculators, with a focus on adapting to regional differences and socio-economic conditions. Whilst location specific design is already part of the climate calculator development process, there is still a disparity between the official uses and users of the calculator (chapter 6) and the perceived uses and users of the calculators (chapter 7). Specifically, the climate calculators should incorporate insights into how individual and collective behaviours impact GHG emissions, with adjustments made to reflect the unique cultural, social, and economic contexts of different regions (Boateng *et al.*, 2018). This includes the development of behaviours related to diet and the food systems, to better represent the land sector (Reisch, *et al.*, 2021). This is because dietary choices and agricultural practices vary greatly across regions, directly influencing land use, deforestation, and emissions from the food production process.

Incorporating behavioural insights that are tailored to specific regional contexts into climate calculators can significantly enhance the accuracy and effectiveness of climate policies (Boateng *et al.*, 2018). By understanding the motivations, habits, and decision-making processes of individuals and communities in different regions, policymakers can design interventions that are more likely to resonate with and engage local populations (Whitmarsh *et al.*, 2021). This approach supports the need for flexibility within global climate frameworks, allowing for strategies that are both scientifically rigorous and contextually relevant. For instance, in the global south, where socioeconomic conditions differ vastly from those in the global north, behavioural insights can guide the development of incentives that are more aligned with local realities, thereby driving substantial reductions in emissions and increasing public participation in sustainability programs (Anderson *et al.*, 2020).

One of the main challenges of integrating behavioural science, particularly when considering regional differences, is the complexity and variability of human behaviour across different cultural, social, and economic contexts (Rogers, 2020). This variability makes it difficult to develop universally applicable strategies and requires a significant amount of interdisciplinary collaboration, additional research, and data collection. Furthermore, incorporating such nuanced behavioural data into climate calculators might complicate the standardisation of these tools, potentially leading to inconsistencies that could hinder meaningful comparisons between different countries' efforts. One way to overcome these difficulties would be to develop modular frameworks within the calculators that allow for the integration of region-specific behavioural data while maintaining a core set of standardised metrics for global comparison (Gan *et al.*, 2022). Regardless of these difficulties, the benefits of doing this, such as improving the relevance and effectiveness of climate policies at the local level, would lead to more sustainable and equitable outcomes. This approach would not only drive more accurate emissions reductions but also enhance global cooperation by recognising and addressing the diverse needs and conditions of different regions.

Tailoring behavioural insights to specific regional contexts within climate calculators can help achieve global climate targets by creating policies that align more closely with the way people actually behave in different parts of the world (Hockin, 2013; Liu *et al.*, 2020b; Reisch *et al.*, 2021). This regional adaptability ensures that climate strategies are not only theoretically sound but also practically effective across diverse settings. For example, by accurately reflecting how farmers in different regions respond to sustainable agricultural practices or how communities approach land use for bioenergy production, policies can be optimised to maximise their impact (Tzemi and Breen, 2019). In the context of food systems, understanding local dietary habits and food production methods can lead to more effective interventions that promote sustainable consumption and reduce land-use-related emissions (Rizvi *et al.*, 2018). These region-specific strategies enhance the overall coherence and success of international climate efforts, particularly in sectors where local practices significantly influence environmental outcomes.

8.6.3. Specific Impact on the Land Sector

In the land sector, incorporating behavioural insights can significantly enhance the adoption of sustainable land management practices by addressing the specific challenges and decision-making processes of farmers and land managers. For instance, understanding the cultural and economic factors that influence farmers' choices can lead to more effective policies that promote conservation practices, sustainable agricultural methods, and responsible land use (Tzemi and Breen, 2019; Hossain *et al.*, 2020; Stands, 2024). This could result in more successful reforestation efforts, improved soil management, and reduced land degradation, all of which are crucial for meeting national and global climate goals. Moreover, policies should ensure that food systems are comprehensively integrated into climate strategies (Crippa *et al.*, 2021; Nabuurs *et al.*, 2022). This involves not only addressing emissions from agriculture but also incorporating behavioural factors related to food consumption, dietary choices, and waste management into climate planning.

In the land sector, incorporating behavioural insights can improve the adoption of sustainable land management practices. Understanding farmers' decision-making processes and the barriers they face can lead to more effective policies that promote conservation practices, sustainable agricultural methods, and responsible land use (Giamouri *et al.*, 2023). This could result in more successful reforestation efforts, improved soil management, and reduced land degradation, contributing to overall climate goals. Policies should also ensure that food systems are fully integrated into climate strategies. This includes addressing emissions from agriculture and incorporating behavioural factors related to food consumption and waste into climate planning.

By incorporating behavioural insights into land management practices, policies can be tailored to overcome specific barriers faced by farmers, leading to greater adoption of conservation techniques such as agroforestry, crop diversification, and sustainable grazing practices (Torres *et al.*, 2020). This tailored approach can enhance soil health, reduce deforestation, and improve the resilience of agricultural systems to climate change. Integrating food systems into climate strategies provides a holistic approach to mitigating greenhouse gas emissions (Doherty *et al.*, 2023; FAO, 2024). Targeted policies can address major emission sources, such as methane from livestock and nitrous oxide from fertilisers, while also promoting dietary shifts toward more sustainable food consumption patterns (FAO, 2024). Reducing food waste and encouraging plant-based diets can lower the environmental footprint of food systems, contributing to significant reductions in overall emissions (Vineis *et al.*, 2016). This comprehensive approach not only supports global climate targets but also promotes food security and resilience in vulnerable regions.

The diverse nature of agricultural practices and food consumption across regions means that one-size-fits-all solutions can be ineffective, necessitating the development of region-specific strategies (Vineis *et al.*, 2016; Smith *et al.*, 2020). Additionally, there may be resistance from agricultural stakeholders concerned about the economic impacts of new regulations and practices. Coordinating across multiple sectors and levels of government to implement these strategies can be complex and resource-intensive, requiring significant investment in research, training, and capacity building. However, the standardisation of definitions and terminology application can help mitigate this by providing a clear and consistent framework for communication and policy development across different regions. This standardisation ensures that all stakeholders have a shared understanding of key concepts, reducing misunderstandings and facilitating more effective collaboration (Bodin, 2017; Popp *et al.*, 2017). It also helps to align regional strategies with global climate goals, making it easier to monitor progress and ensure that efforts are complementary rather than contradictory.

Given these findings, future research should prioritise an integrated approach that acknowledges the intertwined nature of land use, biodiversity, food systems, and other land-based co-benefits, such as human health. Incorporating a stronger focus on health outcomes within climate calculators for example could enhance their utility, ensuring that climate mitigation strategies also optimise public well-being. For example, improved land management practices could reduce air pollution and enhance food security, yielding substantial health co-benefits. Policymakers and researchers must consider the co-benefits of climate mitigation efforts, particularly in ensuring that land-based actions promote ecosystem resilience and public health alongside carbon reductions. This will require improved data collection, interdisciplinary collaboration, and clearer policy frameworks that reflect the multifaceted role of the land sector in global climate mitigation. This, combined with a more concerted effort to homogenise language and methodological approaches within climate calculators, can help highlight areas (including co-benefits) that are sufficiently- or under-represented.

Addressing the full scope of land use and food systems within climate strategies can significantly advance progress toward global climate targets (Roe *et al.*, 2021; Nabuurs *et al.*, 2022). By promoting sustainable land management practices that are informed by behavioural insights, countries can achieve more effective reforestation, improved soil carbon sequestration, and reduced land degradation (Kreft *et al.*, 2024). This is because behavioural insights allow for the development of targeted interventions that are more likely to be adopted by local communities, ensuring that sustainable practices are both culturally appropriate and economically viable (Reisch *et al.*, 2021; Kreft *et al.*, 2024). This leads to greater compliance and participation in conservation efforts, resulting in more substantial and long-lasting environmental benefits. Integrating food systems into climate strategies, particularly by reducing agricultural emissions and encouraging sustainable consumption

patterns, can lead to substantial reductions in greenhouse gas emissions. This holistic approach ensures that both the land sector and food systems contribute effectively to the global effort to combat climate change, thereby enhancing the overall coherence and success of international climate commitments.

8.7. Limitations and Reflexivity

8.7.1. Limitations

Assigned Importance of the NDCs

In the analysis and development of recommendations, one key assumption made was the global importance and effectiveness of Nationally Determined Contributions (NDCs) as the primary framework for driving climate action. However, this assumption carries certain limitations. It presumes that countries have participated in the NDCs out of a genuine commitment to the global climate effort, rather than as a means to sustain or enhance global relationships (Leinaweaver and Thomson, 2021). Furthermore, it assumes that all countries are forthcoming about the extent of effort they will actually put in (Hunter, 2020). While these considerations are important, they remain largely beyond control; ultimately, these must be acknowledged but continue to operate on the basis of trust that all participants are acting in good faith.

Despite these limitations, the assumption of the importance of NDCs was necessary to provide a coherent and focused analysis. It allows for the creation of recommendations that are aligned with the existing global framework, ensuring relevance and applicability in the current international climate policy landscape (Fragkos *et al.*, 2018). To mitigate the potential consequences of this assumption, the recommendations were consciously tailored to account for regional differences and the varying adaptive capacities of countries to implement their NDCs. By emphasising flexibility and context-specific strategies within the overarching NDC framework, the recommendations aim to support the diverse needs and capabilities of different nations, thereby enhancing the overall effectiveness and equity of global climate action (Torney and O’Gorman, 2020).

Moreover, the periodic updates and revisions of NDCs present a dynamic but also a fragmented picture of national commitments (Hermwille *et al.*, 2019). Countries may adjust their targets and strategies over time, influenced by domestic policy changes, international pressures, or advancements in climate science. This fluidity necessitates continuous monitoring and re-evaluation to maintain an accurate understanding of how well global needs are being addressed through national land sector targets. Thus, while NDC analysis is a critical starting point for contextualising and assessing land-based commitments, it must be part of a broader, ongoing evaluation framework to truly gauge the effectiveness of current systems.

Interview and Survey Participants

In an ideal scenario, the number of interviews conducted, and participants engaged through surveys would encompass all individuals necessary to present a complete and accurate representation of the truth (Barriball and While, 1994; McNamara, 2009; Shackelton *et al.*, 2022). Achieving such comprehensive representation would ensure that every relevant perspective is included, providing a holistic understanding of the issues at hand. However, in reality, this ideal is unattainable due to several inherent challenges. Firstly, even if there were no resource constraints, one of the fundamental difficulties in environmental management is determining when a full representation has been reached (Blake, 2015). There is always the potential to engage more people or include additional stakeholder groups that might offer valuable insights. The diversity and complexity of environmental issues mean that new perspectives could continually emerge, making it exceptionally difficult to argue conclusively that all necessary voices have been heard (Turner, 2010).

Additionally, there are limitations to the study design caused by both the researcher and the participants. Limitations such as time constraints and the scope bounding the research are practical limitations implemented by the researcher, in order for focused work to be conducted within the given timeframe (Barletti *et al.*, 2020). These are important to ensure that the findings are relevant to the

broader research and aims, however this can compound the issue of reduced stakeholder representation if done to the detriment of interview design. Additionally, the willingness, capacity, and interest of stakeholders to participate in the research can vary significantly (Maurer *et al.*, 2022). Some stakeholders may lack the time, resources, or motivation to engage fully, which further restricts the ability to achieve comprehensive representation.

Despite these challenges, this research managed to overcome many of these limitations by strategically selecting a diverse range of participants who represented key stakeholder groups. By prioritising engagement with those most directly impacted or with significant expertise, the study ensured that a broad spectrum of perspectives was included (Hoare *et al.*, 2023). However, to enhance future research, efforts could focus on expanding the outreach of the survey (see section 6.2) to a wider selection of countries, and the key informant interviews to a wider pool of participants that would have been unfeasible in the time frame of this research.

Analysis Techniques

The analysis techniques employed throughout this research share a common approach, leveraging semi-quantitative and qualitative methods to explore and interpret the data. Specifically, content analysis, document analysis, and narrative analysis were used to identify patterns, themes, and underlying meanings within the data. These techniques allow for a deep exploration of textual and qualitative data, enabling the researcher to uncover insights that might not be apparent through purely quantitative methods (Love, 2013; Lowe *et al.*, 2018). However, they also come with inherent challenges. One of the primary difficulties with these techniques is the challenge of setting clear scoping boundaries within the work and its results. The open-ended nature of qualitative analysis can make it difficult to define where the analysis should stop, as there is always the possibility of uncovering additional insights through further exploration (White *et al.*, 2006; Ashley and Boyd, 2006). Additionally, these methods can be influenced by the researcher's perspective, as the interpretation of qualitative data is inherently subjective. This subjectivity can introduce biases, potentially skewing the analysis towards the researcher's preconceptions or focus areas.

To mitigate these issues, this research has taken several steps to ensure that the analysis techniques were as robust as possible. By following established methodological practices outlined within the research (See chapters 4 through 7), the study has sought to minimise bias and ensure the reliability of the findings. However, it is essential to acknowledge the potential limitations that these analysis techniques may have imposed on the research. Future studies could address these limitations by employing mixed-method approaches, increasing transparency in the analysis process, or using additional quantitative techniques to complement and validate the qualitative findings (Ashley and Boyd, 2006; Higgins *et al.*, 2019). Such quantitative work could investigate land sector metrics within the climate calculator countries alongside qualitative work to see if there a correlative relationship between metrics measuring climate mitigation progress and climate calculator usage. These steps would help further question or support the outcomes of this research, providing a more comprehensive understanding of the issues explored.

Additionally, future research could also focus on expanding the concept of validation within climate calculators. While existing tools undergo certain validation processes, additional validation methods—such as sensitivity analyses—could enhance their robustness by testing their responsiveness to key variables and assumptions. These approaches would improve confidence in model outputs and their applicability to real-world policy decisions.

The Nuances of Language and the Social and Cultural Implication of Food

It is important to note that without the qualitative analyses employed within this research, the garnered level of insight into the usage of language and terminologies would be significantly less, as this is heavily rooted in the human-side of the climate calculator use and development. However, it is this component that also must be recognised as a potential limitation; the nuances of language and the social and cultural implications of food can differ greatly between countries (Friel *et al.*, 2020). This is because each country's unique cultural context, historical experiences, and social norms shape how language is used and understood, leading to discrepancies in how climate actions are perceived, communicated, and implemented.

Additionally, the way a country might approach the dual nature of the climate calculators and the tools development as both a quantitative analytical tool designed to generate robust scientific outcomes, as well as a societal engagement and expert elicitation tool, will vary (Strapasson *et al.*, 2020; Strapasson *et al.*, 2022). This could limit the research by introducing variability in how effectively the calculators are used to meet their dual purposes. In some contexts, the emphasis might be placed more heavily on the technical accuracy and scientific rigor of the tool, while in others, the focus might be on public engagement and the inclusivity of the process. Such disparities can impact the uniformity of data collection and analysis, leading to challenges in drawing generalisable conclusions from the research.

The way a country approaches the duality and its ability to assess that problem is influenced by that countries' global north or south perspective, the climate calculator team's professional background, the social and political context leading up to the initiation of the programme, and the social settings that exist both for the in-country calculator team, but also the stakeholders and individuals enlisted to assist with the co-design of the calculator (see chapter 7). All of this needs to be considered when synthesising the results of this study, as it could lead to varying interpretations of the effectiveness and applicability of the climate calculators across different regions. These factors might result in biases or gaps in the data, making it challenging to fully understand the global impact of these tools. Future research could address these limitations by exploring the influence of these contextual factors more deeply, perhaps through comparative studies or by integrating more diverse perspectives in the design and implementation of climate calculators, to ensure a more balanced and comprehensive analysis.

The Impact of COVID-19

It is important to recognise the potential historical influences of the global north vs. global south perspective on research. Other studies have highlighted the significance of acknowledging the role of decolonisation in efforts to improve climate mitigation and adaptation, emphasising the need for methods that help minimise researcher bias (Mbah and Bailey, 2022; Mbah and Ezegwu, 2024). Initially, this researcher designed Chapter 6.2 as an in-country case study to be conducted in Nairobi, intending for the survey to be carried out through in-person interviews to glean more insight into the perspective of the participants. However, due to contracting COVID-19 at the time of planned travel, the trip had to be cancelled, necessitating a change in the study's design.

This unforeseen change meant that the researcher could not mitigate the global north perspective as effectively as originally intended. Despite this setback, efforts were made to minimise this limitation by employing alternative methods such as interacting with international members of staff during the design of the questions to ensure that the different potential interpretations of the questions due diverse perspectives were understood and accounted for in the design process (Ashikali *et al.*, 2020). Additionally, extra care was taken to critically reflect on the potential biases introduced by this change and to contextualise the findings within the broader socio-political landscape of the region. While these adjustments helped to address some of the challenges, it is acknowledged that the shift in

methodology may have influenced the depth and authenticity of the insights gathered, pointing to an area for future research to further explore and refine (Popp *et al.*, 2017).

8.7.2. Reflexivity Statement

A researcher's identity and positionality can significantly influence all facets of research, from the formulation of the research question to the study design, data collection, and data analysis. While positionality requires the researcher to clearly articulate their assumptions related to the research topic, context, process, and participants, reflexivity involves a deeper self-examination. It entails the researcher questioning their assumptions and developing strategies to address these, aiming to produce a trustworthy and honest account of the research. The concept of an 'in-between' researcher (Chhabra, 2020) who identifies as neither entirely inside nor outside the research context, underscores the complexity of the researcher's role. A positionality statement can illuminate the connection between the author's intentions and the research purpose, often obscured by writing practices striving for objectivity.

Mitigating Global North Perspective

This researcher's global north perspective was balanced by engaging with international members of the department (Asiaei *et al.*, 2022). These discussions provided diverse viewpoints, crucial for understanding different countries' circumstances, sectors, and processes. In practice, this involved reviewing the developmental process of the national calculator they were part of building and reviewing the different approaches to politically sensitive topics and how they are navigated. Such collaborative efforts helped the researcher in understanding much more holistically the issues that exist in navigating politically complex spaces and enriched the researcher with a more holistic understanding.

Influence of Professional Background

The researcher's previous work experience and education provided access to well-informed and knowledgeable individuals, shaping the research design to utilise these resources effectively (Jamieson *et al.*, 2023). However, this could also introduce bias, as the research might inadvertently reflect the perspectives and interests of these specific groups. To address this, the researcher implemented the strategy of gaining data from diverse sources and engaging with a broad range of stakeholders to ensure a more balanced view. Additionally, being aware of this potential bias can help in consciously striving for inclusivity and representation of diverse voices in the research.

Professional Development and Research Impact

While there were opportunities for professional development through collaborations with different organisations within the consortium, these were primarily through parallel work rather than the specific research design. The researcher's professional background in climate policy development and personal interest in the land sector could introduce bias, influencing the research focus and interpretation (Olmos-Vega *et al.*, 2023). This was managed by maintaining a clear distinction between professional work and research activities, ensuring that the research questions and methods remained unbiased and objective. Regular discussions within the research team also helped mitigate potential biases.

Collaborative Research Approach

The researcher's involvement in the 2050 climate calculator consortium was part of the funded PhD position, influencing the research scope and direction. This involvement could lead to potential conflicts of interest or biases in presenting the consortium's work. To manage this, the researcher maintained transparency about their role and ensured rigorous methodological standards (Djenontin

and Meadow, 2018). Collaboration with the consortium was balanced with independent oversight and peer review to uphold the integrity of the research.

Recognising and Mitigating Researcher Bias

The researcher recognises that their assumptions and experiences could impact the research. For instance, previous experience with one-on-one interviews and stakeholder engagement design influenced the approach to interviews in this research. Prior interview experience was primarily with UK citizens of a similar demographic to the researcher, necessitating the development of questions suitable for different ages, ethnicities, and second-language speakers. This was achieved by piloting interview questions with diverse groups and providing participant information sheets to promote inclusivity. Acceptance of different understandings and viewpoints helped ensure that the research was conducted ethically and inclusively (Djenontin and Meadow, 2018).

Social Setting and Participant Interaction

Awareness of the social setting and the social distance between the researcher and the participants was crucial. Most one-on-one interviews were conducted over Teams, but for those conducted in participants' homes, the researcher had to be mindful of being a guest and adopt a backseat approach (Holbrook *et al.*, 2003). Participant information sheets and opportunities for questions ensured fair dealing and transparency. Reducing bias in qualitative research was achieved by explicitly including a wide range of perspectives.

Addressing Social and Political Context

The research team was aware of the wider social and political context, recognising that participants recruited from policy levels, professional organisations, might have strong personal or political leanings. To handle this, the purpose of the research was emphasised prior to interviews, and questions were carefully designed to keep discussion relevant (Turner, 2010). This approach kept the research focused and relevant, while acknowledging and respecting participants' viewpoints.

Collaborative Knowledge Production

From the outset, there was a strong commitment to work collaboratively in collecting, analysing, interpreting, and reporting qualitative data, though individual involvement varied at different stages (Djenontin and Meadow, 2018). Advice from team members with extensive experience in qualitative research and patient safety research was sought to firm up the coding framework. An intense focus on a subset of transcripts during a half-day analysis session helped draw up a comprehensive coding framework, ensuring that the analysis was informed by insights from both methodological experts and those with field-based contextual understanding.

Managing Potential Psychological Harm

The research team was sensitive to the possibility that focusing on the research topic could provoke anxiety among participants regarding the disclosure of adverse events. Researchers took time at the end of each interview to ensure that participants were not feeling distressed (Heckert *et al.*, 2020). None of the participants expressed concerns or appeared distressed, indicating that the measures taken to manage potential psychological harm were effective. This careful consideration ensured that the research was conducted ethically and responsibly, prioritising participants' well-being throughout the study.

8.8. Conclusion

This research has identified varying levels of success in national efforts to translate global climate mitigation requirements into national-level land sector targets since the Paris Agreement. The land-based commitments and intended actions evidenced within the NDCs submitted for COP21 demonstrated inconsistent application of land sector terminology and reporting. These variations are reflected in the catalogued interventions within the land sector that have taken place since the Paris Agreement, indicating disparities in how countries perceive and prioritise the land sector's role in climate mitigation. This suggests that the global view of the land sector is still evolving, with differing interpretations of its importance and potential across regions, heavily impacted by cultural, social and historical contexts (Meyfroidt *et al.*, 2022).

By questioning the role of climate calculators in addressing gaps in the current system, this research has highlighted key areas for future investigation and improvement. Most notably, it underscored the dual role of climate calculators as both analytical tools and facilitators of expert dialogue (Gan *et al.*, 2022). While this study has shown that climate calculators effectively model and reflect current land sector dynamics, it also suggests that these tools could be expanded to challenge conventional land mitigation measures and address areas that are often overlooked, such as food systems (Roe *et al.*, 2021). The research demonstrates the significant influence of climate calculators on policy, particularly in developing energy-based emissions models and nationwide mitigation pathways to net zero. However, despite the global climate calculator's emphasis on balancing energy systems, the land sector, and food systems, the current climate calculator programs lack a comprehensive integration of the food system, which is responsible for approximately 30% of global GHG emissions (Crippa *et al.*, 2021). Ensuring that these calculators reflect the full scope of emissions sources, including land-based and food system contributions, is essential for more accurate climate planning.

Similarly, biodiversity conservation remains underrepresented in many climate mitigation frameworks despite its critical role in maintaining ecosystem resilience and supporting carbon sequestration. In summary, this research's exploration of the climate landscape reveals both progress and significant gaps across the energy, land, and food sectors. The energy sector has been recognised as an important sector for emissions reduction for decades and has made notable strides in climate mitigation and adaptation (Akpahou *et al.*, 2024). Technological advancements, such as the rise of renewable energy sources and improvements in energy efficiency, underscore the sector's critical role in addressing climate change. Despite these advancements, the energy system remains complex and challenging, requiring ongoing innovation and substantial investment to meet global climate goal. Even with these advancements, the energy sector alone cannot fully address the climate crisis without integrating other critical areas, particularly land and food systems (Nabuurs *et al.*, 2022). Recognising the cascading effects of land-use changes on biodiversity, food security, and human health will be key to ensuring a holistic approach to climate action.

The land sector, while increasingly recognised, has not been addressed with the same depth and consistency as the energy sector. Inconsistent language, varied emphasis, and the complex nature of land use have led to significant challenges in setting and achieving climate targets (Otchere-Darko and Oviaia, 2020). The analysis has shown that while land is discussed in international agreements and national commitments, the lack of standardised reporting and the variability in how land-related actions are defined and measured undermine the effectiveness of these efforts. The land sector's integration into climate calculators and policies remains inadequate, reflecting a broader issue of aligning diverse national strategies with global objectives.

The omission of the food system from national climate calculators and policies highlights another critical gap. The food sector's exclusion reflects a reluctance to tackle the complex interplay between food production, land use, and GHG emissions. Agriculture is a major source of emissions, and its impact on land use, water resources, and biodiversity is profound. However, the integration of food systems into climate policy has been insufficient, despite its recognised importance in the IPCC's 2022 AR6 report (IPCC, 2022). Recognising these variations, future work should explore how the co-benefits of land-based climate action, particularly in relation to public health and biodiversity, can be more explicitly incorporated into mitigation frameworks. A more comprehensive approach should incorporate not only emissions data but also the broader environmental and health implications of food production, including its impact on non-communicable diseases and nutrition security. Pairing this with a standardised approach to food system modelling within climate calculators, led by interdisciplinary teams of scientists, policymakers, and data specialists, could provide a clearer representation of agriculture's role in emissions and mitigation strategies. This research has highlighted that addressing the food sector requires not only acknowledging its significant role but also overcoming the complex cultural and economic factors that influence food production and consumption.

Moreover, the transparency of climate calculators must be improved by critically assessing the underlying assumptions that shape their projections. Since many models rely on predefined emissions scenarios, economic growth trajectories, and land-use change estimates, it is essential to ensure that these assumptions are explicit, justified, and continuously updated to reflect evolving climate science. Addressing embedded assumptions will not only enhance the reliability of these tools but also increase trust in their policy applications. A multi-disciplinary approach that integrates improved validation, transparency, and standardised methodologies within climate calculators would significantly help bridge these gaps and facilitate the advancement of evidence-based policymaking.

The research concludes that while real technological change is occurring within the energy system, the complexity of the food sector and its interplay with land use create a formidable challenge. The IPCC's trajectory indicates that without addressing the multifaceted nature of these sectors, meeting the 1.5°C target will remain out of reach. The AR6 report emphasises the food sector's importance, but this thesis provides a novel perspective on why land-based policies have not achieved their full potential and underscores the need for thoughtful integration of food systems into climate strategies. Language inconsistencies, cultural differences, and varying metrics present ongoing challenges that will inevitably affect the incorporation of food systems into climate policy. As these complexities are addressed, it must be recognised that the difficulties faced in the land sector will similarly impact efforts to integrate food systems, requiring nuanced and comprehensive approaches to create effective and equitable climate solutions.

9. References

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10. Appendices

10.1. Appendix A

Table A.1. List of the categories of data that was extracted and coded during the NDC analysis and the options for coding. Full data extracted available upon request.

Category	Coding Option
Country	*Name of Country*
Part of 2050 Calc Project?	Yes/No
DAC list of ODA recipients	Least Developed, Lower Middle Income, Upper Middle Income, Not a Recipient
Member of the EU	Yes/No
Year 2050 calc launched	*Day/Month/Year*
length (pg)	*number of pages*
Base Year	*Day/Month/Year*
Target Year	*Day/Month/Year*
Land present?	Yes/No
AFOLU	Yes/No
LULUCF	Yes/No
Agriculture (not as a sub-sector)	Yes/No
Forestry (not as a sub-sector)	Yes/No
time span of AFOLU commitment	*Years*
both, just con, just uncon, unspecified	*Both, Just Conditional, Just Unconditional, Unspecified*
Land in unconditional? (y/n)	Yes/No
unconditional measures (expand)	*Free text*
enhanced conditional mentions AFOLU	Yes/No
afolu in unconditional	Yes/No
lulucf in unconditional	Yes/No
agriculture in unconditional	Yes/No
forestry in unconditional	Yes/No
Land in conditional	Yes/No
AFOLU in Conditional?	Yes/No
conditional measures (expand)	*Free text*
Action taken	*Free text*
Imminent Planned Action (≤5yrs)	*Free text*
Future Planned Action (5+yrs)	*Free text*

10.2. Appendix B

Table B.1. Search string development process for Chapter 5 Systematic Map

Search String	Paris Agreement	Land Sector	All dates	2016-2020	changes to syntax	Notes
1	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Land Change")	3305	3288		Started with these base terms, stretching a seemingly broad range of topics to cover the entire scope of the Paris Agreements and the land sector, both notoriously broad in content, meaning and definitions within their own rights. There is also a lack of consistency with definitions and as such, broader is a more appropriate stance to take initially, so nothing is missed, and then to have strict inclusion/exclusion criteria afterwards
2	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Land Change")	3331	3306	added acronyms in (NDC)	NDC was added as this is the primary component of the country-specific analysis of the Paris Agreements
3	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Land Change")	3342	3310	added types of commitments (conditional/unconditional)	These were added as there may be a differentiation between action when the land based action is part of the uncondition vs conditional commitment
4	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Land Change" OR "forestry")	3611	3578	expanded to include forestry	The other components of 'AFOLU' (agriculture and land use) were already included in isolation and for completions sake, adding forestry rounded this off
5	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation")	3639	3606	expanded to include types of forestry management/techniques	This was done to add clarity in what 'actions' will be included and to expand beyond policy-only or policy-oriented action
6	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation" OR "Carbon Sequestration" OR "Carbon Sink")	3925	3892	expanded to include carbon sequestering	This is a key component of atmospheric carbon reduction using the land sector and so can be an action within its own right
7	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments" OR "Post-Paris**")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation" OR "Carbon Sequestration" OR "Carbon Sink")	3994	3960	expanded to include synonyms of 'post-paris'	This was to ensure that papers (primarily 2017 onwards) were highlighting all paris related research
8	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments" OR "Post-Paris**" OR "RCP2.6")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation" OR "Carbon Sequestration" OR "Carbon Sink")	4580	4404	expanded to include RCP2.6	This was done as these targets are often the focus of papers and can be directly attributed a result of the Paris Agreements
9	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments" OR "Post-Paris**" OR "RCP2.6" OR "2 degrees")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation" OR "Carbon Sequestration" OR "Carbon Sink")	4971	4555	expanded to include 2 degrees	This was done as these targets are often the focus of papers and can be directly attributed a result of the Paris Agreements
10	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments" OR "Post-Paris**" OR "RCP2.6" OR "2 degrees" OR "AR5")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation" OR "Carbon Sequestration" OR "Carbon Sink")	8215	7080	expanded to include AR5	This was done as these targets are often the focus of papers and can be directly attributed a result of the Paris Agreements, although this must be taken cautiously as the IPCC report AR5 was one of the informing documents for the Paris Agreements
11	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments" OR "Post-Paris**" OR "RCP2.6" OR "2 degrees" OR "AR5" OR "COP21")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation" OR "Carbon Sequestration" OR "Carbon Sink")	8671	7527	expanded to include COP21	This was done because COP21 can be considered a synonym for the Paris Agreements (often referred to as Paris COP21), as can be seen in many of the papers already informing the different steps on this search string
12	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments" OR "Post-Paris**" OR "RCP2.6" OR "2 degrees" OR "AR5" OR "COP21")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation" OR "Carbon Sequestration" OR "Carbon Sink" OR "land**")	13996	11723	added in land*	To ensure that there is no ambiguity and that everything is sector encompasses is included
13	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments" OR "Post-Paris**" OR "RCP2.6" OR "2 degrees" OR "AR5" OR "COP21")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation" OR "Carbon Sequestration" OR "Carbon Sink" OR "agri**" OR "land**")	14931	12472	added in agri*	to ensure agriculture and agricultural are included
14	("Paris Agreement" OR "Paris Agreements" OR "Nationally Determined Contributions" OR "NDCs" OR "Unconditional Commitments" OR "Conditional Commitments" OR "Post-Paris**" OR "RCP2.6" OR "2 degrees" OR "AR5" OR "COP21")	("Agriculture" OR "Land Use" OR "Land Use Change" OR "LULUCF" OR "AFOLU" OR "Land Sector" OR "Forestry" OR "Land Change" OR "Reforestation" OR "Afforestation" OR "Carbon Sequestration" OR "Carbon Sink" OR "agri**" OR "land**" OR "land use**" OR "Carbon seq**")	14,933	12474	added in OR "land use**" OR "Carbon seq**"	To ensure that there is no ambiguity and that everything is sector encompasses is included

Table B.2. List of the categories of data that was extracted and coded during the NDC analysis and the options for coding. Full data extracted and categories available upon request.

Category	Coding Option
Type of literature	Paper, Conference paper, Book, etc
link	*URL*
Title	*Title*
Authors	*Author list*
Date Published	*Year*
DOI	*DOI*
Date of data collection	*Day/Month/Year*
Region	South East Asia, Europe etc
country	*Country*
year of study	*Day/Month/Year*
Global north or south	*North/South*
DAC classification	Least Developed, Lower Middle Income, Upper Middle Income, Not a Recipient
country case study (y/n)	Yes/No
Global (y/n)	Yes/No
PA analysis (y/n) eg hasn't differentiated the conditionals and unconditionals/is a global look at PA responses	Yes/No

Table B.3. Public policies other than NAP and REDD+ that were identified by the systematic review, and what countries these papers were focusing on.

Paper	Other Policies	Country
(Forsell et al, 2019)	European Commission. Regulation (EU) 2018/841 Foresell, N et al., 2018 European Commission. Regulation (EU) 2018/842	EU
(Fumuro et al, 2020)	Integral Strategy for Controlling Deforestation and Managing Forests	Columbia
(Nabuurs et al, 2017)	climate smart forestry	EU
(Laudari et al., 2021)	Environmental Protection Act 2019 environmental protection regulation 2020	Nepal
(Bentsen et al., 2019)	agricultural agreement	Denmark
M. Bhan et al. Forest Policy and Economics (2017)	Integrated Cropland-Livestock- Forestry Systems Action Plan for the Prevention and Control of Deforestation in the Legal Amazon	Brazil
M. Bhan et al. Forest Policy and Economics (2017)	Green India Mission (GIM)	India

10.3. Appendix C

Bellow is the full list of all categories coded within the climate calculator content analysis. The coding was either directly correlated to the category (e.g. Country/Region, would be coded with the name of the country or region under study). Whilst all categories under lever inputs, outputs and reason for release were coded "Yes/No".

Table C.1. All categories that had data extracted from for the climate calculator analysis in Chapter 6.

Country/Region	name of land lever #2	agricultural	livestock	crop demand
lat	land use	Agriculture and others	energy demand	land use map
long	biofuel		total	Dairy Cattle
Name	food	Aea set aside for nature...	total direct	Beef
Year of release	bio diversity	...from agriculture	land area trade off	other graphs
Link	bioenergy	and forestry	graph	food security
Net zero	marginal land	forestry	forest	food demand
target year	biomass and biogass	Forestry practices	bioenergy land	crop demand
Reason for release/ description	livestock management	commercial&prote	remaining	land use map
engage in debate	per capita meat consumption	ctive reforestation	available land	
explore pathways	name of land lever #3	reduced rate of deforest.		
education	Bioenergy	Carbon forestry	total potential land	
general public use	agriculture	land management	wetlands	
explore a low carbon future	bioenergy conversion	biodiversity	settlements	
decarbonisation	CCS	surplus land (forest and bioenergy)	other	
planning/decision making	name of land lever #4	land-use efficiency	cropland	
hitting ndc targets	biomass collection rate	land use	grassland	
number of levers/ lever groups	name of land lever #5	forest	desert, ice etc	
Land included?	forestry carbon credits	management and biomass	commercial forest	
# land levers/ lever groups?	# of land sub-levers (total)	land for bioenergy	land for non-food crops	
name of land lever #1	farming yield and efficiency	dedicated land for biofuels	land for food crops	
land use	animal husbandry	bioenergy capacity	land for animals (pasture)	
land	livestock	bioenergy	livestock	
biofuel	(grains/residues fed)	hierarchy for biomass end-uses	population type*1, animal product demand *2	
bioenergy	best livestock practices	Wastes and residues	bovine	
food	best livestock practices	waste reduction	pigs	
biodiversity	change in meat and milk consumption	Lever outputs	poultry	
non-energy	Livestock (pasture fed)	land outputs	sheep	
agriculture	climate smart livestock	# of land outputs	other animals	
forestry	climate smart crop production	eg graphs		
waste management	crop yields	emission reductions		
waste	alternative protien source	Indirect emissions		
livestock management	irrigation and other agricultural practices	forestry	Fish: Inland culture	
bioenergy	Best agricultural practices	land	Dairy Goat	
Others	bioenergy from agriculture	agriculture & livestock	Dairy Cattle	
irrigation	agricultural practices	bio-conservation	Beef	
		waste management	other graphs	
		crops	food security	
			food demand	

10.4. Appendix D

See below the survey questions and structure, Chapter 6.2.

Section 1- About You

1. What is/was your role within KCERT?
2. What sector and/or role did you primarily work within? (Please select all that apply)
 - Land Use and Biofuel
 - Electricity
 - Buildings
 - Transport
 - Industry
 - Gases
 - Stakeholder Engagement
 - Excel Modeller and Developer
 - Project Coordinator

Section 2- About KCERT

3. What is the purpose the calculator was made to fulfil?

N.B. Would it be better to list here or let them write out their own answers?

Listing would mean their responses are easily comparable to the other results sections I have already, but does direct/bias their responses

4. Was the calculator designed to help with Kenya's NDCs?
 - Yes, this was the main purpose
 - Yes, this was one of the reasons
 - No
 - Unsure
5. Do you think KCERT has, or will, help with developing any components of Kenya's NDC?
 - Yes
 - No (Skip to question 10)
 - Unsure
6. Which economic sectors has KCERT helped, or is most likely to help, in developing and supporting Kenya's NDC? (select all that apply)
 - Buildings
 - Transport
 - Gas
 - Land and Biofuel

- Electricity
 - Industry
 - Other (Please expand)
7. Do you think KCERT has, or will, help with differentiating policies between Conditional and Unconditional with Kenya's NDC
- Yes
 - No
 - Unsure
8. Do you think that KCERT has, or will, specifically help developed the Land sector within Kenya's NDC?
- Yes
 - No (skip to question 10)
 - Unsure
9. Do you expect KCERT to help develop unconditional, or conditional, land sector commitments within Kenya's NDC?
- Conditional
 - Unconditional
 - Both
 - Undefined commitments (e.g. was used for general NDC development)
 - Unsure
10. Do you think that KCERT has specifically helped support policy (and other interventions) development within the Land Sector? (Outside of the NDC)
- Yes
 - No (Skip to question 12)
 - Unsure
11. In what ways has KCERT helped support policy (and other interventions) development within the Land Sector? (Open question)

Section 3- Land within KCERT

12. Does KCERT include “AFOLU” (Agriculture, Forestry and Land Use), “LULUCF” (Land Use, Land Use Change and Forestry), both, or neither?

- AFOLU
- LULUCF (Skip to question 16)
- Both (Skip to question 19)
- Neither (Skip to question 23)

13. What components of AFOLU does it include?

- Agriculture
- Forestry
- Other Land Uses (Please expand)

14. Is AFOLU included in the inputs or outputs of the calculator?

- Inputs (e.g. there are 1+ levers for land)
- Outputs
- Both
- Neither

15. Please expand on the breakdown of the parts of AFOLU the calculator includes e.g. if you said that it included Agriculture, in what capacity does it include Agriculture? (Crops, livestock, reduction of agricultural land etc)

16. What components of LULUCF does it include?

- Land Use
- Land Use Change
- Forestry

17. Is LULUCF included in the inputs or outputs of the calculator?

- Inputs (e.g. there are 1+ levers for land)
- Outputs
- Both
- Neither

18. Please expand on the breakdown of the parts of LULUCF the calculator includes e.g. if you said that it included Forestry, in what capacity does it include Forestry? (Reforestation, afforestation, Forest restoration etc)

19. What components of AFOLU and LULUCF are included?

- Agriculture
- Other Land Uses
- Land Use
- Land Use Change
- Forestry (within an AFOLU capacity)
- Forestry (within a LULUCF capacity)
- Other (please expand)

20. Is AFOLU included in the inputs or outputs of the calculator?

- Inputs (e.g. there are 1+ levers for land)
- Outputs
- Both
- Neither

21. Is LULUCF included in the inputs or outputs of the calculator?

- Inputs (e.g. there are 1+ levers for land)
- Outputs
- Both
- Neither

22. Please expand on the breakdown of the parts of AFOLU *and* LULUCF the calculator includes e.g. if you said that it included Agriculture, in what capacity does it include Agriculture? (Crops, livestock, reduction of agricultural land etc)

e.g. if you said that it included Forestry, in what capacity does it include Forestry? (Reforestation, afforestation, Forest restoration etc)

23. How accurate do you think the Land Sector representation within KCERT is?

- Highly accurate
 - Minimal, or no, improvement can be made to the land sector in KCERT.
- Quite accurate
 - There are some areas of adjustment/ improvement, but most are reasonable caveats made for KCERT to run as a whole
- Somewhat accurate
 - There are several areas of adjustment/ improvement, some are reasonable caveats, but future iterations of KCERT will be more representative
- Minimally accurate
 - There are many areas of adjustment/ improvement, and future iterations of KCERT could see the Land sector have much greater representation
- Not at all accurate

24. Could you please expand on why you answered Question 23 the way you did?

10.5. Appendix E

See below the interview questions asked to participants in Chapter 7.

1. The original calculator

- 1.1. What was the original purpose(s) of the UK 2050 climate calculator?
- 1.2. Who was the calculator designed to be used by?
- 1.3. Do you think that the intended users are those who have ended up using it?

2. The Global Calculator

- 2.1. When do you think that the UK climate calculator began to be used more widely and decision makers became interested in its application outside of the UK?
- 2.2. What was the original purpose(s) of the global calculator?
- 2.3. Do you think that that the purpose of each national climate calculator was the same as that of the UK?

2.2.1. If no, expand- why not? What do you think became the new purpose?

- 2.4. Were the intended users for the global calculator the same as those for the UK calc? How were they different?

☐yes ☐no

2.4.1. Could you expand? (If no, how were they different?)

- 2.5. Do you feel that this is the same for all the subsequent national calculators that have been, or are being developed? (or is there an example of where you think that the intended user base significantly differs)

- 2.6. What does the process of deciding what sectors are included within a calculator currently look like to you?

2.6.1. Do you think there is anything that you would change about this?

- 2.7. What do you think the role of having a user demand workshop is?
- 2.8. Do you think all of the sectors are as important as each other?
- 2.9. Is there a sector that you think is the most influential in the functioning of the calculator?

3. The climate calculator programme now

- 3.1. How would you define the purpose of the national calculators now?

3.1.1. Has it changed from it's conception

- 3.2. Do you think that the calculator programme has helped with policy making?

3.2.1. Do you think that there is an example of where the programme has done well?

3.2.2. Do you think that there is an example of where the programme has underperformed?

- 3.3. What areas of policy creation do you think that the calculator will be most helpful in?

3.3.1 Are all sectors equally benefited?

3.4. Do you think in the completed, or developing, calculators that there are sectors that should always be included, and why?

3.5. Is there a sector that you think is universally/majority most influential in the functionality of the calculators?

3.6. Are there any specific levers, or sub levers, that you feel should (almost) always be included? Why?

3.7. Are there any specific outputs the calculators should always have?

3.8. In terms of the land sector component of a national climate calculator, should there be any levers, or sub levers, that should always be considered, if not included?

3.9. In terms of the land sector component of a national climate calculator, should there be any land-specific outputs that should always be considered, if not included?

3.10. What do you think the role of Land plays within a country's national calculator?

4. Snowballing

4.1. Who would they suggest would be good individuals to have this same discussion with?

Interested in those with a lot of knowledge and opinions.

4.2. Also ask for concept development/help with the semi-quantitative informant engagement- style of help TBC.