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A study on the deployment and acceleration of low carbon technologies

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University of Dublin, Trinity College

A thesis in fulfilment of the requirements for the degree of

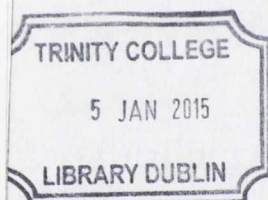
Doctor of Philosophy

2013

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Summary

The work presented in this thesis is an investigation into the variables that are considered by consumers when selecting low carbon technologies (LCT) and the barriers that are encountered by implementers when deploying such technologies. This involves an exploration of approaches to accelerate low carbon technology across various jurisdictions and a methodological analysis that predicts the factors influencing consumer choice of low carbon technologies. The achievement of sustainable energy objectives requires policy makers to be informed of the considerations that consumers make prior to deploying low carbon technologies in their homes. This thesis ascertains the key factors that affect and inform consumer choice and proposes a framework that facilitates the international deployment of clean technology.

The thesis is structured around a number of different scenarios. By using the Irish residential sector as a case study, and by analysing the take-up of over 31,500 technology installations, the thesis explores the variables and determinants that influence consumers' decision-making regarding their choice, take-up and acceleration of low carbon technology. In doing so, it explores the various drivers that inform consumer selection of technology in terms of security of supply and low carbon technology policy. It focuses on a mature technology market, Ireland, and on less mature markets, namely five developing and emerging economies, India, China, Fiji, Mozambique and Uganda. The thesis explores the impact of regulatory, financial, institutional and information frameworks as it highlights the significant challenges and barriers that low carbon technology projects are encountering. A number of exemplar actions are presented.

The thesis assesses and predicts the factors influencing consumer choice of low carbon technologies. It provides policy makers with a modelling tool by proposing a procedure to analyse and predict customers' choice of low carbon technologies using artificial neural networks. The procedure serves as a framework for better understanding the various factors that influence consumer selection of one low carbon technology over another. This modelling-based contribution could assist policy makers in their analysis and understanding of uncertainty surrounding technology choice.

In analysing the take-up of LCT on a more global context, the thesis draws on economic game theory modelling, interprets the latest developments within the international negotiations and provides a political economy analysis of the climate change architecture. It places the pursuit of international co-operation, via the Kyoto Protocol's second commitment period, in the context of a country's maintenance of national interest and a flexible emissions abatement strategy. It incorporates a new game theory model and presents a new scenario with a non-monotonic polluting payoff function. Attention is placed on enabling conditions that entice countries to ratify a climate agreement, thereby encouraging participation and accelerating near term deployment of low carbon technologies. Finally, a number of recommendations are presented that could aid the acceleration and deployment of low carbon technologies.

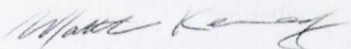
Acknowledgements

I wish to express my sincere gratitude to my supervisor, Professor Biswajit Basu, for his valuable guidance, contribution and thought provoking analysis which helped to shape this thesis. I wish to also extend my appreciation to the technical staff in the Department of Civil, Structural and Environmental Engineering of Trinity College Dublin for their welcome input and contribution.

I wish to acknowledge the support from Trinity College Dublin and the Sustainable Energy Authority of Ireland in kindly sponsoring this research.

Many thanks also to my parents for twenty years of academic encouragement and support and for shaping a home where learning was actively encouraged. I will forever be grateful to you both.

Finally, special thanks must go to my family, my children, and especially to my wife Hazel, for her encouragement, patience and unwavering support over the past years. I dedicate this thesis to you.



Matthew Kennedy

December 2013

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“There is an urgent need to discover what effective language a Copenhagen agreement needs to entail in order to unleash the full potential of technology”
[De Boer, 2008]

“Unless low-carbon technologies are deployed over the next two decades, the world will be locking-in to high enough CO₂ emission levels to break most reasonable emissions budgets”
[Sims Gallagher, 2009]

“Climate change is a complex phenomenon, subject to great uncertainties, with changes in our knowledge occurring virtually daily... There are big economic stakes in designing efficient approaches to slow global warming and to ensure the economic environment is friendly to innovation. The current economic approach in the Kyoto Protocol will be economically costly and will have virtually no impact upon climate change.”
[Nordhaus, 2009]

“The path towards sustainable energy sources will be long and sometimes difficult. But America cannot resist this transition; we must lead it. We cannot cede to other nations the technology that will power new jobs and new industries – we must claim its promise. That is how we will maintain our economic vitality and our national treasure – our forests and waterways; our croplands and snowcapped peaks. That is how we will preserve our planet”
[President Obama, 2013]

Chapter 1

Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) emphasises the priority needs of developing countries for the achievement of sustained economic growth, as energy access concerns and associated poverty engulf developing countries. The provision of clean energy services to society, while minimising health risks and protecting the environment, combine to form part of the wider climate change agenda. Reducing greenhouse gas (GHG) emissions from energy use requires significant shifts in the energy system. The setting and achievement of carbon dioxide (CO₂) emissions reduction targets, in terms of sustainable development, energy security and environmental protection, is complex. Reducing our dependence on high carbon fossil fuels provide co-benefits in the form of improving energy access and sustainable development. Countries, institutions and individuals often seem unwilling or unable to act in time, especially when acting sooner rather than later may be far less costly in the long term. This is especially valid if one considers the investment decisions for a premature retirement of energy technology infrastructure or a mass deployment of energy technology. Such inaction is relevant to the climate issue where a concentrated or immediate cost is required to achieve a diffuse or distant benefit [Ellwood, 2009].

The overall climate change regime focuses on ‘what’ actions need to happen across its framework of targets, plans and objectives, rather than elaborating and enabling ‘how’ action happens. In meeting ambitious energy policy objectives, countries should utilise different

strategies and policies and optimise their low carbon¹ technology (herewith referred to as LCT) resources, generation and usage. Such technologies lead to an absolute reduction in GHG emissions and can reduce the carbon intensity of processes across the energy supply chain. In doing so, the accelerated deployment of LCT can reduce CO₂ emissions and strengthen competitiveness and technological innovation. For the purposes of this research, low carbon technology transfer is defined as:

“technology diffusion, a means for deployment of new equipment, products, processes or knowledge, previously not accessed by a recipient country” [WBCSD, 2010, p6], including “a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders” [IPCC, 2000, p.3].

While technology development and transfer can enable the achievement of the mitigation and adaptation provisions of the UNFCCC, there is a limited understanding of the variables that influence a wider adoption of such technologies and the opportunities and potential that could result in a wider appreciation of the broader impact of market barriers. The exact mechanism to facilitate such enabling environments that foster the accelerated deployment of LCT is unclear. Countries are subsumed by budgetary crises and national political opposition has undermined strives towards achieving consensus and has discouraged further commitments to reduce CO₂ emissions.

This introductory chapter provides some context of the global energy and environmental challenges that we face. Attention focuses on the pursuit of a ‘clean energy revolution’ and

¹For the purposes of this research, low-carbon includes all six Kyoto greenhouse gases, namely carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons as defined by the UNFCCC.

the role of government in realising this objective through stable energy and environmental policies that stimulate investment. The emergence of technology as a driving force within the international climate architecture is presented and the concept of enabling environments, and accompanying economic costs to curb emissions growth, is introduced. Finally, the research aims are introduced, namely an analysis of how the deployment and acceleration of LCT can be a significant ‘game changer’ for economies on rapid growth trajectories as their emissions are reduced and climate stabilisation becomes more achievable.

1.1 Global challenges: the clean energy revolution

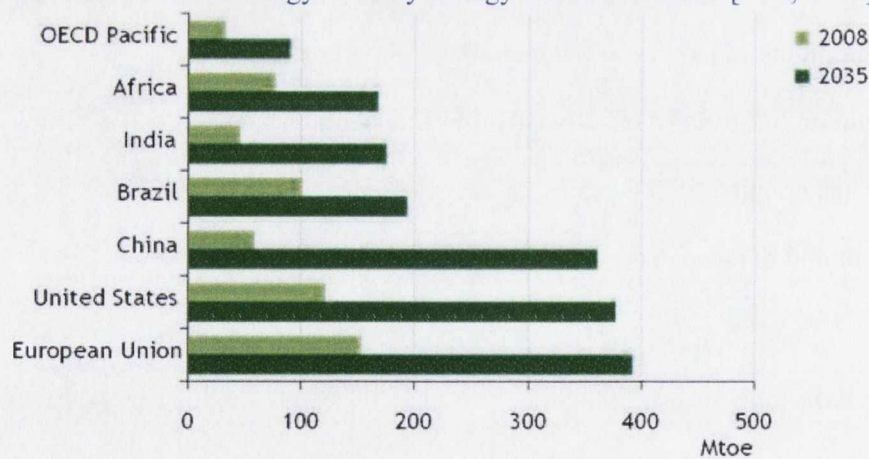
The International Energy Agency (IEA) and Organisation for Economic Co-operation and Development (OECD) estimate that CO₂ emissions will double over the next four decades, a rise in average global temperatures of between 3-6°C [IEA, 2011 and OECD, 2012]. Governments and policymakers are being urgently asked to act to reverse these trends and let scientific evidence inform their pathway. The transition to low carbon society will require a shift in the development trajectory of the majority of developing countries, especially as they are heavily reliant on fossil fuels and almost 1.4 billion people lack access to electricity [IEA, 2006, 2009]. This, coupled with a projected energy demand increase of up to 75% to 2030, reduces the likelihood of clean energy fitting within the energy mix.

Given this long term time horizon, pursuing a strategy of advancing LCT may aid a meeting of these longer term needs while guiding and facilitating all countries onto low carbon and climate resilient growth pathways. The pursuit of such a strategy to curb climate change is an exceptional challenging problem at a political level due to the ‘global commons problem’. For the majority of countries, the direct costs of action to reduce emissions and curb climate change will inevitably be less than the direct benefits that result, despite the fact that global

benefits may be greater than global costs [Stavins, 2012]. Flexibility should feature within national commitments, reflecting national circumstances that relate to a country’s political and physical circumstances, capabilities and legal systems. This is not aided by recent research that found that arguments surrounding climate change could not easily be proven or disproven and the requirement for action lies with governments rather than individuals [Happer et al, 2012].

Historically, the majority of technology transfer occurred between developed rather than to developing countries: between 1985 and 2004, nearly 80% of the transfer of new mitigation technologies occurred between developed countries, while the remaining 20% was transferred between China, Korea and Taiwan [Hascic, 2009]. In the past decade, LCT has attained significant investment in developed economies and in emerging markets such as India, with China emerging as the leading solar photovoltaic manufacturer.

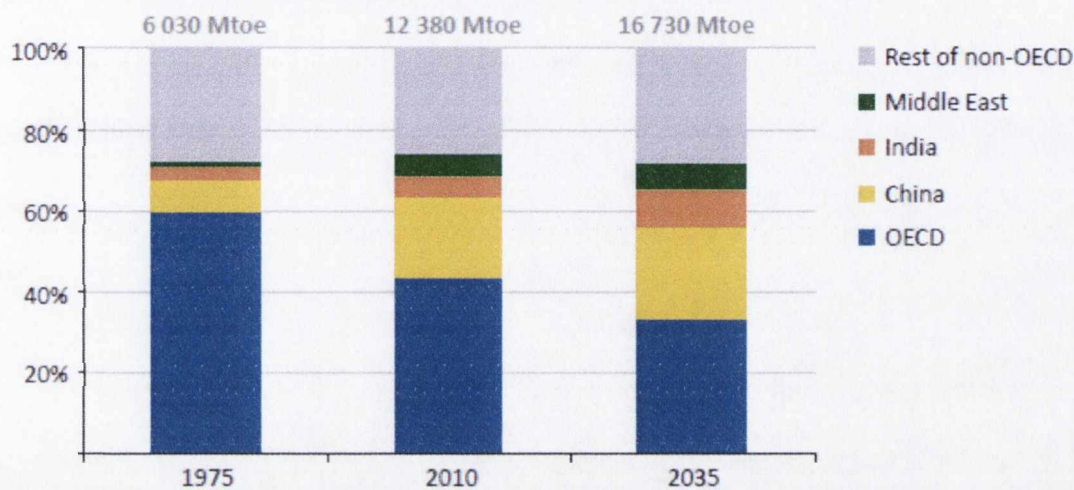
Figure 1.1: Low Carbon Technology Primary Energy Demand to 2035 [IEA, 2010]



The IEA’s reference scenario [2008 and 2010] indicates that an 85% increase in global energy demand and a 97% increase in energy related CO₂ emissions will come from developing countries by 2035 (See Figure 1.1). Such change and accompanying GHG

emissions, in million tonnes of oil equivalent (Mtoe), are projected to occur mostly in the developing world, particularly underpinned by raising living standards in China, the Middle-East and India, with estimates indicating that India’s emissions could increase three to four fold by 2030, ranging from 4-7 billion tonnes [UN-Desa, 2009] (see Figure 1.2).

Figure 1.2: Share of Global Energy Demand (Mtoe) to 2035 [IEA, 2012]



A broader spectrum of levels of development has emerged among developed and developing countries, increasing the challenge of controlling GHG and strengthening capabilities to mitigate the effects of climate change. The main challenge is to identify new ways to widely deploy existing technologies or to adapt new technologies to local conditions [WBCSD, 2010]. Meeting the demand trajectory will require significant technological change through deployment that re-orientates the energy sector, most likely through the promotion, diffusion and transfer of LCT for GHG mitigation and adaptation² in developing countries. The challenge involves fuelling economic growth and social progress within countries while avoiding a lock-in to energy intensive, carbon emitting infrastructures and technologies, and a strengthening of endogenous technological capabilities [WBCSD, 2010]. A further challenge

² Available mainstream technologies, such as cooking stoves, biomass devices and solar lanterns, could be refined in the near term and adapted to meet the needs of developing countries.

is the creation of stable local policies that can productively harness the international flow of LCT [Grubler, 2011].

A key United Nations Millennium Development Goal relates to ensuring environmental sustainability. This is linked to the availability of natural resources and the provision of clean energy services. In effect, the use of cleaner, more efficient fuels and the reduction of GHG emissions could make a significant positive contribution to climate change [DFID, 2004]. Diverting attention away from the acceleration and deployment of LCT will reduce the likelihood of achieving such goals.

1.2 Technology as a climate ‘building block’

As technology largely determines the level of emissions, it is both the primary source of the climate change problem and the key to the solution [Carpenter, 2012]. Clean and efficient energy technologies have the ability to meet emerging societal challenges that range from enhancing industrial competitiveness, to limiting vulnerabilities associated with fossil dependence, and addressing the threat of climate change.

Technology, as a mechanism for combating climate change, first featured within the Article 4.5 of the UNFCCC Marrakesh Accords (2001) where parties agreed to work together on a set of technology transfer activities. While the Kyoto Protocol’s Clean Development Mechanism (CDM) did not explicitly relate to technology transfer, such LCT transfer was viewed as an important indirect consequence of the encouragement of more sustainable

development patterns in non-Annex 1 countries³ [Hascic & Johnstone, 2011]. While the CDM indirectly provides the opportunity to gain access to advanced technologies and low carbon infrastructure to developing countries, much of the mobilised investment has gone to developed countries with limited technology transfer [Nicholls, 2008] and with questionable success [Haïtes et al, 2006 and de Coninck et al, 2007]. The UNFCCC's Bali Action Plan (2007, Para1.d) includes the provision of low carbon technology as one of four 'building blocks' towards a binding agreement, alongside mitigation, adaptation and finance. This accepts that there are significant linkages between all four building-blocks, and acknowledges that technology plays a horizontal role within and across all blocks. The additional mechanisms under the Bali Action Plan, to transfer technology and mobilise financial resources and capital, potentially, hold the most interest for the business community.

The pursuit of clean technology transfer was reinforced by the European Union through its Climate and Energy Package (2008). This established a legally binding framework to deliver LCT via national climate plans and programmes to meet their Kyoto targets. This was swiftly followed by the establishment of the International Renewable Energy Agency (IRENA) in January 2009, reflecting a change in the global energy paradigm arising from growing commitments from governments. A key role for IRENA is fostering cooperation at the global, regional and national levels, sharing of knowledge, enabling policies and enhanced capacity, while also encouraging investment flows and strengthened LCT and innovation.

The UNFCCC 'Copenhagen Accord' [2009] committed to establishing a Green Climate Fund⁴ aimed at raising \$100billion in climate financing by 2020. It focused on "supporting

³ Annex I countries are the group of countries included in Annex I (as amended in 1998) to the UNFCCC, including all the OECD countries and economies in transition. By default, the other countries are referred to as Non-Annex I countries.

⁴ The Republic of South Korea was chosen as the city to host the GCF in 2012. Germany, Mexico, Namibia, Poland and Switzerland had also sought to be the headquarters.

projects, programmes, policies and other activities in developing countries related to mitigation including REDD-plus⁵, adaptation, capacity-building, technology development and transfer". In order to further enhance action on the development of low carbon technology, the UNFCCC, through the 'Accord', decided to establish a Technology Mechanism, guided by a country-driven approach and based on national priorities. The decisions under the Durban Platform for Enhanced Action (2011) brought to fruition much of the progress made within the Bali Action Plan (2007), Copenhagen Accord (2009) and Cancun Agreements (2010) by committing to a full operationalisation of the Technology Mechanism in 2012. A schematic that maps the growth of technology related architecture under the UNFCCC is redrawn from the UNFCCC [2012] and presented in Figure 1.3.

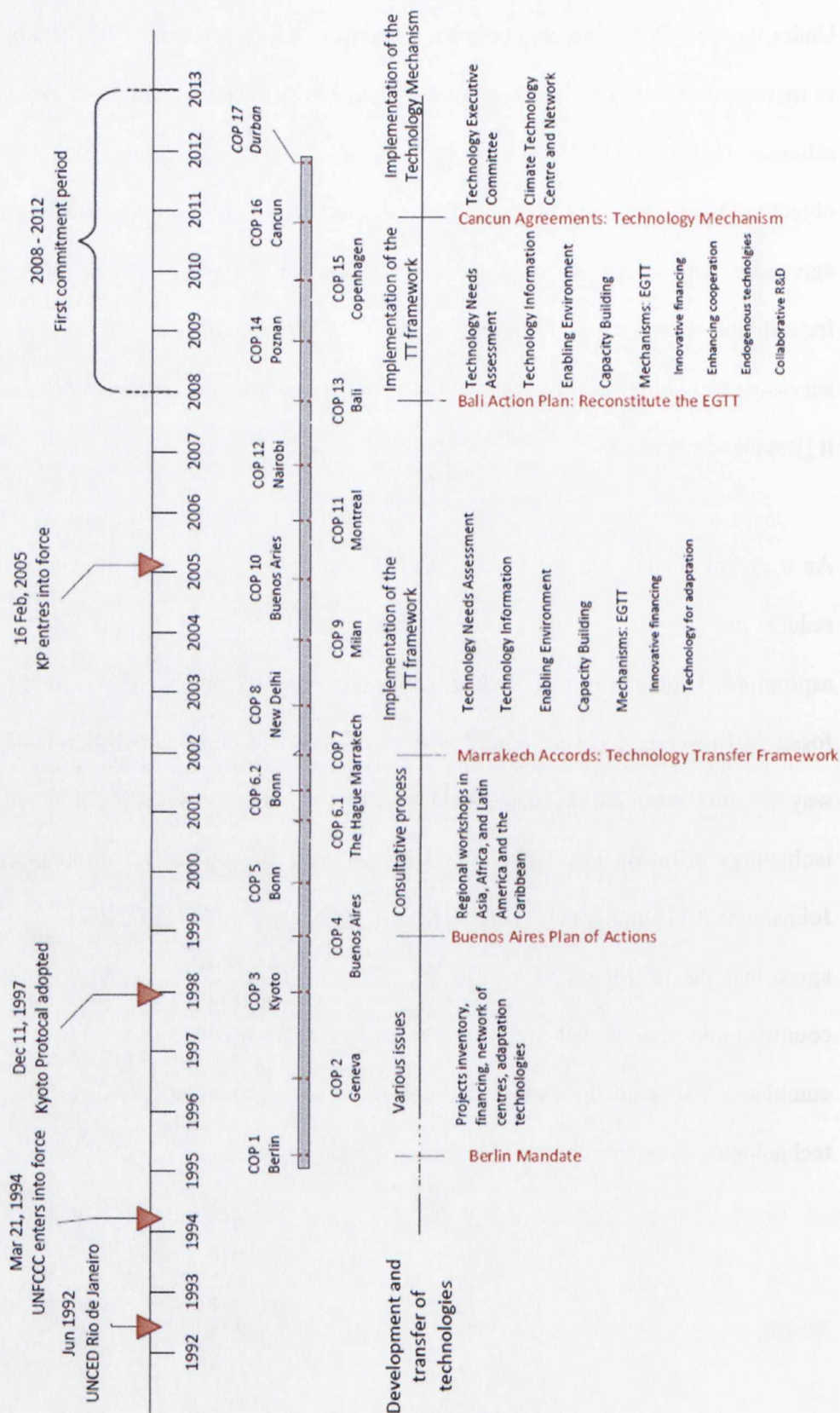
Low carbon technologies enable an exploitation of existing and new sources of energy while allowing cheaper, cleaner and efficient ways of converting energy into desired end use services. The Intergovernmental Panel on Climate Change (IPCC) Special Report on Renewables (SRREN) [2011] assessed existing literature on the future potential of renewable energy for the mitigation of climate change. SRREN covers the integration of 6 low carbon technologies into present and future energy systems, while considering the environmental and social consequences associated with these technologies, the cost and strategies to overcome technical and non-technical obstacles to their application and diffusion. It concluded that the consistent growth of clean energy technologies would reduce global carbon emissions by a third and would benefit 1.4 billion people who currently do not have access to the grid. LCT deployment faces economic, institutional or technological barriers and requires a sharing knowledge and adaptation to local conditions, thereby strengthening human and technological capacity in developing countries [IEA, 2001, IPCC, 2007].

⁵REDD-Plus is the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries. REDD-plus includes Reducing Emissions from Deforestation and Forest Degradation in Developing Countries; and the role of Conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks.

Under the UNFCCC, Governments are required to develop meaningful and effective actions to increase and improve the transfer of, and access to, clean technologies. This reduces their reliance on fossil fuelled technologies and their GHG emissions. Delivery of this key objective happens centrally, through the construction and implementation of a binding agreement, and locally where signature parties adopt a country-driven, integrated approach. Indeed, the incentive to participate in such an agreement stems from the possibility of accessing technological information, and whether countries foresee advantage from receiving it [Bazilian et al, 2008].

As a global society we are facing security and environmental challenges as we strive to reduce our fossil dependence and achieve affordable energy to meet our economic aspirations. Global warming, carbon emission penalties, nuclear power mistrust and finite fossil fuel reserves have all contributed to a surge in technology deployment, pointing the way towards surmounting these challenges and achieving a more sustainable future. Such technology diffusion is critical to addressing the problem of climate change [Hascic and Johnstone, 2011] and climate authors [Stern, 2006, IPCC, 2007, McKinsey 2008, IEA, 2008] agree that the utilisation of a suite of LCT can mitigate the negative climate effects in countries and regions that are currently dependent on hydro carbon systems. Based on the cumulative nature of the carbon cycle, there is an urgent requirement to deploy mitigation technologies more now than ever before.

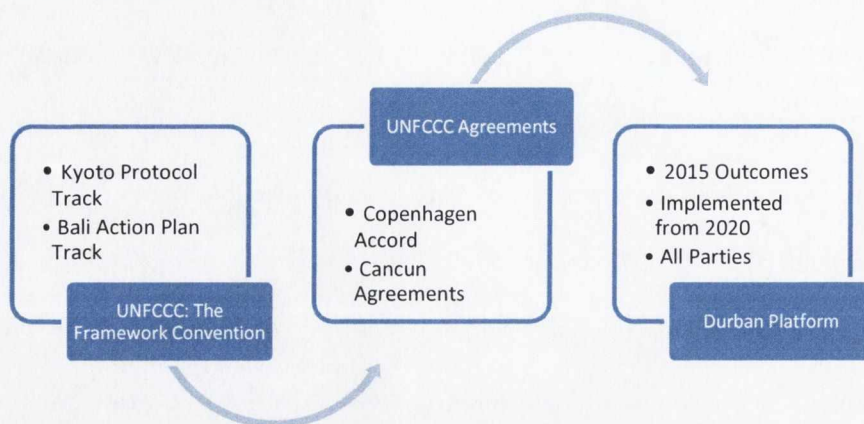
Figure 1.3: The growth of technology related architecture under the UNFCCC (UNFCCC, 2012)



Such clean technology utilisation can offer a viable solution aimed at reducing global GHG emissions of up to 80% compared to 1990 levels. It has the potential to maintain global warming below 2°C, and limit CO₂ emissions to a maximum of 450 parts per million (ppm) of equivalent concentrations in the atmosphere. This ‘decarbonisation imperative’ is more a minimum requirement [IPCC, 2007] and a political assessment of the risk to climate that leading economies are prepared to tolerate.⁶ Authors have concentrated on calls for “parallel efforts” [Pew Center, 2005], an “accord” [Clinton, 2009] and various integrated approaches based on establishing targets that utilise a market based approach, such as emissions trading. The UNFCCC’s ‘Copenhagen Accord’ (2009) and ‘Cancun Agreements’ (2010) encouraged pledges from developed countries and resulted in mitigation policies being enacted in nearly 50 developed countries. The ‘Durban Platform on Enhanced Action’ (2011) presented a new architecture (Figure 1.4). It provided a core agreement and a number of optional annexes among which countries can pick and choose, thereby presenting a “house with many rooms in which all countries could find a place” [Bodansky, 2012]. Such solutions potentially acknowledge “a world of unequal participation and provide for the evolution and expansion of commitments over time”. They may offer a solution to the problem of carbon leakage and the movement of production emissions under the Kyoto Protocol [Grubb, 2011, p1270]. Equity principles, such as adjusting emissions based on per capita income (‘progressivity’), are included alongside the potential to make targets more stringent as countries become wealthier.

⁶ Post industrial revolution CO₂ in the atmosphere was 280 ppm, growing to 384ppm in 2007. [National Oceanic & Atmospheric Admin, 2009]

Figure 1.4: New Climate Architecture



1.3 Technology as the ‘decarbonisation solution’

Despite over twenty years of UNFCCC negotiations the current carbon emissions trajectory reflects the ‘business as usual’ scenarios drawn up by IPCC. The improbability of UNFCCC success has led to many scientists, campaigners and policy makers to conclude that “Two degrees is a wishful dream” [Economist, 2010]. Figure 1.5 presents the policy implications of meeting such a 2°C target or 450ppm of CO₂ equivalent to 2020 and 2050.

Figure 1.5: Policy implications of meeting climate stabilisation targets [IPCC, 2007]

Scenario category	Region	2020	2050
A-450 ppm CO ₂ -eq	Annex I	-25% to -40%	-80% to -95%
	Non-Annex I	Substantial deviation from baseline in Latin America, Middle East, East Asia	Substantial deviation from baseline in all regions
B-550 ppm CO ₂ -eq	Annex I	-10% to -30%	-40% to -90%
	Non-Annex I	Deviation from baseline in Latin America and Middle East, East Asia	Deviation from baseline in most regions, especially in Latin America and Middle East
C-650ppm CO ₂ -eq	Annex I	0% to -25%	-30% to -80%
	Non-Annex I	Baseline	Deviation from baseline in Latin America, Middle East, East Asia

Furthermore, IEA modelling analysis [2012] shows that our current emissions pathway will fall significantly short of this 2°C target as the goal becomes more costly with each year that passes. Indeed, once the impacts of fast varying natural effects, such as volcanic, solar and *El Nino*, are removed from climate models, it shows how human action contributes to temperature increases of 0.15°C per decade [Skeptical Science, 2013]. This perspective is further strengthened by the Alternative Policy Case of BP's Energy Outlook to 2030 [Ruhl and Giljum, 2011], which shows global emissions, though declining after 2020, to be higher in 2030 than in 2010.

While many of the technologies to be transferred are mature and well understood, significant technology cooperation, including R&D, demonstration, and projects to improve the identification of, access to, and deployment of LCT is required. The UNFCCC notes [2007] that financial benefit of over US\$3.3 billion has been allocated by the Global Environment Facility from 2001-2007, mainly targeting renewable energy and efficiency projects. Arguably, it is the transfer of such mitigation technologies from Annex 1 to non-Annex 1 countries that has the potential to bring the greatest economic and environmental impact [Hascic & Johnstone, 2011].

The IPCC Fourth Assessment [2007], the Stern Review [2008] and the IEA [2008c] cite that sustainable GHG emission levels can only be achieved if new and improved LCT are developed. Analysis shows how, over the coming 20 years, non fossil fuels are likely to make the biggest contribution to energy consumption growth [Ruhl and Giljum, 2011]. The IEA *Markal* model predicts LCT as the world's second-largest source of power generation by 2015 and roughly half that of coal. By 2035, LCT will approach coal as the primary source of

global electricity [IEA, 2012]. Where the technology development is considered very expensive it may be hindered by significant barriers to deployment.

The upcoming IPCC's Fifth Assessment Report (AR5) will inform a review of the 2°C target objective and the context for preparing a post-Durban 2015 Agreement. It outlines how emissions projects at the lower range scenario still present the ability to meet the 2°C target and have a 50% chance of meeting a 1.5°C target by 2100 [Van Ypersele, 2013]. However, observed estimated emissions for 2012, in combination with a range of global emissions, are now closer to the range presented in higher carbon growth scenarios [Peters et al, 2012], bringing a growing political acceptance and recognition that this 2°C target is simply not achievable. Indeed, the OECD [2012] warns the concentration of warming gases in the atmosphere could reach 685ppm by 2050, calling for a change in global government policy and a switch to LCT acceleration and deployment. While scientists estimate that one third of mid-21st century warming is committed given the amount of GHG in the atmosphere, the remaining two thirds are dependent on what is discharged in the coming two decades [Sims Gallagher, 2009]. This brings a realisation that emerging economies will play a significant role in the future global energy system. This is placed in a context of a likely bottom-up international policy architecture that presents a "pledge and review" approach to emission reductions [Stavins, 2012]. This could enable a gradual reduction of CO₂ rather than a 'Kyoto Protocol-type centralised approach' linked to targets and strict timetables.

Technological progress within developing countries depends on the pace at which LCT diffuses within a country [World Bank, 2008]. The International Energy Studies Group, at the Lawrence Berkeley National Laboratory, found that the development of new technologies can be more costly in developing countries when compared to industrialised countries. Innovative

LCT cooperation mechanisms are required to deploy existing and new technologies in developing countries and economies in transition. Such mechanisms involve assessing the global framework for delivering such climate change reductions and assessing the various impediments to delivering technologies. Cross-sectoral interventions could induce a transition towards a truly sustainable global energy system as a ‘side effect’ [Bruckner, 2007]. An investigation into the mechanisms for technology deployment under the climate regime must be considered of paramount importance.

1.4 Creating enabling environments, overcoming barriers

There are a number of factors that influence the proliferation of LCT and prevent them from competing in the marketplace and achieving the necessary large scale deployment. Such factors are attributed to the environment in which they take place and often are dependent on the people, systems, techniques and knowledge and overall conditions that are required for mass uptake and deployment. While hardware deployment to developing nations can reflect lessons from developed countries’ experiences, the barriers and obstacles that are encountered and the tools to enable full transfer differ significantly across countries. They often include regulatory barriers, a lack of information and policy uncertainty. Under the UNDP Technology Needs Assessments Synthesis Report [2010], 83% of developing countries identified economic and market conditions as the key barrier to the transfer of LCT. A further 74% of countries identified a lack of information and awareness as key barriers.

Technology diffusion can be enhanced by action that erodes such barriers. This includes establishing an adequate institutional and regulatory framework alongside accompanying economic incentives that foster and stimulate low carbon growth. Furthermore, developing country environments can offer opportunities to deploy LCT more cheaply than developed

countries, thereby providing a rationale for enhanced investment in these countries [IEA, 2005].

The establishment of an 'enabling' environment for technology acceleration involves the building of suitable endogenous capacity and a mobilisation of private sector investment to enable developing countries to apply these technologies. "Governments, through, *inter alia*, sound economic policy and regulatory frameworks, transparency and political stability, can create an enabling environment for private and public sector technology transfers" [IPCC, 2000, p.3]. For the purposes of this thesis, an 'enabling environment' is defined as a conducive institutional context that embodies the appropriate institutional, policy, market and regulatory conditions for the uptake and deployment of low carbon technologies. The UNFCCC (Article 4.5 and 4/CP.7) defines enabling environments as:

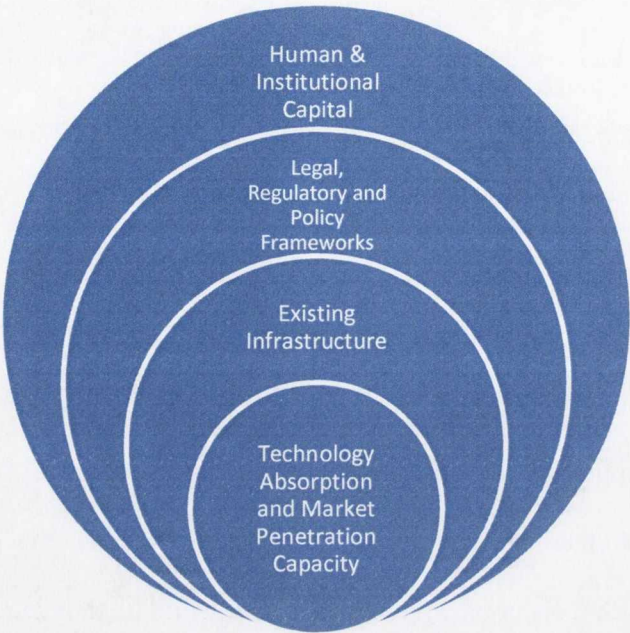
"fair trade policies, removal of technical, legal and administrative barriers to technology transfer, sound economic policy, regulatory frameworks and transparency, all of which create an environment conducive to private and public sector technology transfer."

A number of tools used for energy subsidies, including grants and loans from multilateral development banks, tax measures, R&D, could be realigned with climate change priorities and could be very influential in moving towards such a sustainable economy [Bazilian et al, 2008]. Further exploration of mitigation potentials, identification of exemplar best practices and piloting of projects can all make a positive contribution to achieving climate goals.

Successful technological deployment generally implies the implementation of the adopted technology resulting in increased productivity in its use, and the creation of the long-term capability to manage that technology [Foray, 2009]. These capabilities strengthen environments that stimulate the transfer and acceleration of LCT in developing countries that are currently in the process of developing such frameworks as part of their Technology Action Plans.

The UNFCCC Technology Mechanism (2012) was established to promote technology transfer to developing countries. Its operationalisation should be clearly aligned with the enabling frameworks that facilitate private and public sector investment. This Mechanism focuses attention on creating ‘enabling environments’ that facilitate the transfer of technology into developing countries where barrier removal and sound economic and regulatory frameworks will facilitate private and public sector technology transfer. Such institutional contexts, or ‘enabling environments’, outlined in Figure 1.6, enable Governments to manage technological change. This avoids the ‘institutional inertia’, a concept coined by Perez [1983] and Freeman [1997], as a constraint towards adoption of such new low carbon opportunities.

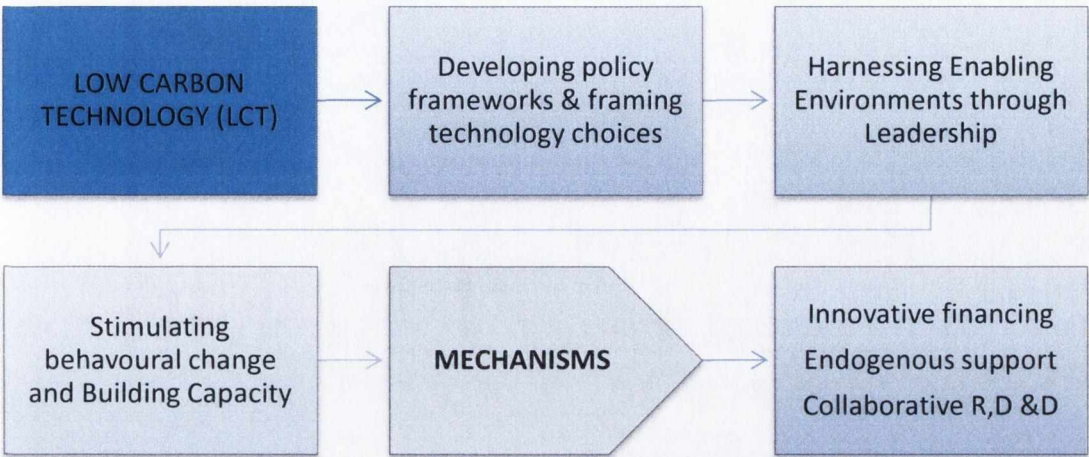
Figure 1.6: Enabling environment schematic [redrawn, UNFCCC, 2003]



1.5 The role of government in supporting LCT

Low carbon technology acceleration and deployment can flourish within a suitable enabling environment at a national level. Governments have a significant role that involves the provision of signals through stable energy and environmental policies that stimulate low carbon investment and create new product markets. Such policies often focus on maintaining the macroeconomic environment that fosters cooperation between developers, suppliers and consumers, and creating predictable policies that enable greater market and system integration and higher penetrations of variable renewable energy. Governments can stimulate the development of the national skills base and improve consumer access to low carbon technologies by developing policy, legal frameworks and the institutional base for transfer. Appropriate mechanisms include innovative financing and support, endogenous support and R&D stimulation and are outlined in Figure 1.7.

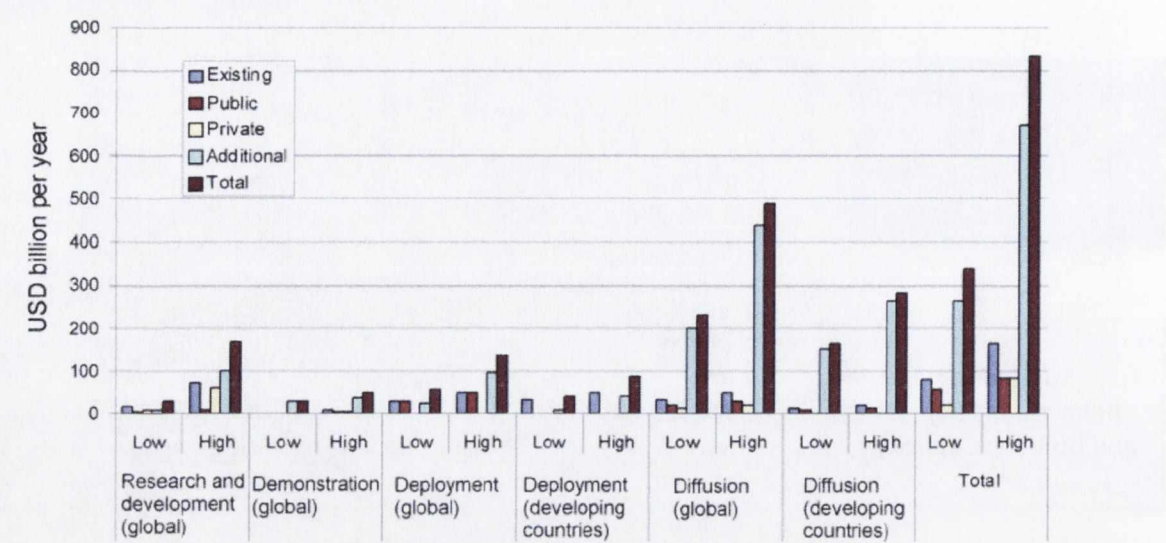
Figure 1.7: Government role in LCT development



Ultimately, success involves harnessing the technical capacity and institutional capacity for LCT transfer within countries, developing policy frameworks that incentivize investment and enhance private finance, and developing the infrastructure to support the diffusion of technology. Technology developers and implementers should also consider the stage of technology maturity, regulatory failures, system integration issues, the supply–demand impacts, and the diverse nature of energy markets within developing countries. Furthermore, such technology transfer should also be aligned with financing that is specific to the context of the technology and of the country where it is realised [Bazilian et al, 2008].

Figure 1.8 illustrates the public and private financing global levels and requirements required to stabilise GHG at 450ppm across the low carbon technology project innovation cycle. Estimates indicate that global technology financing requires an increase above current levels of USD 262–670 billion annually until 2030. Of this increase, 40%-60%, or an additional USD 105–402 billion per year, is projected to be needed in developing countries, representing the emissions reduction potential in these emerging economies.

Figure 1.8: Annual estimates of global technology financing levels required to stabilise GHG (at 450ppm), [UNFCCC, 2009]



National policy frameworks can establish longer term policy interventions that eliminate legal and regulatory barriers to LCT deployment [Sandén and Azar, 2004]. Undoubtedly, many developing countries will require energy programmes that differ in scale and structure, and that focus on establishing ‘enabling environments’ and building institutional capacity. The UNFCCC Technology Executive Committee advises that activities related to the technology cycle, policy and regulatory frameworks and financing should be considered in an integrated manner and the capacity of developing countries to assess, absorb and develop technologies needs to be enhanced.

Developing countries may lack the technological capability to immediately stimulate and deploy such technologies, even with the appropriate energy policy and economic incentives in place. Governments can improve the cost effectiveness of options through framing technological choices and implementing behavioural change programmes [Anderson, 2006]. While Government intervention tends to focus on national interests, research commissioned by the IEA [2008] describes how non-economic barriers impact on the success of policy

incentives irrespective of their design, and draws attention to the importance of the country-specific contexts. Ultimately, there is a requirement to understand the nature of public attitudes and their beliefs with regard to behavioural change.

Enabling early action is critical and requires a channelling of investment through bilateral and multilateral agencies, regional development banks, and private industry. Developed countries, through the 'Cancun Agreement' and 'Durban Platform', have committed to funding the incremental costs to deploy LCT, thereby overcoming perceived financial risk, as seen through Global Environment Facility support. Such investment could enable the production and catalyzing of LCT roadmaps or action plans, such as Low Carbon Growth Plans. These will set out countries' needs and priorities for building capacity and potentially fast-track capacity building activities in the context of national appropriate mitigation actions (NAMAs). Emerging low carbon technologies, such as electric vehicles and fuel cells, require significant action planning and joint R&D to test their applicability in the market and adapt to local conditions. While such action plans outline the state of LCT development, further instructions on the diffusion methods should be defined.

Inherent within LCT deployment is a focus on near term policy objectives. Where directed at specific technologies, this involves moving technologies across the value chain through a spectrum of interventions based on the maturity of the technology. Over a time horizon, a LCT should move along the spectrum or lifecycle and move from prototype development, to demonstration and ultimately to deployment and commercialisation. For example, since 2008, PV has moved from the category as a "nice market high cost-gap technology" into a commercial technology (see Figures 1.9 and 1.10).

Figure 1.9: Framework of policy incentives as a function of technology maturity [IEA, 2008]

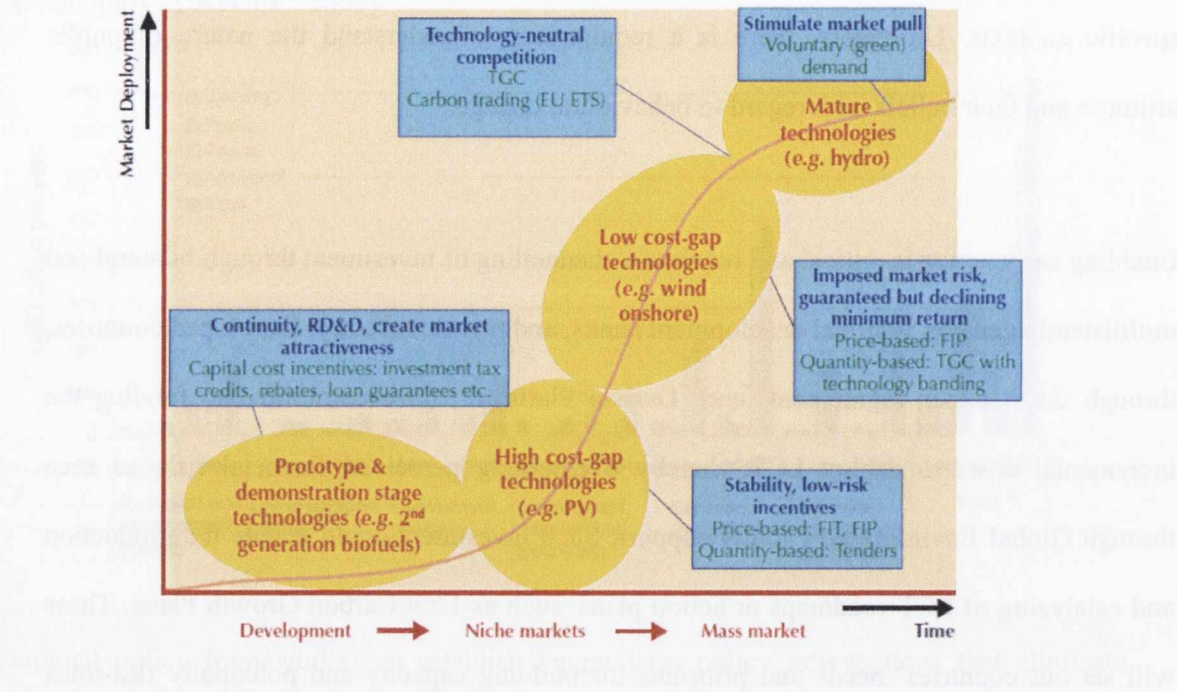


Figure 1.10: Maturity of selected LCTs [IEA, 2011]

Technology	Sector	Demonstration	Commercialisation		
			Inception	Take-off	Consolidation
Biomass	Electricity and heat	Thermal gasification		Aerobic digestion	Cofiring Modern boilers and stoves
	Transport	Advanced biofuels		Conventional biofuels	
Geothermal		Enhanced geothermal		Conventional geothermal	
Hydro					Hydro
Marine		Wave Tidal and stream			
Solar	Heat	Solar cooling			Solar water heaters
	Electricity	PV - 3rd generation CSP tower	CSP trough	PV crystalline and thin-film	
Wind			Offshore wind	Onshore wind	

Governments have a significant role to play across the stage of technical innovation, notably in barrier erosion and stimulating market confidence in LCT through shared costs demonstration. They should avoid an exclusive focus on short-term measures as they will undoubtedly result in 'lock-in' to high carbon infrastructure. Instead, government approaches to LCT deployment should focus on setting the appropriate policy frameworks that create environments to incentivize investment in technologies. The IEA [2012] modelling finds that "almost four-fifths of the CO₂ emissions allowable by 2035 are already locked-in by existing power plants, factories, buildings, etc. If action to reduce CO₂ emissions is not taken before 2017 all the allowable CO₂ emissions would be locked-in by energy infrastructure existing at that time" [p.3]. This makes near term government action an urgent requirement prior to 2017 in order avoid a high carbon infrastructural pathway.

1.6 Economic considerations and commitments

Within the UNFCCC process, the relative power of countries is becoming a significant issue in that, with the exception of the European Union (EU), the larger emitting economies, such as the U.S. and China, seem unwilling to curb their emissions in exchange for actions by other parties. The 'Doha Gateway' agreement (2012) simply urges parties to announce further pledges "when their financial circumstances permit". This has led to a clear dichotomy between countries with serious emission reduction responsibilities and other countries with no perceived responsibilities [Aldy & Stavins, 2012]. It raises concerns surrounding equity⁷, mutual compliance and reciprocity across the UNFCCC. For example, is it the developed world that is producing too much energy or is it the developing world potentially expanding their consumption at too fast a rate? Indeed, when a problem, such as climate change, presents valid but competing views about equity and blame, then finger

⁷ Equity is reflected in the concept of 'common but differentiated responsibilities' where developed nations are expected to take responsibility for current emissions within the environment (Article 4.7).

pointing replaces action. This often leads to stalemate or inertia resulting from an opposition of particular solutions rather than the endeavour to find consensus [Ellwood, 2009]. Developed countries through the 'Doha Gateway' deal argued for differentiation and changing economic circumstances, stressing the emission profiles of countries are now different from what they were when the UNFCCC was established. Any future agreement will need to reflect this new context.

All countries will benefit from GHG mitigation arising out of the diffusion of clean technologies, with many indirectly benefitting from knowledge spillovers. While the UNFCCC focuses on achieving climate effectiveness through reductions in net GHG emissions, little consideration is placed on other factors, such as economic cost. Strives towards achieving climate stabilisation and the 2°C goal have 'a primarily environmental rather than an economic rationale' and if the costs of achieving the goal exceeds the benefits, then the goals of benefit-cost optimisation and climate effectiveness would diverge [Bodansky, 2012]. With deeper interrogation, an analysis of the cost impact on a countries' national autonomy versus the benefits of a global agreement is a growing consideration for major economies.⁸ These considerations have led the OECD to call for Governments to "break out of their national mindsets and look at the global picture" as it called for policies to build low carbon, climate resilient economies [McDonald, 2011]. The mission to negotiate such a single binding agreement is 'near impossible' as there are huge economic interests between different countries that are partly diametrically opposed [de Coninck, 2009]. Indeed, if it is unclear who is going to pay the final cost, and it is not all that clear who is going to gain how much from acting, it results in an energised set of supporters and a weak group of opponents [Ellwood, 2009].

⁸ This is a much smaller consideration for small island developing nations (SIDS) and least developing countries (LDCs).

Today, just 20 countries and regions account for nearly 90% of emissions and so national, bilateral and multilateral action is required to stimulate action and curb growing emission trajectories. The extension of the Kyoto Protocol commitment period was a critical bridge towards reaching a binding deal in 2015 and in maintaining a rules-based and common accounting system. Unfortunately, it achieved minimal signatories, representing 10-12% global emissions, and reflects the design inadequacies of the original Kyoto Protocol from a major emitter perspective. Indeed, this commitment period to 2020 will only include the European Union, Australia, Norway, Switzerland and a few smaller countries, such as Lichtenstein, and did not include Canada, Russia, Japan and New Zealand. Belarus and Kazakhstan announced their intention to join the second commitment period, totalling 35 developed countries and economies in transition that made binding commitments.

China, Indonesia, India and Brazil were not constrained due to a lack of commitments, while the US failed to ratify. Despite its failure to ratify, the US federal government has passed legislation to promote LCT, improve efficiency and reduce GHG through regulation. When analysing the income and emissions per capita of the U.S., EU and China to 2020, and modelling the current ‘business as usual scenario’, then carbon emissions in the form of CO₂ tonnes per capita, are very similar for both the EU and China, but half those of the United States (see Table 1.1).

Table 1.1: Comparison of CO₂ emissions of major economies [UNEP Gap Report & PBL Netherlands Assessment Agency, 2012]

	Emissions (including land use) / capita, tonnes CO ₂ / capita			
	1990	2010	2020 BAU	2020 Pledges
EU-27	11.9	9.2	10	8.8 (20% reduction) 7.7 (30% reduction)
China	3.5	7.4-8.3	9.9	9.7
United States	24.3	21.5	21	17.7

As long as CO₂ accumulates in the atmosphere and its sources are greater than sinks, the historical responsibility of countries has a scientific basis in the climate change research. It could also be argued that a number of economies⁹, classified as non-Annex-1, should no longer be the beneficiaries from climate financing as, from 2009-2011, their GDP was higher than the average EU 27 countries.

1.7 The research aims and scope

As countries make the transition to more sustainable economies, the achievement of climate and sustainable development goals will require a shift in the development trajectory of these nations. This thesis aims to analyse how the deployment and acceleration of LCT can play a significant role in achieving these CO₂ emission reduction shifts. Acknowledging that the transfer of LCT to developing countries is a relatively complex task, this research aims to explore the factors that may influence the choice, take-up and acceleration of low carbon technologies and aims to identify the action that is required to erode barriers to deployment, thereby stimulating low carbon growth.

1.7.1 The research focus

This research involves an analysis of international technology deployment. It begins by presenting the importance of low carbon technology in terms of an emerging energy revolution where clean technology sources can minimise our fossil fuel dependence and address the threat of climate change. It explores the role of technology as a building block under the UNFCCC and champions low carbon technology as ‘the decarbonisation solution’.

⁹ These countries include Qatar, Singapore, Kuwait, Brunei Darussalam, United Arab Emirates, Equatorial Guinea, and the Bahamas [LeFevre, 2012].

It highlights the factors that may influence the proliferation of LCT and prevent them from achieving the necessary large scale acceleration and deployment.

In assessing the market opportunities for clean technologies, it describes the factors influencing the proliferation of LCT in different socio-economic contexts. Through case study investigations, the thesis analyses the barriers encountered in LCT deployment. These barriers affect the overall implementation of initiatives aimed at meeting climate stabilisation and the 2°C target. The deployment and acceleration of LCT is explored within a mature technology market (Ireland) and in less mature markets (five developing and emerging economies) and the factors that may restrict the international deployment of LCT at a global level are determined. Put another way, the research analyses the complex and dynamic interaction between countries and users in terms of the acceleration of technologies in the broad context of climate change.

1.7.2 The research relevance

While technological diffusion remains difficult to achieve, identifying the appropriate conditions, barriers to overcome, and the appropriate enabling environment to transfer technology to developing countries becomes critical. Integral to the thesis is a determination of the most appropriate conditions and enabling environments for the acceleration and deployment of technologies. A number of social, environmental and economic factors are required to create the environment in which a technology must compete [Gielen, 2011]. In the context of technological take-up, this thesis explores the factors that affect and/or inform choice and the related socio-economic conditions that influence deployment.

The research considers perspectives from game theoreticians as a way of informing the strategic interactions of individual countries in the UNFCCC negotiations. Attention is placed on actions that may entice engagement of countries within an agreement process and new dimensions are identified that could add flexibility.

1.7.3 Organisation of the thesis

This thesis is based on a set of interconnected studies on the accelerated deployment of LCT that have been undertaken over the past years. These have been published, or will soon be published, in international referenced literature. It comprises of six chapters. Chapter 2 assesses the relationships and dependencies that may influence LCT decision making and investigates consumer behaviour within a developed mature market. Chapter 3 analyses and predicts the factors influencing consumer choice of low carbon technologies. This provides policy makers with a modelling tool by proposing a procedure to analyse and predict customers' choice of LCT using artificial neural networks. Chapter 4 explores a number of market barriers and behavioural factors that hinder LCT deployment and transfer in less mature markets, across five developing and emerging economies. Chapter 5 extrapolates the lessons from the mature and less mature technology market case studies and places them within the context of the international climate change policy architecture under the UNFCCC. Finally, Chapter 6 draws some conclusions, recommendations and lessons through a retrospective and prospective review.

Chapter 2

Implementation of renewable heating technologies in the Irish domestic sector

This chapter critically reviews and explores the factors that may be influencing the impact of renewable energy heat technologies in the residential sector in Ireland. It is in response to the challenge of better understanding the broad effects and attributes of low carbon policy instruments to induce technological change in Ireland and beyond. Using the Irish residential sector as a case study, and analysing data of more than 31,600 technology installations under the Irish Government's Greener Homes Scheme [GHS], it assesses the extent to which policy makers may be informed of the willingness of consumers to deploy these low carbon technologies (LCT) in their homes. In doing so, it attempts to provide valuable guidance for policy evaluation in relation to renewable energy in the residential sector. It represents investment decisions and technological choice by the end user and reflects the growing concern among energy policy markets regarding the representation of user preferences. The overall intent of the chapter is to investigate the implications of analysing different variables and their contribution to making more balanced renewable energy policies. It provides a critical analysis of the Greener Homes Scheme, the key instrument for implementing Ireland's renewable heating policy from 2006-2010, established to induce technological change within the residential sector.

In assessing the impact of the Scheme, attention focuses on decision frameworks for low carbon technological choice and the treatment of market and behavioural failures. It considers how consumers have responded to new technological policies aimed at deploying renewable

heat technologies, and the specific policies aimed at advancing certain LCT over others. Through a case study investigation, the study explores the relationship and dependencies that influence consumers' decision-making regarding the choice of renewable energy heating technologies in the domestic sector in Ireland. Consumer preferences and their subsequent investment decisions, motives and technological choice are reflected.

2.1 Introduction

In moving towards the long term imperative of a carbon-free energy system, Irish energy policy makers have placed attention on accelerating the development and adoption of technologies to exploit renewable energy sources. Considering the significant growth of energy prices and the reduced availability of oil over the past decade, low carbon energy sources are becoming more and more indispensable in the current global energy landscape. The requirement to incorporate a sustainable energy portfolio can also be attributed to growth in energy demand, global warming, fluctuating fossil fuel prices [Cetin et al, 2009] and large fossil import dependency (88% in Ireland in 2011). While the end-point is carbon-free, indigenous energy inputs into a system that emphasises electricity as the carrier, the starting point involves building the consumer confidence through the deployment of LCT, thereby achieving an increased penetration of renewable heating in the residential sector. An important tool to assess the viability of options is user behaviour [Natarajan et al, 2011].

The advantages of most low carbon technologies include that, once in operation, they have no fuel costs, they exhibit very few unexpected outages and in several cases, less maintenance is required to keep them functioning [IEA, 2005]. Accepting this international perspective, it is worth acknowledging that most LCT (with the exception of large hydropower) requires some form of subsidy to compete with other technologies. Investments in LCT are cost effective,

resulting in significant societal benefits [Allen et al, 2008]. The hope of industrial policy makers is that these technologies will become more price-competitive once they are more developed and the external effects of CO₂ emissions are priced in. Indeed, the predominant economic approach behind most sustainable energy policies assumes that improving the cost-benefit ratio of technologies via grants and subsidies will automatically incentivise consumers to invest in low carbon technologies [Claudy and O'Driscoll, 2008]. Put within the context of the EU Climate and Energy Package, LCT targets remain relative targets, in that they depend on decreasing final energy demand and deploying these technology types.

Significant research is based around consumers' assessment of technology choice using economic or engineering evaluation decision criterion. These studies analyse the uptake of both renewable energy and energy efficient technologies in the residential market by addressing policy instruments through the cost of technology measures and associated technical variables. These decisions are based on cost or monetary aspects [Natarajan et al, 2011]. Various studies [Jenninga et al, 2001, Haas et al, 1998, Linden et al, 2006 & Guerra Santin, 2011] have suggested that occupant behaviour exerts a strong influence on energy consumption. Indeed, "besides technical parameters, consumer behaviour is the most important issue with respect to energy consumption in households" [Haas et al, 1998 pp195] representing a complex interplay of socio-cultural, economic and contextual factors at play [Stieb and Dunkelberg, 2012].

The Fourth Assessment Report of the Inter-governmental Panel on Climate Change on mitigation highlights the importance of 'consumer choice and the use of technology' as major determinants of energy use in buildings [IPCC, 2007]. This also features in the theory of consumer choice of values where consumer decisions may be affected by personal factors

where behaviour is influenced by functional, social, emotional and epistemic values [Van Raaij et al, 1983]. This chapter attempts to explore the patterns and co-occurrence of consumers' decision making regarding their choice of technology under Ireland's Greener Homes Scheme.

The chapter has the following aims:

- To assess the technology take-up by consumers within the Irish Government's Greener Homes Scheme, a grant-aid scheme that from 2006-2010 focused on the deployment of renewable energy (heat) technologies in the residential sector in Ireland.
- To explore the decision-making framework for choice, evaluate policy instruments, and present an understanding of market failures in terms of the various selection choices that were made by consumers within the Greener Homes Scheme and the relationship and dependencies that may have influenced such decisions.
- To consider the impact of various variables that may have influenced LCT take-up in terms of changing consumer confidence levels in technologies and changing national economic circumstances.

It builds on work by Van Raaij and Verhallen [1983] and Guerra Santin [2011] who characterised attitudes relating to energy under variables, including price, environmental concerns and comfort levels.

2.2 Irish energy policy response

In establishing the Greener Homes Scheme, the focus of Irish energy policy was on building a sustainable energy market that was based on quality, confidence and proven performance. The specific policy goal was meeting Irish renewable energy heating targets (RES-H: 5% by 2010; 12% by 2020). The overall aim was to drive a decarbonisation of energy supply, and raising standards in renewable energy products and services that were to be deployed to market. The steps on the pathway involved setting out a road-map for maximising Ireland's ability to meet heat energy demand across residential buildings and creating consumer choice in relation to heat energy, based on reliable information and high standards throughout established supply and service chains. Energy modeling analysis predicted that the electrification of residential heating to 2020 would produce 2.7 million ktoe. Consequently, heating improvements within the existing building stock would afford considerable scope for reducing Ireland's energy consumption.

By early 2010, Irish Government energy policy had focused on the promotion of energy efficiency measures in the residential and industrial sectors. The launch of Ireland's Home Energy Savings Scheme (HESS), a grant scheme aimed at energy efficiency improvements in the residential sector, may have impacted on the number of applications to GHS. The HESS brought more competition for available, yet scarce, consumer disposable income, thereby impacting on the numbers of consumers that installed low carbon technologies. Enhanced marketing campaigns targeting efficiency upgrades and payback periods for homeowners were impacting upon consumers and, by end 2010, Irish consumers had installed over 64,000 energy efficiency technologies in their homes under the HESS (see Table 2.1), resulting in consumer expenditure of nearly €115 million directed to efficiency upgrades rather than renewable energy technology installations. The Irish Government was also engaging with

Ireland’s dominant utility in providing both subsidized and free home energy audits for consumers wishing to avail of grant incentives for efficiency upgrades.

Table 2.1: Consumer take-up under Ireland’s Home Energy Savings Scheme (HESS)

Year	2009	2010	2011
Grant Spend €M	16.34	45.27	56.70
% grant of total cost	35%	35%	32%
Total spend implied €M	47.2	129.3	162.0
Number of homes	18,152	45,940	48,707

Irish energy policy lessons could have been learned from the implementation of renewable heating technologies in the United Kingdom’s domestic sector where hidden costs associated with technology featured. In addition to the high financial costs associated with the uptake of renewable heat, impact assessment analysis by Enviro for the Department of Energy and Climate Change Renewable Heat Incentive Model [Enviro, 2011] showed that investors could face significant non-financial barriers when deciding whether to invest in renewable heat (e.g. the hassle of taking fuel deliveries for biomass boilers).

Consideration of such hidden costs is important for all policy makers in developing LCT schemes and for consumers in influencing technology selection. These costs could also include obtaining planning permission, construction management, disruption cost, and hassle cost of fuel deliveries and costs of additional works. Scott [1997] described how the lack of information, due to hidden costs, was the main reason for underinvestment in energy efficiency measures in Irish households, while Banfi et al [2008] confirmed this in a similar study for Swiss households. Privitera et al [2011], in describing a set of factors required to assess the viability of renewable technologies, include consideration of capital costs, maintenance costs and payback of technology investments. Often consumers are required to

have access to specialist information and expert knowledge concerning the performance of various technology options, their reliability, associated costs and benefits and compatibility with existing energy systems [Stieb and Dunkelberg, 2012].

2.3 Methodology and data

This chapter presents a study on the implementation of renewable heating technologies in the domestic sector in Ireland with implications on consumers' decision-making.

Data is based on successful participants under the Sustainable Energy Authority of Ireland's (SEAI) renewable energy heating programme (branded as the Greener Homes Scheme). All dwellings underwent LCT improvements, such as biomass boiler, solar panel and heatpump installations. The chapter's methodology is exploratory rather than confirmatory and accesses the key influences of consumer technology take-up from 2006-2010. It presents its analysis from the perspective of the policy maker.

In exploring the relationship and dependencies that influenced consumer choice, the chapter looks across the three phases of the GHS to determine the impact of three (grouped) LCT, namely bioenergy, solar and heatpump technology. Assuming that technological choice is driven by a number of economic variables such as energy prices, operational and maintenance costs, discount rates and market information about the efficiency of certain technological choices, the chapter explores some behavioural variables that may have impact on the sustainable energy policy. The paper examines the effect of various attitudinal and behavioural variables on LCT selection in the Irish residential sector.

2.4 Characterisation of the Greener Homes Scheme

The SEAI has the statutory responsibility for the management of schemes aimed at promoting the deployment of energy technologies and raising awareness of energy efficiency by providing information, advice and publicity on best practice in the energy environment. These schemes are designed to implement part of Ireland's sustainable energy policy, which is focused on a combination of improved energy efficiency and the wider exploitation of renewable energy. SEAI's strategic goal to 2025 states that "renewable sources represent over 40% of electricity supply, within an active, smart grid, with newer sources such as ocean starting to show a significant contribution renewable sources for heat are the norm" [SEAI, 2010].

Today, like most industrialised countries, low carbon technologies in Ireland are supported by government policy schemes and subsidies to bring this option to the market. In 2006, SEAI established the GHS (see Table 2.2). This scheme enabled new technologies to become available on the Irish market that could reduce carbon emission dioxide emissions and slow resource depletion.

As wind power approached the stage of commercial operation in Ireland, renewable energy for heating technology was also regarded as a high potential energy source, but one which came at a high cost of supply. This had two important consequences on public opinion: (i) It prevented the widespread uptake of renewable energy systems regardless of their environmental soundness and (ii) it placed a requirement for public funding to support LCT development. The Irish Government assumed that, as consumers became positively aware of the ability of LCT to mitigate environmental damages, they would attach a value to technology and influence their willingness to pay. These findings were also recorded in the

Italian market where the residential sector’s willingness to pay would augment the premiums that they are potentially appropriate to pay for such new technology and, potentially, reduce the needed amount of public funding [Bollino, 2009]. Indeed, this is the approach being adopted by SEAI, post 2010, as it introduces a *Pay as You Save* scheme.

Table 2.2 Greener Homes Scheme Factsheet

The Greener Homes Scheme was established in 2006 to provide grants for the installation of certain renewable energy technologies. It had a planned duration of five years. The objectives of this scheme were to

- increase the number of households in Ireland that use renewable energy heating
- guide consumers and enhance awareness of renewable energy heating choices
- ensure that the market for the products, services and fuel continues to develop in a robust manner
- decrease Ireland's reliance on imported fossil fuels and so reduce Ireland’s carbon dioxide emissions.

Budget

The budget for the Greener Homes Scheme for the period 2006-2010 was €27 million. The budget allocation increased to €57 million in 2007 to take account of higher than anticipated demand levels. In 2009, the budget allocation for the scheme was €68 million.

Eligible Technologies

Technology installations in this category can include solar heating panels, heat pumps, wood chip\pellet stoves\boilers and wood gasification boilers. The level of grant support varied from €800 to €3,500 per installation. An installer registered with SEAI must carry out installations. These installers have received qualifications under training schemes approved by Further Education Training and Awards Council.

Implementation Arrangements

Applicants apply directly to SEAI for a grant. When they receive SEAI approval they may then proceed with the installation. The applicant hires an installer. The installer carries out the work and certifies that work performed meets the required standards. Payments are made directly to the applicants on foot of documented claims and installer's certification.

SEAI Role:

In delivering the GHS, SEAI adopted roles as an agency, academy and activator. It was required to ensure its new renewable heating programme was delivered effectively and efficiently (the agency role), that the necessary capacity and standards (academy role) were built whereby product and technology installers had access to appropriate training. Finally, and most importantly, government had to engage with energy consumers, raise awareness of the renewable energy product offering and change behaviours (the activator role).

The GHS's first intervention in 2006 involved supporting householders wishing to install LCT, including wood pellet and chip stoves and boilers, solar panels and heat pumps in their homes. The programme aimed to facilitate the wider deployment of LCT in the residential sector and support the development of a sustainable heat market, resulting in reduced dependency on fossil fuels and in lower CO₂ emissions. By the end of 2009, the GHS resulted in the installation of over 26,600 renewable energy heating technologies in homes across Ireland, with cumulative expenditure of €66.91m. This extended to 31,150 by end 2010. Residential energy use had decreased by 2.7% in 2009. When corrections for climate effects are taken into account the decrease was 2.9%, energy consumption per household was 5.3% lower in 2009 than in 2008.

2.5 Characterisation of the residential sector in Ireland

Ireland aims to reduce Non-Emissions Trading Scheme sector CO₂ emissions (primarily residential, services, transport, and agriculture) to 20% below 2005 levels by 2020. In Ireland, alongside many industrialized countries, the residential sector accounts for more than 24% of energy consumption, the overwhelming share of which is consumed for space heating and hot water preparation. Placing this in a global perspective, commercial and residential buildings consume about 30% of global electrical energy consumption [Prasartkaew and Kumar, 2010] and over 50% of carbon dioxide emissions come from the building sector, with solar energy technology expected to 50% of total energy consumption in buildings by 2010 [Uihlein and Eder, 2010]. Within the European Union, the building stock is responsible for about 40% of primary energy consumption and about 25% of the CO₂ emissions [Uihlein and Eder, 2010, and OECD, 2008].

Within Ireland residential final energy use grew by 37% (1.7% per annum) over the period 1990 – 2009 [to a figure of 3.1 Mtoe]. During this time the number of households in the State increased by 53% from approximately 1.0 million to 1.5 million [CSO, 2007].

Figure 2.1: Residential final energy use by fuel [SEAI, 2012]

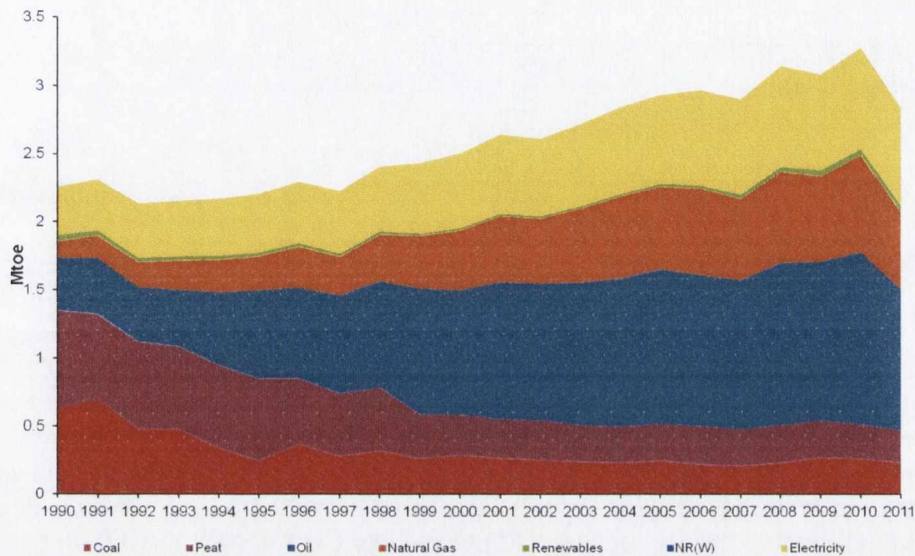


Figure 2.1 presents the changes that have taken place in the Irish residential sector’s fuel mix since 1990. New houses built in the 1990s predominantly had oil or gas-fired central heating and there has also been a recent trend to convert existing back-boiler systems to either oil or gas. It is estimated that the building sector is responsible for more than 40% of energy use in most countries, thereby offering a significant opportunity to mitigate greenhouse gases [WBCSD, 2009].

Table 2.3: Growth Rates / Shares of Final Consumption in Residential Sector [SEAI, 2012]

	Growth %	Average annual growth rates %				Quantity (ktoe)		Shares %	
	1990–2011	'90–'11	'00–'05	'05–'10	2011	1990	2011	1990	2011
Fossil Fuels (Total)	11.9	0.5	3.1	1.9	-16.6	1,857	2,078	82.2	73.3
Coal	-62.9	-4.6	-3.0	1.2	-11.1	626	232	27.7	8.2
Peat	-66.7	-5.1	-1.8	-1.5	-4.8	725	241	32.1	8.5
Briquettes	-49.3	-3.2	-5.5	-0.5	-10.8	155	79	6.9	2.8
Oil	165.8	4.8	4.4	2.2	-18.3	389	1,035	17.2	36.5
Gas	385.5	7.8	6.7	3.2	-19.8	117	569	5.2	20.1
Renewables	2.3	0.1	5.6	16.4	-5.6	45	46	2.0	1.6
Combustible Fuels (Total)	10.4	0.5	3.1	2.0	-16.6	1,902	2,100	84.2	74.1
Electricity	100.0	3.4	3.3	2.6	-3.1	356	712	15.8	25.1
Total	25.6	1.1	3.2	2.2	-13.4	2,258	2,836		
Total Climate Corrected	18.6	0.8	3.8	-0.7	-2.2	2,378	2,819		

Table 2.3 displays the significant deployment of direct renewable energy usage in households in Ireland. Indeed, this Table also depicts a reduction in renewable energy deployment from 1990-2000 as consumers abandoned using solid fuel (fires and back boilers) and replaced with oil or gas fired central heating or electric storage heating. The renewable share of energy used in households in 2011 was 1.6%. The Irish residential sector was the second largest (after transport at 34%) and energy-related CO₂ emissions were 10,479 kt CO₂ representing 27% of the total (energy related) emissions [SEAI, 2012] (see Figure 2.1).

2.6 Data collection, analysis, programme expenditure and overall installations

SEAI provided anonymised application data for over 31,600 technology installations under the Greener Homes Scheme was obtained across three phases. A database was developed where data was organised into three distinct 'calendar' phases in which the GHS was delivered from March 2006 to December 2010: (a) Phase 1 (04/2006-09/2007) (b) Phase 2 (09/2007-09/2008) and (c) Phase 3 (09/08-12/10). To ensure sufficient data was available on measure or technology type (see Table 2.4), property type, grant type and amount and property age, only grant beneficiaries were included. The data was cleaned to remove applicants that had accepted the grant offer but failed to draw it down within GHS timescale.

Table 2.4: The various measures included in GHS

Measures under GHS	Technology Type
Heatpump	Air source Heat Pump
	Ground source Heat Pump
	Vertical Ground collector Heat Pump
	Well to water Heat pump
Bioenergy	Biomass Boiler
	Biomass stove
	Biomass stove with backboiler
	Wood Gasification Boiler
Solar	Solar Tube (evacuated)
	Solar Flat Plate
	Solar thermal (Heating & Space)

Findings were extrapolated from the technologies that consumers applied for through these three phases. This enabled an analysis of consumer take-up by renewable energy technology. Technology uptake was categorised by technology type and numbers of technologies deployed by phase. Technology types applied for under each phase were also placed into subcategories by grant type. For example, heatpump technology was subcategorised into three types: vertical ground collector, horizontal ground collector and air source heat pump.

Changing financial support levels, associated with grants, were mapped and analysed by technology type and by programme phase. The database also captured changing (non financial) conditions associated with eligibility of applicants to the GHS. Further exploration was made of changing consumer confidence levels in technologies and the impact of hanging national economic circumstances.

An analysis of the data of more than 31,500 applications (see Table 2.5 and 2.6) reflects a significant deviation in technology take-up across the three phases of the GHS. This equated to an investment of over €73 million of government exchequer financing, equating to approximately a 30% grant aid investment from Irish exchequer funds.

Table 2.5: Planned costs, out-turn and number of installations for the GHS, 2006-2009

	Year					
	2006	2007	2008	2009	2010	Total
Planned costs €m	4.9	28.2	22.5	12.35	6.0	73.95
Outturn €m	5.04	27.67	22.55	11.65	6.3	73.21
No. installations	1,338	8,387	9,643	7,311	4,957	31,636

Table 2.6: Number of Grants by Low Carbon Technology

Technology	GHS Phase and Date Range			
	Phase 1 (04/06-09/07)	Phase 2 (09/07-09/08)	Phase 3 (09/08-12/10)	Total
Air Source Heat Pump	625	271	168	1064
Ground Collector Heat Pump	2433	722	91	3246
Vertical Ground Collector Heat Pump	897	371	93	1361
Well to Water Heat Pump	82	33	17	132
Biomass Boiler	3487	214	155	3856
Biomass stove	608	237	300	1145
Biomass stove (with backboiler)	457	21	144	622
Wood Gasification Boiler			125	125
Solar Tube (evacuated)		1770	4545	6315
Solar Flat Plate		3208	4501	7709
Solar thermal (Heating & Space)	5584			5584
Total	14173	6847	10139	31159

A number of techno-economic variables were identified as determinants for technology choice. From a (technical) non-economic perspective variables included the perceived confidence in an available technology, technology support and maintenance systems and suitability. From an economic perspective variables included the availability of 'grant-based' financial assistance, the hidden costs associated with technology installation, overall project costs and level of disposable income of homeowners. For example, the residential sector responded very favourably to the introduction of biomass [boilers and stoves] in Phase 1, but did not engage in similar levels of technology take-up in Phases 2 and 3. Indeed, using solar

technologies and low grade heat technologies, such as biomass, contribute to a significant reduction in CO₂ emissions [Prasartkaew and Kumar, 2010]. The growth in solar tube and flat plate reflects the case study findings from Rezaie et al [2011] where solar panels were identified as a good choice to heat domestic water due to their ease of installation and low maintenance costs. Hidden costs are further explored later in this chapter.

2.7 Results and discussion

The results of this chapter add considerably to the understanding of low carbon technology choice in the domestic sector. Through a case study investigation and analysis of over 31,500 applications, it draws conclusions that consumers responded to the introduction of the GHS by choosing and advancing certain technologies over others. It explores a number of factors that may have influenced consumer behaviour in their take-up of technologies. While the provision of grant assistance to consumers and subsequent changing of grant conditions may have influenced LCT decisions, thereby achieving the desired market (barrier eroding) effect for policy makers, our analysis shows that a number of variables may have also influenced and impacted upon consumer behaviour. These variables including changes to (non-financial) conditions associated with eligibility of applicants to the Scheme, confidence levels of selective technologies, low carbon technology product supply chains, uncertainty surrounding security of supply and the impact of the green agenda. This chapter's analysis is presented across the GHS's three programme phases.

2.7.1 Technology take-up by phase: Changing support levels & eligibility conditions

The following section categorises the low carbon technology take-up by consumers across three phases of deployment under the Greener Homes Scheme.

The Greener Homes Scheme was established to provide grants for the installation of certain renewable energy technologies and was structured around three phases from 2006-2010. The changes to Scheme condition aligned within a new phase within the Greener Homes Scheme. The time period per phase within accompanying internal financial and eligibility criteria changes to conditions and external regulations are outlined below:

Phase 1: April 2006 to September 2007

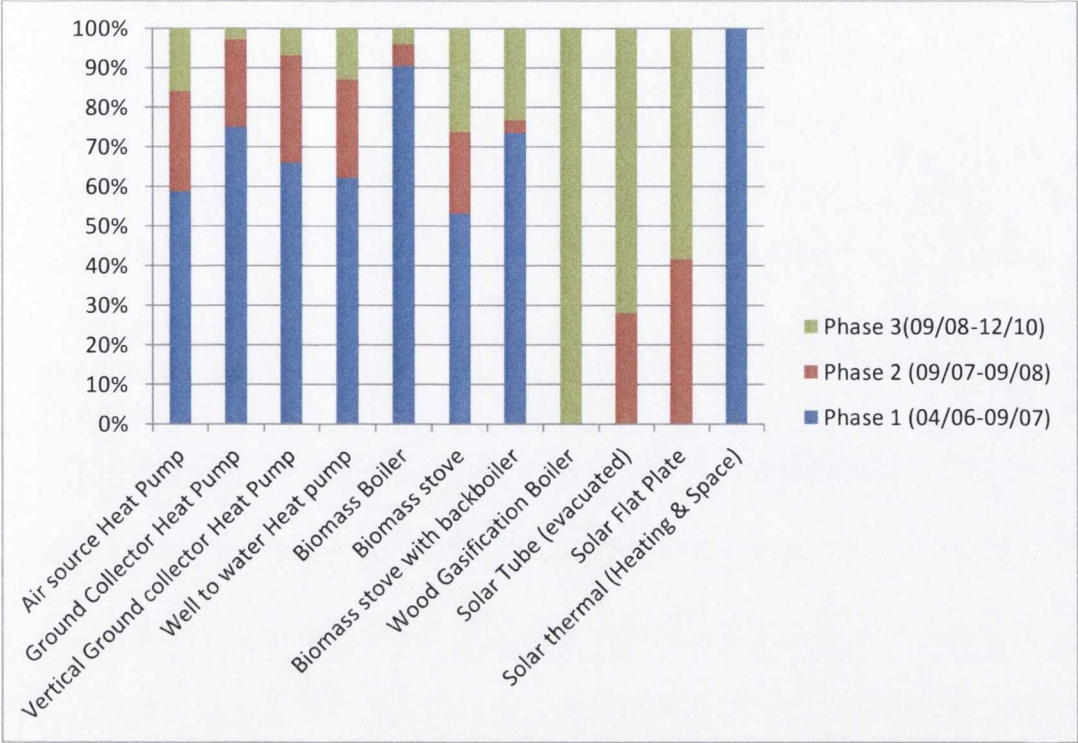
Phase 2: September 2007 to September 2008 (e.g. Grant reductions, home ownership exclusion post 2008, inspection regime, inclusion of new build and retrofit applicants)

Phase 3: September 2008 to December 2010 (e.g. Grant reductions, new build regulations, restriction of new build applicants)

2.7.1.1 Phase 1

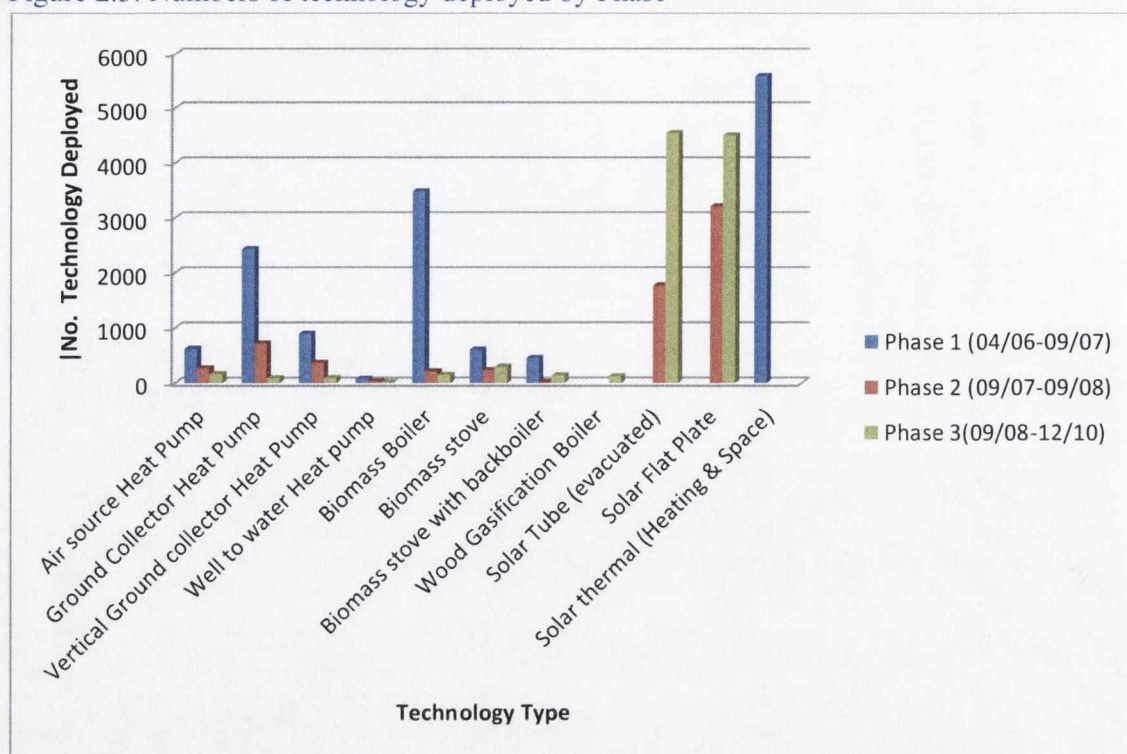
Heat pumps, biomass boilers and solar thermal for heating and space constituted significant technology take-up by consumers in Phase 1 of the GHS (see Figure 2.2 and 2.3). While ground collector heat pumps experienced growth throughout Phase 1, air and vertical heat pumps all experiencing limited success in terms of consumer take-up in Phase 1 and all experienced significant fall in consumer take-up post Phase 1.

Figure 2.2: Technology % take-up across all phases



From the commencement of the GHS and throughout Phase 1, bioenergy boilers and stoves were the most successful technology deployed in Irish homes. Biomass boilers were introduced into the Irish market on a large scale in 2006. Consumers opted for biomass boilers and stoves rather than heatpumps or solar panels. SEAI financial assistance/ grants targeted this technology over solar technology in Phase 1 with over 4500 successful bioenergy deployments in Phase 1. Growth in this technology was aided by the lack of grant support for solar tube or flat plate in Phase 1. Furthermore, the availability of fuelling sources, such as wood pellets and woodchips, were actively communicated through media channels. A significant industrial supply chain was established that promoted and installed bioenergy boilers throughout 2006 and 2007.

Figure 2.3: Numbers of technology deployed by Phase



Consumer take-up of bioenergy technologies changed towards the end of Phase 1 of the GHS. Given the high technology take-up of bioenergy technologies in Phase 1, it is understandable that a slight shift in technology take-up may occur in subsequent phases as many of the early adopters had applied for support for bioenergy, resulting in a reduced pool of willing consumers to apply for grant assistance in Phases 2 and 3.

Research case studies have also explicitly referred to the importance of the institutional and market conditions surrounding where the technology is deployed [Greening and Bernow, 2004]. Support systems for LCT in 2006 were immature and not prepared to match take-up in phase 1 of the GHS. Local enterprise product support regimes for bioenergy technologies were not in place in Ireland when mass technologies were deployed. By the time the market had responded and put in place bioenergy product supports, confidence in bioenergy, as a technology, had eroded. Concerns were raised surrounding the quality factors for both wood

chip and pellets, including moisture content, chip size and contaminants, durability, calorific value and ash content and the requirement for a certification system to be put in place.

2.7.1.2 Phase 2

The take-up of both heatpumps and biomass technologies (bar solar thermal for space heating which was stopped after Phase 1) had significant fall off in Phase 2 and 3.

Our analysis shows a significant deterioration in take-up of bioenergy technologies beyond Phase 1 with technology take-up of less than 500 technologies across the three bioenergy technology types in Phase 2 (See Figure 2.3). One of the potential reasons for this shift in consumer choice may be a change in GHS grant support criteria for consumers installing bioenergy in Phase 2. Since many possibilities existed for the combining of different renewable technologies, the associated costs of installation vary widely. The grant support levels available for bioenergy reduced from €4,200 to €2,500 (boiler), from €1,100 to €800 (stove) and from €1,800 to €1,400 (stove with backboiler) (See Table 2.7).

Table 2.7: Grant support / financial assistance by LCT across phases

	Phase 1 (04/06-09/07)	Phase 2 (09/07-09/08)	Phase 3(09/08-12/10)
Air source Heat Pump	€4,000	€2,000	€2,000
Ground Collector Heat Pump	€4,300	€2,500	€2,500
Vertical Ground collector Heat Pump	€6,500	€3,500	€3,500
Well to water Heat pump	€4,300	€2,500	€2,500
Biomass Boiler	€4,200	€3,000	€2,500
Biomass stove	€1,100	€1,100	€800
Biomass stove with backboiler	€1,800	€1,800	€1,400
Wood Gasification Boiler			€2,000
Solar Tube (evacuated)		€1,206	€1,187
Solar Flat Plate		€1,324	€1,274
Solar thermal (Heating & Space)	€1,639		

A competing technology to bioenergy, namely solar tube and flatplate, was introduced into the GHS at the commencement of Phase 2, resulting in the number of grants deployed to solar technology in the residential sector increasing throughout phases 2 and 3 of the GHS. Data analysis [per annum] shows that LCT, such as solar tubes and flat plates, introduced at the commencement of Phase 2 of the GHS, experienced considerable growth throughout Phase 2 and Phase 3. Furthermore, consumers responded favourably to the introduction of biomass [boilers and stoves] in Phase 1, but did not engage in similar levels of technology take-up in Phases 2 and 3. Indeed, using solar technologies and low grade heat technologies, such as biomass, contribute to a significant reduction in CO₂ emissions [Prasartkaew and Kumar, 2010]. Unlike in Phase 1 with bioenergy, in phase 2, when mass solar technology was deployed, a rigorous product support scheme had been developed thereby providing confidence in solar technology to the market.

Throughout Phases 2 and 3 of the GHS, the average installation costs of solar significantly reduced from €7,000 to €3,400, thereby stimulating uptake, while the grant levels available to consumers did not significantly reduce. Figure 2.3 displays the growth in the number of grants deployed to solar technology in the residential sector. Table 2.7 displays the significant alteration in grant supports across the three heatpump technologies throughout the phasing of the GHS, with grant reductions of 40-50%.

A number of eligibility criteria were added into the GHS by SEAI in Phase 2. For example, in order to be eligible for grant assistance in Phase 2, home owners must have occupied their homes prior to June 2008. While this change in eligibility criteria may have impacted upon the take-up of bioenergy technology from its introduction in Phase 2, it does not explain the continued growth in solar tube and flat-plate technologies post the changes to eligibility

criteria. Rather it could be argued that, given installation of bioenergy technology is limited to houses with access and storage facilities, post Phase 1, there was a reduced available market share for this technology.

In reviewing consumer take-up of LCT, the research analysed the utility associated with each technology and identified a number of suitability factors. The suitability of bioenergy technology to mass consumers is questionable: for example, a 3 tonne bulk storage unit is often required to ensure the fuel source remains moisture free and consumers express air quality concerns surround biomass combustion. The maximisation of the value of bioenergy technology deployment is related to proximity to the supply chain of bioenergy pellet and chip providers (within a 100km radius). This may have also reduced the potential market for technology uptake across Phase 2 and 3. A more mature market highlighted the disadvantages of heatpumps as a LCT in its inability to produce the required grade of heat.

As part of its governance function, SEAI, as the managing authority of the GHS, developed an inspection and installer registration regime and this had become more rigorous in Phase 2. SEAI identified gaps in the capacity of installers to install technologies in line with GHS guidelines and established a mandatory training for installers (after Phase 1). Strengthened inspection regimes and associated training initiatives aimed to encourage best practice to installation and remove unscrupulous installers that were identified throughout the early stages of the GHS. In 2006, it was planned that 10% of installations were to be inspected each year. By December 2009, 2,255 inspections had been completed which represents 8.5% of all installations. Inspections found that 1,477 installations or (65% of all work inspected) required a revisit and resolution by the installer (see Table 2.8).

Table 2.8: Inspection and severity levels of issues

	2006	2007	2008	2009	Total to end 2009
Level a	21	81	105	36	243
Level b	124	419	399	292	1234
Level c	31	125	126	131	413
No issues		116	134	115	365

- a potential health and safety risk, required return visit
- b matters that have capacity to impact the system performance, required return visit
- c issues identified to installer, not requiring return visit

The approach taken to inspection was a risk-focused approach. The results of inspections fed into training programmes, continuous development workshops for installers, newsletters for installers identifying common reasons for rework and identifying remedies. Combined with the introduction of mandatory training in 2008, this has led to a reduction in the level of rework following inspections in latter years of the Scheme. It provided confidence to consumers who wished to apply for grant aid and deploy LCT.

2.7.1.3 Phase 3:

Of the systems installed by Phase 3, in 2009, solar technology systems proved the most popular with about three quarters of all homes opting for this technology. If consumers were making decisions based on investment costs alone (excluding performance metrics), solar water panels provide the lowest upfront cost, especially for a residence with high energy consumption and so could be seen as the most attractive technology choice.

Throughout the three phases of the GHS, the average costs of solar significantly reduced from €7,000 to €3,400, thereby stimulating uptake, while, unlike bioenergy, the grant levels available did not significantly reduce. The reducing cost of solar was a worldwide trend as the panels achieve mass deployment [Lawrence Berkeley National Laboratory, 2009]. Furthermore, the installation of the size of solar panels being deployed by consumers had

reduced in size, mirroring the economic downturn in Ireland. This development reflects microeconomic theory where the Homo Economicus seeks to maximize utility within given budget constraints [Claudy and O'Driscoll, 2008].

Solar technology, primarily based on the premise that it does not require fuel to be sourced, is readily accessible and by Phase 3 market confidence in solar as a technology was high, especially when compared to other technologies such as bioenergy and heatpumps. Indeed, from a solar panel perspective, the cost of a fully installed solar energy system did vary. Often the variables include: (a) age of roof which provides an added cost of solar installation (b) depending on the type of solar panel installed, the consumer's per-watt cost will vary. Research conducted by Rezaie [2011] found that, based on a number of case studies that analysed energy options for detached residential buildings, solar thermal options for hot water and space heating were the most cost effective, while ground source heat pumps were attractive in terms of environmental impacts, yet require significant maintenance. Rezaie [2011, pp 60] noted that, for domestic buildings, "a geothermal system is the most reliable energy system, which requires specialized initial installation, but with low maintenance cost".

There are two possible competing reasons that impacted upon solar panel take-up in Phase 3 of the scheme: The price of oil significantly increased from 2009 to 2010 (See Figure 2.4), thereby potentially impacting consumer choice towards deploying solar for security of supply reasons. This fossil price increase, coupled with the ease of solar deployment, may have shifted trends in consumer take-up. Solar technology also had mature supply chain system and its flexibility of deployment (in scale) may also have been a factor. The environmental agenda and associated considerations were heavy on societal consciousness, potentially making the external visibility of solar panels very attractive for consumers. This could be

linked to the consumers’ conditional value and epistemic value of their selected technologies where consumer behavior and LCT choice could be linked to the technology novelty [Lin and Huang, 2012].

Empirical research describes how such “behavioural factors explain a great amount of variation in pro-environmental behavior and provide valuable insights for policy makers and analysts” [Claudy and O’Driscoll, 2008, Stern, 1986, and Bang et al, 2000]. Stieb and Dunkelberg [2012] describe how consumers’ motives and goals concerning low carbon technology adoption include a willingness to contribute to climate protection, to become less dependent on fossil fuels or to support a low-carbon lifestyle. Quigley and Rubinfeld [1989] analysis addresses the effect of changes in energy prices on the consumption of housing, residential energy and other goods.

Figure 2.4: Changing price of oil over GHS phases [United States EIA, 2012]



Uitdenbogerd [2007] describes how the household decision determinants may not focus on whether to adopt a sustainable energy technology, but rather what technology type should be chosen. The decision to opt for solar above both heatpumps and bioenergy as the consumer

choice of technology reflects the case study findings from Rezaie et al [2011] where solar panels were identified as a good choice to heat domestic water due to their ease of installation and low maintenance costs. Indeed, contrary to the findings of Rezaie et al [2011], where reliability and cost effectiveness were strengths of heatpumps, Irish consumers elected more towards solar, potentially based on a shift towards building retrofitting rather than new build development.

Significant consumer confidence issues impacted upon bioenergy as a fuel source in 2008 and 2009. This confidence may have eroded due to the fuel versus food bioenergy debate and debates concerning the security of supply and availability of bioenergy products as an energy resource in Ireland as wood fuel availability decreased in 2008/2009. Indeed, the increasing penetration of technology has caused concerns over the inconsistency of supplies [Uitdenbogerd, 2007]. Confidence levels were further eroded due to a lack of infrastructure [Breen, 2008] and technology support in the market. This aligns with research conducted by Steib and Dunkelberg [2012] where the adoption of low carbon technologies were not solely driven by economic considerations alone, rather personal and contextual socio-cultural factors (including education, income and age) influence consumers decisions.

New build applicants were restricted from applying for financial assistance/ grants across the technologies in Phase 3. Undoubtedly, consumer take-up of both bioenergy and heatpump technologies is more attractive for consumers when entering into a new build of their home rather than retrofitting an existing home. This may also explain the low levels of take-up of both technologies. Indeed, across the three phases, geothermal heatpumps were seen by the market as an expensive (in terms of upfront cost) technology for large extensions and for non occupied homes. This reflects work by Kempton and Montgomery [1982] concerning energy

efficiency technology take-up. They found that consumers apply heuristic approaches to decide on their energy use in which purchase costs are ascribed a higher priority than the common determinants of technology choice, namely operational costs and resulting savings. Indeed, the importance of these common determinants is often not fully comprehended by consumers [Mundaca et al, 2010 and Levine et al, 2007] as non-economic determinants drive consumers' energy-related decisions regarding technology choice. This is especially relevant for energy efficiency technology choice where determinants include improved comfort, noise reduction, functionality, performance, quality, reliability, and design [Mundaca et al, 2010, Levine et al, 2007, Mills and Rosenfeld, 1996 and Lutzenhiser, 1993].

It is plausible to assume that changing market and economic circumstances impacted significantly on the consumer choice of low carbon technology. When the GHS was launched in 2006, Ireland was at the peak of its economic 'boom' and the economic downturn commenced in Phase 3 (2008/2009). Taken on its own merit, reductions in various technology choices could be mirrored with Ireland's economic circumstances and consumer disposable income levels. The changing economic circumstances impacted on householders' perceived personal capabilities and associated financial resources. This is also reflected in research conducted by Stieb and Dunkelberg [2012] who identified how the unwillingness for consumers to go into debt and the lack of available financial resources present serious hindrances to low carbon technology adoption. This is contrary to research that found that technology price are not significant impacts on consumer choice behaviour as consumers are increasingly willing to pay more for green products [Lin and Huang, 2012].

2.8 Market barriers influencing technology uptake

Any analysis of consumer take-up of LCT policies requires a focus on decision frameworks for technological choice and an understanding of market and behavioural failures.

The potential adoption of low carbon technologies is the result of an alliance of economic and non-economic motivations and considerations, including personal factors associated with attitudes and economic, ecological and technical concerns [Stieb and Dunkelberg, 2012]. There are numerous non-economic determinants affecting technology choice, including non energy benefits such as performance, reliability, quality systems and design [Stern, 1986]. Indeed, SEAI had focused attention from 2005-2006 in eroding some of the misperceptions surrounding renewable energy technology and improving consumer confidence. These misperceptions focused on technology cost, reliability and performance, technology maturity, impact on energy demand and availability of raw materials/ fuels within the Irish market. Researchers have determined how different knowledge, environmental feeling and social class are crucial determinants of individual preferences [Roe et al, 2001].

Individual valuation process is often pervaded by uncertainty [Wang, 1997]. While the decision to deploy renewable energy technology, especially linked to the GHS, may be driven by two determinants, investment costs and the savings from reduced energy, the household choice is difficult to anticipate due to several uncertainties. These uncertainties surround expectations of future energy prices, and many households may face information deficits as well as high costs of information acquisition concerning various renewable energy technologies to be deployed in homes. Certainty of product support systems may explain the take-up of solar technologies throughout the life of the GHS, while uncertainty associated with the available of supply may explain why take-up of bioenergy technology diminished.

Consumers' real world decisions deviate from ideals of preference maximisation ('bounded rationality'). Often, throughout their technological choice, consumers fail to consider hidden costs associated with a technology (such as noise and dirt from technology deployment), leading to heterogeneity with respect to the household's net benefits. One of the many assumptions made by the United Kingdom's Department of Energy and Climate Change on their study relating Renewable Heating Incentives [Element, 2011], referred to up-take of renewable technologies being highly dependent on the relative costs of heat generation from a renewable source compared to conventional fossil fuel heating. Within this there are a number of hidden costs (outside of costs associated directly with the technology) specifically relevant to installing a bioenergy chip pellet boiler.

The grant provided to householders under the Greener Homes Scheme was a fixed amount, based upon the particular technology selected, towards the cost of purchase of the chosen system, from the Scheme's registered products list, and subsequent installation, by an installer on the Scheme's registered installer list. As the grant amount reduced the technology installation costs remained the same. In considering the costs associated with the overall technology product, consumers should have considered the technology costs and hidden costs that could include the performance and suitability characteristics, fuel costs, LCT supply chain capacity, the extent and cost of overcoming non-financial barriers.

In defining the costs associated with specific low carbon technologies, this research considered once off costs and ongoing technology management costs. This research categorised such hidden costs, in terms of the domestic sector, as: project identification (e.g. searching for products and identifying problem), research scoping, construction and

installation (e.g. waiting in, clearing space, loss of space taken up with storage tanks, additional unforeseen works), and hassle costs (e.g. fuel deliveries) and ongoing management. In considering such hidden costs this research found that they range from €946 to €4133 and so are much larger than the equivalent costs for solar tubes and panels, ranging from €571 to €1746 (see Table 2.9 and 2.10).¹⁰

Table 2.9: Hidden costs associated with a biomass chip pellet boiler

Hidden Cost	Low	high	units	Calculation	Cost (€/installation)	
					Low	high
Project Identification	0.5	2	Hrs	Hours * time cost	€ 2.87	€ 11.48
Research & Scoping	5	20	Hrs	Hours * time cost	€ 28.70	€ 114.81
Construction and installation	5	15	Hrs	Hours * time cost	€ 28.70	€ 86.11
Additional Engineering	5%	10%	Of capital costs	% * capex * plant size	€ 600.00	€ 1,200.00
Hassle Costs	0%	0%	Of capital costs	% * capex * plant size	€ 0.00	€ 0.00
Production Disruption	0%	0%	Of capital costs	% * capex * plant size	€ 0.00	€ 0.00
Space for fuel tank/water tank	1	1	yes/no	space cost * footprint	€ 285.84	€ 1,084.55
Spare	1	1	yes/no	standard cost	€ 0.00	€ 1,636.23
Garden being dug up?	0	0	yes/no	standard cost	€ 0.00	€ 0.00
Ongoing management	0	0	Hrs/yr	NPV of (hours * time cost * lifetime)	€ 0.00	€ 0.00
biomass boiler					Total included Cost	€ 946.11 € 4,133.17

Table 2.10: Hidden costs associated with installing solar tubes and panels

Hidden Cost	Low	high	units	Calculation	Cost (€/installation)	
					Low	high
Project Identification	0.5	2	Hrs	Hours * time cost	€ 2.87	€ 11.48
Research & Scoping	5	20	Hrs	Hours * time cost	€ 28.70	€ 114.81
Construction and installation	5	15	Hrs	Hours * time cost	€ 28.70	€ 86.11
Additional Engineering	5%	10%	Of capital costs	% * capex * plant size	€ 225.00	€ 450.00
Hassle Costs	0%	0%	Of capital costs	% * capex * plant size	€ 0.00	€ 0.00
Production Disruption	0%	0%	Of capital costs	% * capex * plant size	€ 0.00	€ 0.00
Space for fuel tank/water tank	1	1	yes/no	space cost * footprint	€ 285.84	€ 1,084.55
Spare	0	0	yes/no	standard cost	€ 0.00	€ 0.00
Garden being dug up?	0	0	yes/no	standard cost	€ 0.00	€ 0.00
Ongoing management	0	0	Hrs/yr	NPV of (hours * time cost * lifetime)	€ 0.00	€ 0.00
					Total included Cost	€ 571.11 € 1,746.94

¹⁰ Ecofys (2009) considered £4.88 STG/ per hour as a representative of how consumers in the domestic sector value time. In considering this, a calculation of the hidden costs of installation was made, based on two scenarios. A further background reference have a look at Element Energy's (2008) Report on *The growth potential for microgeneration in England, Wales , and Scotland*, and Section 4 of the Element Energy and NERA Report (2011) *Achieving the deployment of renewable heat*, for the Committee on Climate Change.

Whereas capital and operational costs are certainly relevant, they do represent only a part of the determinants that drive consumers' energy related decisions regarding customer choice [Mundaca et al, 2010]. In considering adoption of LCT, and associated energy improvements in the residential sector, many consumers are not aware of the market barriers associated with take-up. These may include the costs of maintenance, fuel availability, and information asymmetries. The predominant economic approach behind government policies assumes that the abolition of these market barriers will incentivize householders to invest in such technologies [Sorrell et al, 2004]. This implies that the same framed policies have a great understanding of consumer needs and behaviour. Furthermore, uncertainty prevails throughout decision making as "the individual is able to express preferences or evaluation of some good or service in a way that is not mathematically certain" [Bollino, 2009. p85]. Due to prevailing market barriers, consumers may not minimise the costs of obtaining energy services, may be misinformed and may have trouble when making 'correct choices' when given full information.

Changing market and economic circumstances impacted significantly on the consumer choice of LCT. This is what Stern [Stern, 2005] has described as 'contextual factors' and 'personal sphere variables'. It is further explored by Natarajan et al [2011] using Van Raaij and Verhallen's behaviour model [1983], who identified that consumer uptake of a particular technology (here, double glazing) was influenced by three factors: (a) household income, (b) installation by neighbours, and (c) government policy in the form of fiscal incentives stimulate uptake.

2.9 Conclusion

This chapter analysed the implementation of ‘Greener Homes Scheme’ from a policy maker’s perspective, explored how the Scheme was implemented, and drew conclusions and lessons that will inform energy policy in Ireland. It explored the relationship of variables that influence consumer behaviour, choice and technology take-up across the Scheme.

Through an investigation of consumer behaviour within a developed technology market, this chapter interrogated the factors that inform choice and affect the selection of one LCT over another LCT. In establishing the Greener Homes Scheme, targets surrounding state expenditure and associated technology deployment were set. Given the GHS was expanded into an additional two phases, the Government viewed technology deployment and the building of market confidence in renewable energy as key successes resulting from the Scheme. The level of success of the GHS was not benchmarked with similar international schemes, yet it could present some perspective to policy makers that may be planning the development of similar renewable heating programmes in other jurisdictions. In exploring the relationship of these variables, the chapter provides some insight into the representation of end user preferences and their subsequent investment decisions and technological choice.

Undoubtedly, there is a level of uncertainty in representing the attitudes and decision making processes of Irish consumers. It has not been possible to gather Irish-specific empirical data (using surveys) to validate the assumptions within this chapter. Further work in this area is recommended so as to provide additional confidence to this analysis. While this exploratory analysis assessed the relationships and dependencies that may influence LCT decision making, it also provides a rich collection of data that can inform a quantitative analysis in Chapter 3.

Chapter 3

Analysis and prediction of consumer choice of LCT by using neural networks

Chapter 3 expands the contribution from Chapter 2 by modelling decision frameworks and determinants that influence low carbon technological choice. The objective is to provide a LCT model that can be replicated across technology programmes that service consumers.

The key objective of this chapter is to analyse and predict the factors that influence consumers' decision-making regarding their choice of low carbon (renewable energy heating) technologies, by using developed neural networks models. It proposes an approach for analysing and predicting customers' choice of LCT. This approach serves as a framework for enhanced understanding of the various factors that influence consumer selection of one low carbon technology over another. Several neural network models are developed in this chapter to classify LCT. This modelling-based contribution can be used to inform LCT policy development within different jurisdictions. It analyses a number of case studies of domestic dwelling heating in Ireland. It utilises the data set of 31,560 technology choices that formed the exploratory analysis within Chapter 2.

This chapter considers the relationship between input data, including the investment phase, grant amount, date received, property age and total installation cost, and how they correspond to each consumer. The target data, encompassing solar, bioenergy and heatpump technologies, is explored. Technology choice is estimated collectively for all phases and individually for each phase by using several developed neural network models. This chapter

learns from these past applications and presents neural networks as an appropriate approach to analysing and predicting customers' choice of low carbon technologies.

3.1 Introduction

Quantitative analysis provides an ability to both understand and accurately predict a consumer's decision. This information can enable companies to more effectively target consumers by directing technology product and services offerings to meet their anticipated choices. Such analysis involves responding to problems associated with pattern recognition. Artificial neural networks are very good at pattern recognition problems [Bishop, 1996]. An artificial neural network (ANN) with enough computational units (called neurons) can classify any data with arbitrary accuracy. They are particularly well suited for complex decision boundary problems over many variables. Neural network models are deployed across a range of disciplines to enable an understanding of consumer choice; within business administration for forecasting tax revenues, in financial services for predicting earnings, and in marketing for predicting responses, targeting customers and segmenting markets.

The research expands the exploratory approach outlined in Chapter 2 [Kennedy and Basu, 2013] by modelling the take-up of geothermal heatpumps, solar and bioenergy technologies in the domestic sector in Ireland. The chapter proposes a procedure to analyse customers' choice of renewable energy heating technologies using artificial neural networks. The chapter analyses a number of case studies of domestic dwelling heating in Ireland, utilising the data set of 31,560 technology choices that formed the exploratory analysis within Chapter 2. It delivers a generic 5 neuron, 3 layer model that can make accurate predictions, based on certain social conditions, on the choice of certain low carbon technologies.

Through the proposed model and associated case studies, the following is achieved:

- A validation of the Irish Government implemented Greener Homes Scheme (GHS) and customer-supported policies.
- A forecasting of consumers' technology choice of future low carbon technology schemes, based on data being made available relating to grant, time, property characteristics, expected installation and policy.
- A facilitation of the transfer and deployment of low carbon technologies to developing and emerging economies.

3.2 Methodological review and approach

The complexity of understanding consumer decision-making is often based on a lack of the information that determines an individual's choice. Researchers often approach this problem by observing the consumer's characteristics and choice, and using the findings to estimate the relationship between them. This chapter's methodological approach focuses on determining and recognising patterns in consumer choice of LCT. A number of inputs were determined from the exploratory analysis conducted in Chapter 2. These inputs are associated with different LCT and include (a) Greener Home Scheme phase (b) grant amount paid to consumers (c) date received (d) LCT installation cost, etc.

The research proposes and adopts a neural network methodology. There are a number of alternative approaches for pattern recognition such as template matching, syntactic or structural matching, and neural networks [Basu *et al.*, 2010]. Template matching is a traditional generic approach to pattern recognition, often used to determine the similarity between two entities of the same type. It is computationally demanding and its rigid template has a number of disadvantages, for instance, it would fail if the patterns are distorted,

viewpoints change, or large intra-class variations among the patterns. Syntactic approach adopts a hierarchical perspective where a pattern is viewed as being composed of simple sub-patterns which are themselves built from yet simpler sub-patterns. That approach may yield a combinatorial explosion of possibilities to be investigated, demanding large training sets and very large computational efforts [Jain *et al.*, 1999, p6]. The key contribution of neural networks in terms of patterns recognition is that they employ basis which are adapted to the data, leading to efficient techniques for multi-dimensional problems.

Predictions of consumer choice were traditionally conducted using conventional econometric models and, more recently, artificial neural networks (ANN) have become popular [Ripley, 1994]. ANN models have been widely applied to the predictive analysis of consumer behavioural patterns and to model the consumer decision-making process. It is a suitable technique for both pattern-recognition processes [Setyawati, Sahirman, & Creese, 2002] and for prediction and classification areas [Warner & Misra, 1996]. This ANN model is an “adaptive learning-from-data property” and so is a powerful model for pattern recognition and pattern classification [Hu *et al*, 2008]. Artificial neural networks are generally applied to recognition problems and generalisation problems, including classification and prediction [Gan *et al*, 2005]. Such networks are inspired by the neural architecture of the brain, based on its strengths in predicting consumer choice. The main strength of the ANN approach is its potential to deliver more accurate prediction results in comparison to other quantitative models. However, ANN does lack a theoretical background concerning the explanatory capabilities¹¹ and the extraction of learning processes can be time consuming to model.

¹¹The connection weights in the ANN networks cannot be interpreted or used to identify the relationships between dependent and independent variables and there are no formal techniques for non-linear methods to test the relative relevance of the independent variables and to carry out the variable selection process [Gan *et al*, 2005].

The processors in the neural network are extremely interconnected and allow for an adjustment of interconnection parameters. This ANN approach does not require the restrictive assumptions about the relationship between the dependent and independent variables, as it delivers superior predictions regarding consumer decision processes. The ultimate goal involves building a model with the fewest number of independent variables while producing equal or comparable predictive power as larger models [Hu et al, 2008]. In the context of modelling consumer judgment and decision making, West et al [1997] described the superiority of neural network modelling techniques over alternative approaches, as they capture nonlinear relationships associated with the use of non-compensatory decision rules.

Neural networks are very good at pattern recognition problems [Lippmann, 1987, Bishop, 1996] and as a modelling method they handle nonlinearity associated with the data [Razi et al, 2005]. A neural network with enough computational units, or processing elements, consists of a set of input connections that receive signals and can classify data with arbitrary accuracy. Each unit or neuron receives one or more inputs, processes them and generates a single output. This layered computing system of interconnected nodes performs a linking or mapping of functions from input layer to output layer. ANN configurations are particularly well suited to complex decision boundary problems over many variables, thereby making such networks an appropriate option for solving classification problems associated with low carbon technology.

Several neural network models are developed in this chapter to classify LCT. The methodology proposed in this chapter builds up on the ANN modelling work [Bishop, 1996, Matlab 2011], explores its application in pattern recognition [Bishop, 1996, Matlab, 2011,

AL-Allaf et al, 2012] and interprets the influence of ANN in predicting customer behaviour [Briesch and Rajagopal, 2010].

3.3 Proposed procedure using Artificial Neural Network

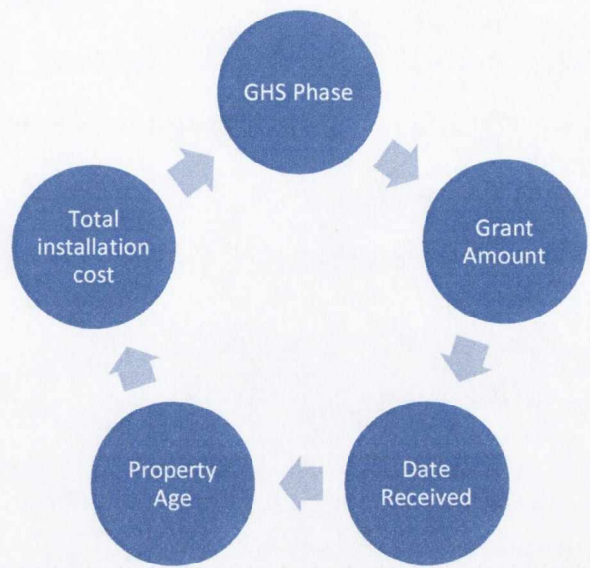
The following section outlines the proposed procedure using artificial neural networks.

3.3.1 Organisation of data

ANNs are data dependent, enabling their performance to improve with sample size [Razi et al., 2005]. The dataset explored is 31,560 and is based on technology take-up of consumers under the Irish Government's Greener Homes Scheme from 2006-2010. All consumer dwellings underwent LCT improvements, such as biomass boiler, solar panel and heatpump installations. The GHS data is grouped into three phases to predict the choice of consumers across these three LCT types.

In overcoming the challenge of data classification, an artificial neural network is established by organizing the data into two matrices, the input matrix and the target matrix. This input matrix involves the identification of 5 input parameters or rows and the assignment of a numeric value to each variable. These 5 input parameters are presented in Figure 3.1. The main dataset reflects 31,560 data lines (consumers) within the Irish Government's Greener Homes Scheme (GHS). The number of columns N refers to the number of data lines, number of customers under the GHS.

Figure 3.1: Input Schematic



3.3.2 Data Preparation

The proposed procedure involved preparing the data into two matrices, the input matrix [P] and the target matrix [T]. The input matrix [P] consists of five rows and N columns where the first, second, third, fourth and fifth rows represent the input data in ‘phase’, ‘grant amount’, ‘date received’, ‘property age’, and ‘total installation cost’, respectively. N is number of data lines i.e. the number of dwellings.

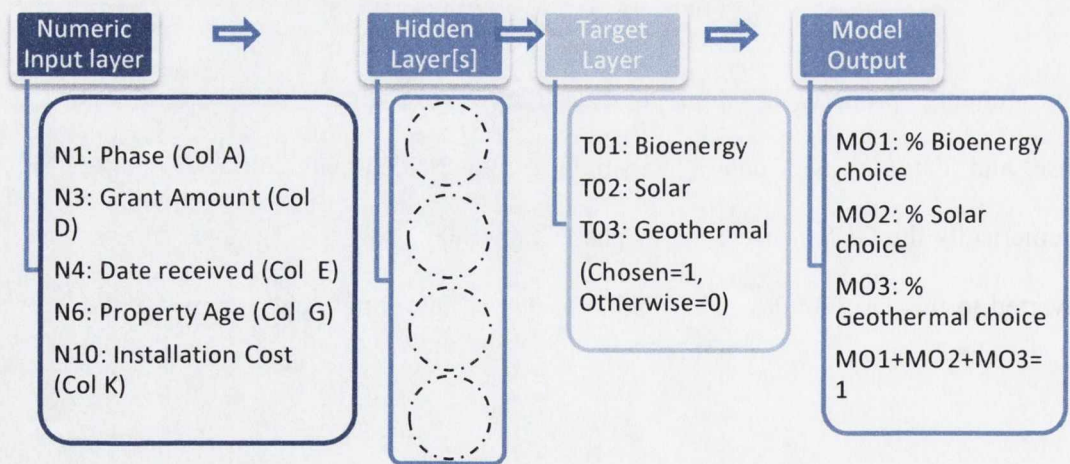
The ‘grant amount’, ‘property age’ and ‘total installation’ are already in numerical values. The ‘phase’ and ‘date received’ data is converted to numerical forms. Values of 1, 2 and 3 denote numerically the GHS phase 1, GHS phase 2 and GHS phase 3. The date received is first converted to the absolute day. The minimum day is then found and assumed to be the first day.

The target matrix [T] consists of three rows and N columns where each row represents one of the technology types: bioenergy, solar, or heatpumps. If the technology type is chosen, it's value is 1, otherwise it is 0, so each row of the target matrix should contain two 0 and one 1. The outputs of the procedure are the estimated percentage of choices of the three LCT. An overall estimation of errors can also be calculated.

3.3.3. Data Division and Artificial Neural Networks

In order to train data and to validate the data (prove they found coefficients accurate enough) within the model, the input data and the target data are divided into three groups: training, validating and testing. As the data was collected at various time periods and locations, it cannot be divided into three sub-blocks for training, validating and testing as the implications of data in each sub-block may significantly differ from that of the full dataset. This fact is further proven in the case studies of each phase presented in Section 3.4. A continuous division of data is applied.

Figure 3.2: ANN model for customer choice of technology



The ANN schematic is reflected in Figure 3.2 where the information flows in the direction from the origin. The computational units are grouped into three main layers: the first layer is the input layer, hidden layer(s) in the middle and the output layer being the last layer [Hu et al., 1999]. Determining the optimal internal error within the model (the appropriate number of hidden nodes and layers) is challenging as action should not hinder the network's learning or its efficiency. This approach therefore involves significant trial and error.

The model development involved three stages, (1) training (2) validating and (3) testing. Errors were averaged across the three technologies and the model was tested with an independent set of data. The training phase involved:

- (a) calculating the neural network weights (by randomly initializing connection weights),
- (b) introducing a set of data inputs and actual outputs to the network,
- (c) calculating the network output, and
- (d) comparing the network output to the actual output and calculated error.

The fastest training function in MATLAB is generally the 'trainlm' function representing Levenberg-Marquardt algorithm. This is the default training function for feed-forward neural networks. However, that method tends to be less efficient for large networks (with thousands of weights), since it requires more memory and more computation time for these cases. Also, 'trainlm' performs better on function fitting (nonlinear regression) problems than on pattern recognition problems.

When training pattern recognition networks, the 'trainrp' function (representing resilient back-propagation algorithm) is used. In defining the learning algorithm, attempting to seek

predictive accuracy and minimising the network total mean squared error, the ANN adjusts the connection weights by propagating the error backward to determine how to best update the interconnection weights between individual neurons [Gan et al, 2005 and Rao and Ali, 2002]. Several neural network models are developed in this chapter to properly classify each technology. The 'trainlm' function is used for training these models.

3.4. Case Studies: [A and B]

The case studies involved dividing 31,560 rows of data by three sets for the purposes of (a) training, (b) validating and (c) testing. We applied a clear division of data (data index) across the three sets, attempted to capture the trend of the dataset, and compared results within a confusion matrix (Figure 3.5 and 3.6). Given the large size of the dataset, it provided ample training and test data was available, making ANN methods particularly valuable.

- For training, 50% of the available dataset was used (data ratio, 50/100). The data index applied was [1, 2, 5, 6,...]. This involved data formulation but did not find the coefficient.
- For validating, 25% of the available dataset was used, (data ratio, 25/100). The data index applied was [3, 7,...]. This validation was aimed at testing if the coefficient is correct and accurate.
- For testing, 25% of the available dataset was used, (data ratio, 25/100). The data index applied was [4, 8,...]. This testing was based on an independent set of data.

3.4.1 Case Study [A]

Several ANN models were developed in Case Study [A] across all 31,560 data lines and across all Phases of the GHS. The output results of technology choice percentage based on

the model, overall error and numbers of iterations are presented in Table 3.1 and Table 3.2. Table 3.1 presents ANN models of one hidden layer with various (numbers of) neurons and Table 3.2 presents ANN models of multiple hidden layers.

Table 3.1 Technology choice by one hidden layer, various neurons, 31,560 dataset

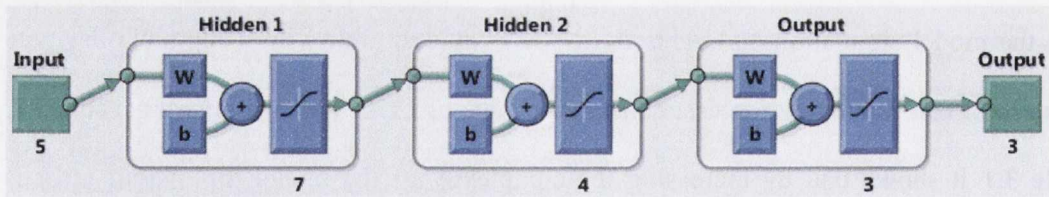
ANN Model	Bioenergy choice (%)	Solar choice (%)	Heatpump choice (%)	Overall error (%)	No. of iterations
4 neurons, initial reset	12.8	61.9	13.3	12.0	917
5 neurons, initial reset	13.0	61.3	17.8	7.9	1685
6 neurons, initial reset	11.5	61.9	16.7	10.0	528
7 neurons, initial reset	12.7	61.9	19.0	6.4	1909
8 neurons, initial reset	12.6	62.4	16.6	8.4	1806

As Table 3.1 shows, the ANN simulation by one hidden layer with various neurons identifies the ‘7 neurons’ simulation as the best case. It presents an empirical relationship between the numeric input layer percentages and the number of neurons. The best case delivers an overall error of 6.4% and limits variation across technology choice. There are two interesting findings: (i) consumer choice of LCT reflects the data for solar (62%) and heatpumps (19%) and (ii) the model simulation highlights the ANN’s forecast ability; in using a similar type input matrix it can accurately forecast consumer choice of LCT. When comparing Table 3.2, to Table 3.1 it shows that by increasing the complexity of the model the overall error is generally reduced. The application of such hidden layers implicitly improves the accuracy of the model. The number of neurons in the final hidden layer should be larger than, or equal to, that of the target layer. A two hidden layer (7 and 4 neurons) network model (as depicted in Figure 3.3) provides an improved overall error percentage (7%). The three hidden layer (7, 6 and 4 neurons) model provides the best accuracy with an overall error range of 5.0%.

Table 3.2 Technology choice by multiple hidden layers, initial reset, 31,560 dataset

ANN Model	Bioenergy choice (%)	Solar choice (%)	Heatpump choice (%)	Overall error (%)	No. of iterations
2 hidden layers (4 + 3 neurons)	13.0	61.9	14.4	10.6	650
2 hidden layers (4 + 4 neurons)	12.7	61.7	16.8	8.8	1652
2 hidden layers (5 + 3 neurons)	13.2	62.0	17.5	7.3	1281
2 hidden layers (7 + 4 neurons)	13.0	62.1	18.5	6.5	741
2 hidden layers (10 + 5 neurons)	10.8	62.1	18.7	8.5	607
3 hidden layers (7 + 6 + 4 neurons)	14.9	61.4	18.7	5.0	276
3 hidden layers (10 + 7 + 5 neurons)	10.7	62.2	18.7	8.4	171
3 hidden layers (9 + 6 + 4 neurons)	14.5	62.3	18.8	6.5	643

Figure 3.3: Two hidden layer (7 & 4 neuron) network



3.4.1.1 Empirical ‘Predictive accuracy’ Results: Case Study [A]

Table 3.3 presents the best cases from the simulations across Table 3.1 and Table 3.2. There is a very minor differentiation across technology choice percentages for both solar and heatpumps across the 3 simulations. The differential is 0.5% for solar and 0.3% for heatpumps. In determining the most suitable configuration of the ANN model, the three

hidden layer (7, 6 and 4 neurons) network, presented in Figure 3.4, displays the least number of iterations (276). This makes it the most suitable model configuration to employ to successfully forecast consumer technology choice.

Table 3.3 Most suitable ANN simulations (initial reset, 31,560 dataset)

ANN Model	Bioenergy choice (%)	Solar choice (%)	Heatpump choice (%)	Overall error (%)	No. of iterations
7 neurons, initial reset	12.7	61.9	19.0	6.4	1909
2 hidden layers (7 + 4 neurons)	13.0	62.1	18.5	6.5	741
3 hidden layers (7 + 6 + 4 neurons)	14.9	61.4	18.7	5.0	276

Figure 3.4: Three hidden layer (7, 6 and 4 neurons) network

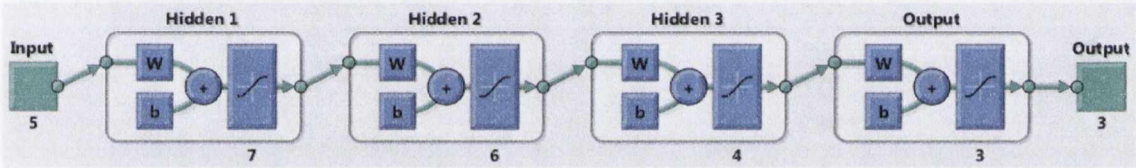
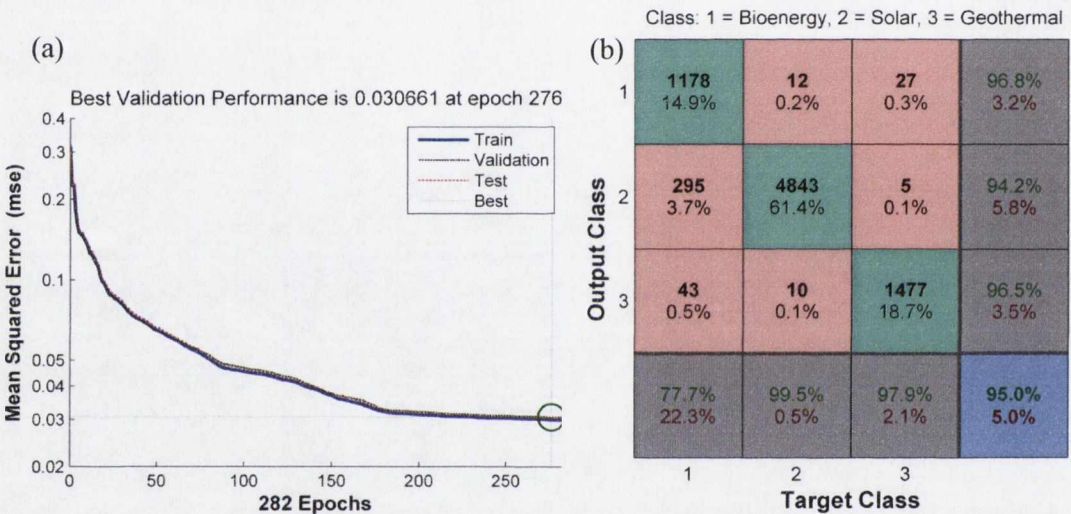


Figure 3.4 graphs the results of the ANN model using three hidden layers (7, 6 and 4 neurons). The results are configured in an analysis performance and confusion matrix in Figure 3.5 (1 = Bioenergy, 2 = Solar, 3 = Heatpump). The analysis performance validates the results of the three hidden layer network, by data index and across the three sets (training, validation and testing). It maps how the overall error percentage decreases with iterations, finally decreasing with 500+ iterations.

The confusion matrix in Figure 3.5 presents the three hidden layer (7, 6 and 4 neurons) network model. The diagonal cells display the number of cases that were correctly classified

and the off-diagonal cells present the misclassified cases. The blue cell in the bottom right displays the total percent of correctly classified cases (95%) and the total percent of misclassified cases or total errors (5.0%). The overall percentage correct (95%) reflects the accuracy of the model in predicting consumer choice. The best network for the ANN in this case study is the three hidden layer (7, 6 and 4 neurons) model as it can make predictions with 95% accuracy on the choice of certain LCT over other alternatives (based on certain social conditions).

Figure 3.5: Results of the ANN model using three hidden layers (7, 6 and 4 neurons) model, (a) Performance curves (b) Confusion matrix.



In validating the results in Figure 3.5, with explanations based upon the physical results, a broader variety of determinants needs consideration when analysing consumer choice of technology. Taken as a full dataset (31,560), the ANN model still reflects the dominant choice of solar technology. Determinants of choice include financial (grant) attractiveness, security of supply considerations, building regulation alterations, reducing installation/ maintenance costs, mature support systems, and product confidence. Section 3.5 of this

chapter provides some explanations, by phase, that validate the proposed procedure outlined, while also providing insights into the estimated values and the choice trends.

3.4.2 Case Study [B]

The data analysis in Case Study [A] displayed a large data differential and variation across the Greener Homes Scheme three phases. As the data variation in each phase is expected to be less than that in the all-phases case, the focus on Case Study B is to train, validate and test the ANN model for each phase (Cases B1, B2, B3). The data in each phase amounts to the first 14,192 data lines for Phase 1 (B1), next 7,239 data lines for Phase 2 (B2) and the last 10,129 data lines for Phase 3 (B3)..

3.4.2.1 Empirical ‘Predictive accuracy’ Results: Case Study [B]

Table 3.4 presents the simulation findings from the ANN model with multiple hidden layers using data from Phase 1 of the GHS. The findings represent a higher percentage of overall error (ranging from 7.0% -11.7%) than the two hidden layer (7 and 4 neurons) model and the three hidden layer (7, 6 and 4 neurons) model. The most suitable configuration and network for the ANN in this case study (B1) is the three hidden layer (7, 6 and 4 neurons) model.

Table 3.4: Technology choice with multiple layers for Phase 1 (B1 with 14,192 data lines)

Phase & ANN Model	Bioenergy choice (%)	Solar choice (%)	Heatpump choice (%)	Overall error (%)	No. of iterations
1 hidden layer (7 neurons)	23.8	39.9	24.4	11.7	955
2 hidden layers (5 + 3 neurons)	24.4	38.9	29.2	7.5	273
2 hidden layers (7 + 4 neurons)	25.9	37.8	29.0	7.3	255
3 hidden layers (7 + 6 + 4 neurons)	25.6	37.8	29.6	7.0	220

The confusion matrix in Figure 3.6 confirms the accuracy/error findings and presents the two three hidden layer (7, 6 and 4 neurons) model. Again the results are configured (1 = Bioenergy, 2 = Solar, 3 = Heatpump).

Figure 3.6: Results of the ANN model using three hidden layers (7, 6 and 4 neurons) network model for Phase 1 (B1, 14,192 data lines), (a) Performance curves, (b) Confusion matrix.

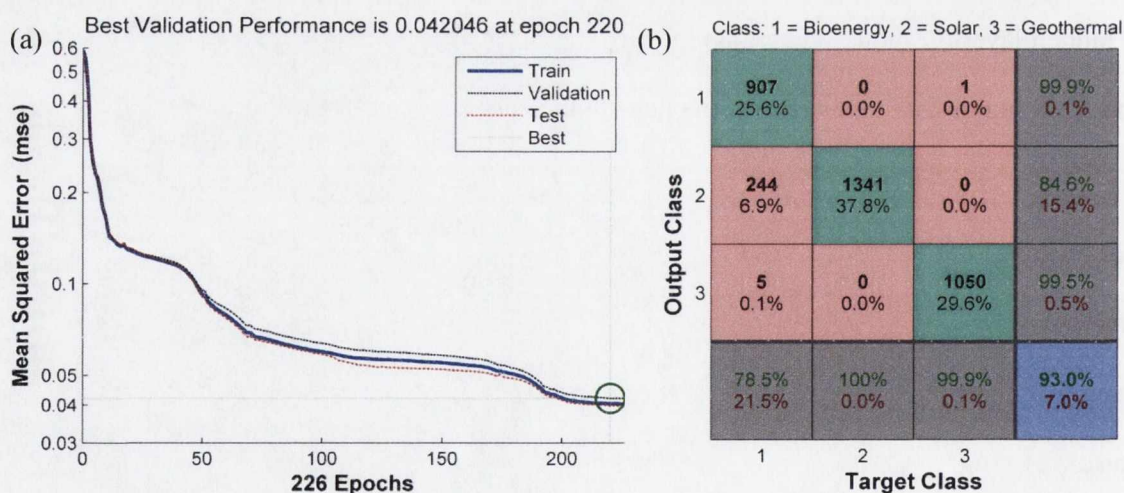


Table 3.5 presents the simulation findings from the ANN models with multiple hidden layers using data from Phase 2 of the Greener Homes Scheme. The Phase 2 results highlight a smaller percentage of overall error than the results presented in Table 3.4 (Phase 1). The percentages of technology choice (solar and bioenergy) reflect the real data analysed in Chapter 2. The main reasons for data error include the size of data set (when compared to Phase 1) and the data range is more uniform than in Phase 1.

The most suitable configuration and best network for the ANN in this case study (B2) is the three hidden layer (7, 6 and 4 neurons) model. As presented in Table 3.5, it displays the least number of iterations (132).

Table 3.5: Technology choice with multiple layers for Phase 2 (B2 with 7,239 data lines)

Phase & ANN Model	Bioenergy choice (%)	Solar choice (%)	Heatpump choice (%)	Overall error (%)	No. of iterations
1 hidden layer (7 neurons)	7.4	70.1	18.4	4.1	204
2 hidden layers (5 + 3 neurons)	7.5	67.7	19.9	4.9	329
2 hidden layers (7 + 4 neurons)	7.0	69.3	19.7	4.0	221
3 hidden layers (7 + 6 + 4 neurons)	8.1	68.8	19.2	3.9	132

The low percentage of error (3.9%) is in the two hidden layer (7 and 4 neurons) model (see Figure 3.7). However, the positive combination of low error and limited iterations makes the three hidden layer model the most suitable model configuration to use to successfully forecast consumer technology choice.

Figure 3.7: Results of the ANN model using three hidden layers (7, 6 and 4 neurons) network model for Phase 2 (B2 with 7,239 data lines), (a) Performance curves (b) Confusion matrix.

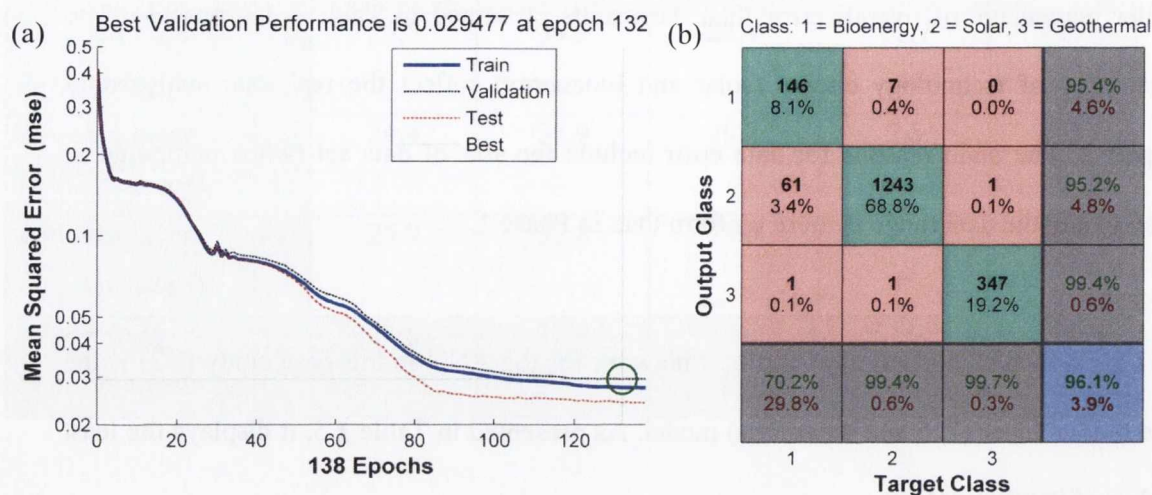
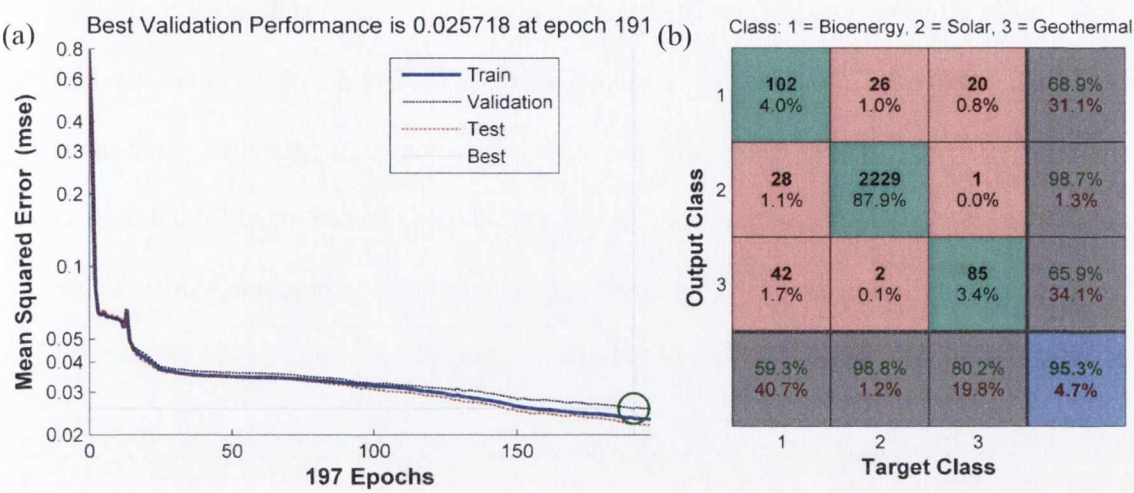


Table 3.6 models the consumer technology choice for Phase 3. Within this one hidden layer model, the accuracy is lower than previously (Table 3.5) and the percentage choice of bioenergy technology is implausible (0%). The best selected configuration model is a three hidden layer (7, 6 and 4 neurons) model and, when compared to actual data, predicts consumer choice of solar technology at 88%.

Table 3.6 Technology choice with multiple layers for Phase 3 (B3 with 10,129 data lines)

Phase & ANN Model	Bioenergy choice (%)	Solar choice (%)	Heatpump choice (%)	Overall error (%)	No. of iterations
1 hidden layer (7 neurons)	0.0	88.2	3.7	8.1	115
2 hidden layers (5 + 3 neurons)	1.2	89.2	2.3	7.3	123
2 hidden layers (7 + 4 neurons)	1.3	88.8	3.0	7.0	163
3 hidden layers (7 + 6 + 4 neurons)	4.0	87.9	3.4	4.7	197

Figure 3.8: Results of the ANN model using three hidden layers (7, 6 and 4 neurons) network model for Phase 3 (B3, 10, 129 data lines), (a) Performance curves, (b) Confusion matrix.



3.5 Validation

This section aims to provide explanations that validate the proposed procedure outlined in this chapter, while also providing more insights of the estimated values and the choice trends. Indeed, there are a number of implications for the estimated choices of low carbon technologies across each phase. The aspects that influence consumers’ decision making regarding the choice of low carbon technology relate to the decision frameworks for technological choice, market failures, and the role of non-economic determinants.

Bioenergy technologies were introduced into the Irish market at a large scale in Phase 1 of the GHS. The suite of technologies were strengthened by media campaigns that championed the availability of woodchip and wood pellet supplies, strengthened industrial supply chain for bioenergy technologies, and overshadowed support for solar thermal technology. By Phase 3 of the GHS, bioenergy grant supports had been significantly reduced and the hidden

costs associated with boiler maintenance were deterring consumer choice. Non-financial determinants had impacted consumer choice. Amended GHS conditions had excluded new build developments, thereby significantly impacting upon bioenergy installations. From the commencement of Phase 2, security of supply concerns surrounding fuel availability had eroded confidence in bioenergy technology and poor infrastructure supports impacted upon take-up. Furthermore, negative media reports eroded confidence. These ranged from concerns about material (combustion), air quality, moisture content, durability, product calorific value and the 'food versus fuel' debate.

Phase 2 introduced a competing technology to bioenergy, namely solar. Solar (tubes and panels) commenced with strong grant support and was deemed a passive technology by reputation (no supply issues) with accompanying low maintenance and reducing installation costs. Unlike bioenergy, rigorous product support schemes and mature supply chains were in place from the outset. The Irish market had also experienced a shift away from new build and toward the retrofitting market. The exclusion of new build from grant applicability further consolidated solar technology as the optimum choice. By Phase 3, the Irish Government had amended its building regulations to make renewable technologies compulsory in new build. This change, coupled with the global cost reduction in solar, highlighted its attractiveness. The economic downturn suited solar technology above competing technologies as consumers had the option to reduce solar panel installation size while maintaining technology uptake percentages. The impact of the green agenda stimulated consumers' environmental consciousness and the external visibility of solar technology met consumers' requirements. Finally, throughout the 3 phases of the GHS, heatpump technologies were deemed to require high maintenance in comparison to alternatives, expensive in terms upfront costs, and had the inability to produce the required grade of heat.

It would have been very useful if the ANN model was carried out throughout the life of the Greener Homes Scheme in that it would have

- (a) Provided recommendations/solutions to re-allocation of grant fund to each technology type. For example, if the model was run after Phase 1, the fund amount and number of granted consumers would have been allocated more to the solar energy technology.
- (b) Provided recommendations /solutions to adjust the duration of the following phase.
- (c) Estimated the demand and behaviour of customers to the GHS in later phases.

3.6 Conclusion

Neural networks for pattern recognition and classification have significantly advanced throughout the past decade. While being more computationally intensive than classical models (such logistic regression), they are very useful when accompanied by a rich dataset and can aid theory development. In terms of prediction accuracy, the results presented in this chapter indicated that an artificial neural network (ANN) model can be successfully implemented to predict consumers' choices of low carbon technology due to its high accuracy rate.

Chapter 3 interrogated a number of case studies [A and B], modelling technology choice with multiple layers across the full dataset (31,560 data lines) and by Phase (14,192 data lines for Phase 1 {B1}, 7,239 data lines for Phase 2 {B2} and 10,129 data lines for Phase 3 {B3}). Based upon the ANN study, Table 3.7 presents the most suitable results from the numerous cases (A, B1, B2, and B3) and concludes that the most suitable network for the ANN is the three hidden layer (7, 6 and 4 neurons) model. Indeed, Case B2 makes predictions on the choice of certain LCT with 96.1% accuracy and with very little iteration (132).

The usefulness of the results of the ANN modelling are that it enabled a prediction of (a) the impact of low carbon heat policies to induce technological policy development within different jurisdictions, (b) the factors that influence consumers' decision-making regarding their choice of low carbon technologies. Finally, they provided a means to frame and evaluate energy policy in similar socio-economic situations. The procedure serves as a framework for better understanding the various factors that influence consumer selection of one low carbon technology over another. It serves as a modelling-based contribution that can be used to inform low carbon technology policy development within different jurisdictions.

Table 3.7: Most suitable ANN model

Phase & ANN Model	Bioenergy choice (%)	Solar choice (%)	Heatpump choice (%)	Overall error (%)	No. of iterations
Case Study {A} 3 hidden layers (7 + 6 + 4 neurons)	14.9	61.4	18.7	5.0	276
3 hidden layers {B1} (7 + 6 + 4 neurons)	25.6	37.8	29.6	7.0	220
Case Study {B2} 3 hidden layers (7 + 6 + 4 neurons)	8.1	68.8	19.2	3.9	132
3 hidden layers {B3} (7 + 6 + 4 neurons)	4.0	87.9	3.4	4.7	197

Chapter 4

Exploratory analysis of the impact of LCT projects in emerging economies

The findings relating to LCT take-up within Chapters 2 and 3 are translated and transferred to a developing country context in this chapter. Through a case study investigation, it presents and assesses a number of clean energy technology interventions within developing and emerging economies. A suite of project impacts are assessed, highlighting the significant challenges that LCT projects are encountering. It analyses the market imperfections and barriers that hinder the impact of five clean energy projects and considers the realms of regulatory, financial, institutional and information frameworks that prevent the accelerated development of markets for low carbon technologies.

Chapter 4 critically reviews and explores the impact of a number of project interventions within developing and emerging economies that are advancing low carbon technologies. It is in response to the challenge of better understanding the broader effect of imperfections and barriers that may alter the acceleration of such technologies. In analysing the impact of a number of projects, it highlights the challenges that projects are encountering and attempts to provide some valuable guidance for policy makers.

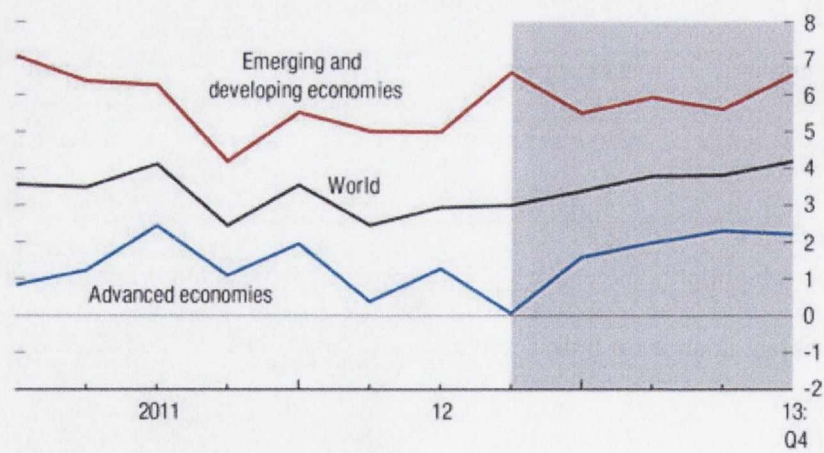
4.1 Introduction

Governments face global environmental and security challenges as they strive to reduce fossil dependence and achieve affordable energy to meet their economic aspirations. Global

warming, carbon emission penalties and finite fossil fuel reserves have all contributed to a surge in low carbon technology deployment, pointing the way towards surmounting these challenges and achieving a more sustainable future. Moves toward climate stabilisation are enhanced through the deployment, diffusion and transfer of LCT aimed at reducing CO₂ emissions. Low carbon technologies, including both renewable energy and energy efficiency, could play a central role in meeting climate objectives by exploiting sources of energy and allowing cheaper, cleaner and more efficient methods of converting energy into desired end use services.

With the IEA and OECD estimating that CO₂ emissions will double over the next four decades, an accelerated investment in LCT deployment and technology transfer must happen now. Developing countries and emerging economies are already experiencing faster rates of growth in economic activity, industrial production, and urbanisation (See Figure 4.1).

Figure 4.1: Global GDP Growth (% , by quarter, annualised) [IMF, 2013]



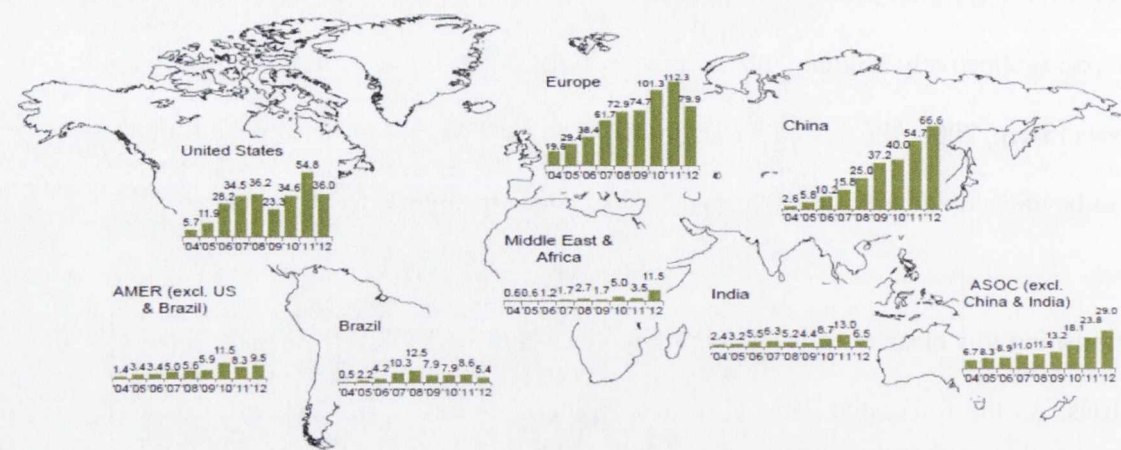
Historically, the majority of technology transfer know-how and experience occurred between developed countries rather than to developing countries: between 1985 and 2004, 80% of the

transfer of new mitigation technologies occurred between developed countries, while the remaining 20% was transferred between China, Korea and Taiwan [Hascic, 2009]. In the past decade, LCT have attained significant patent investment in countries within the E.U., U.S. and Japan (collectively holding 80% of patents [OECD, 2008], and in emerging economies. Analysts [Stern, 2006, IPCC, 2007, McKinsey 2008 and IEA, 2011] have called for a suite of LCT to be utilised, identifying the key technologies and their scale for deployment.

The transition to a clean energy economy requires a shift in the development trajectory of all countries. As the forecasted demand in developing countries is anticipated to increase, the smaller size and level of development of many of the energy systems and infrastructures may serve as an opportunity. As emerging economies become significant energy users, focus could shift to the deployment of LCT and the transfer of advanced technologies that meet their longer term needs.

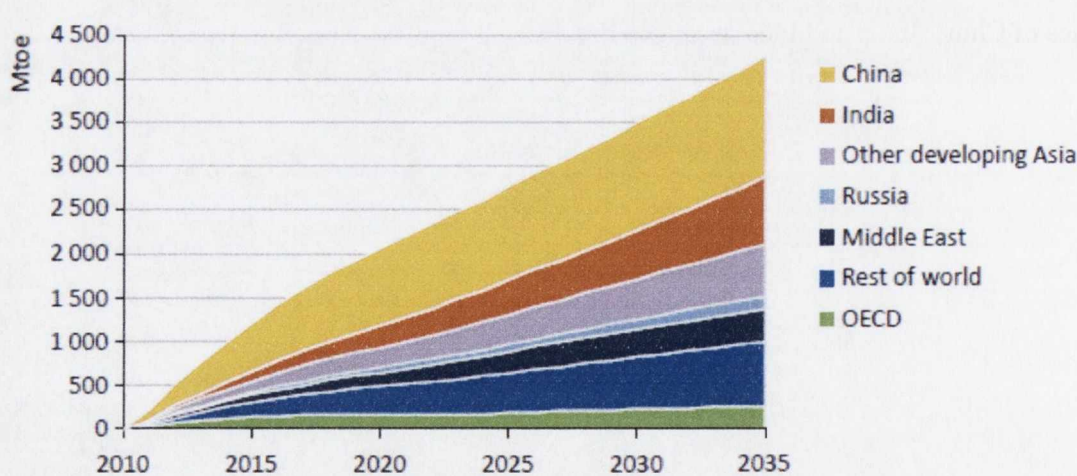
Many countries, especially in Sub-Saharan Africa, are rich in energy resources but the deployment of new clean energy technologies have been eclipsed by the emerging Asian economies of China, India and Indonesia (see Figure 4.2).

Figure 4.2: Global new investment in renewable energy by region 2004-2012 (\$B) [UNEP, BNEF, 2013]



The increase in primary energy demand (Figure 4.3) and associated emissions is projected to occur mostly in the developing world. As countries consider following a sustainable energy pathway, they encounter barriers that may hinder technology deployment.

Figure 4.3: Incremental Primary Energy Demand in new policies scenario 2010-2035 [IEA, 2011]

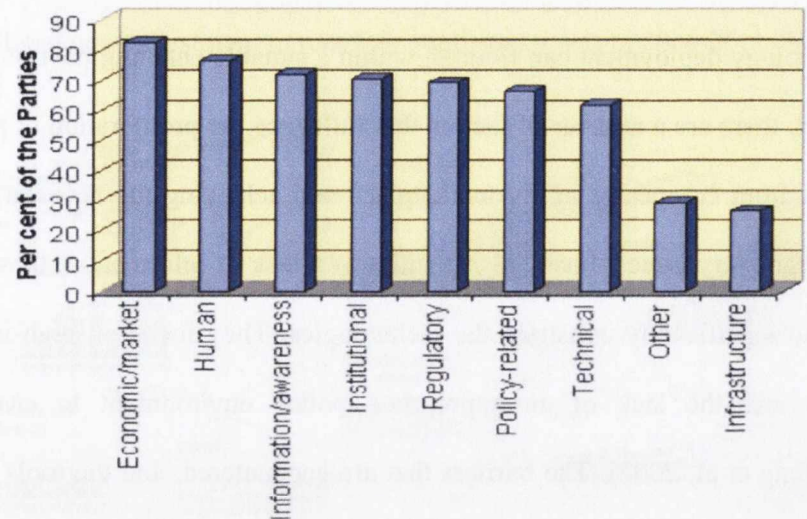


4.2 The role of barriers and imperfections

Low carbon technology deployment can flourish within a suitable enabling environment at a national level. Yet, there are a number of factors that influence the proliferation of such LCT and prevent them from competing in the marketplace and achieving the necessary impact. Whether due to regulatory issues, financial capacities or a lack of information, these barriers have the ability to significantly constrain the technologies. They focus on high initial and transaction costs and the lack of an appropriate policy environment to enable such deployment [Junfeng et al, 2002]. The barriers that are encountered, and the tools to enable full technology transfer, differ significantly across countries and often include regulatory barriers, a lack of information and policy uncertainty. Deficiencies remain in our understanding of economic and institutional frameworks, identifying and addressing barriers, and elaborating measures to overcome these barriers [Boldt et al., 2012].

The UNFCCC Second Synthesis Report [2013] involved a review of 69 technology needs assessments across 39 countries. A categorization of the needs and barriers that are most identified by countries is outlined in Figure 4.4. The three main barriers identified were economic and market (high cost of technologies and limited state resources), human (inadequate capacities of personnel), and information and awareness (shortage of information on LCT and energy efficiency).

Figure 4.4: Barriers identified through Technology Needs Assessments [UNFCCC, 2013]



Governments must play a role in overcoming perceived barriers, often influencing and shaping the people, systems, techniques and knowledge and overall policy conditions. Such action could involve the provision of signals through stable energy investment policies, and the development of the national skills capacity by developing policy, legal frameworks and the institutional base for transfer. Creating an appropriate enabling environment to stimulate such energy projects involves a rethinking about how markets are created. In many developing countries such markets are heavily subsidized and regulated, with significant barriers or ‘subtle imperfections’ [Lovins, 1997] that inhibit the efficient allocation and use of resources within that market. As we move to understand the barriers that exist to the transfer and deployment of low carbon technologies, this chapter explores the impact across a suite of five supported projects and draw lessons for policy makers in terms of actions to overcome barriers that are encountered. The next section categorises such barriers into three groups: [4.2.1] Policy, regulatory and institutional capacity; [4.2.2] Investment and finance-related; and [4.2.3] Information and technical barriers. These examples of symptoms of ‘imperfections’ encountered in deploying low carbon technologies are based on the categorisation of Painuly [2001] and Boldt et al [2012] and are expanded below:

- **policy, regulatory and institutional capacity:** Symptoms include political instability; bureaucracy; insufficient legal framework; poor market infrastructure; market control by incumbents; unsupportive external environment (such as high cost of regulatory compliance); low R&D investment.
- **Investment and finance-related:** Symptoms include a lack of access to finance; high upfront capital costs; inappropriate tariff incentives; subsidised electricity rates below cost recovery levels.
- **information and technical:** Symptoms include a lack of consumer awareness; inadequate information and feedback loops; dearth of professional institutions; limited institutional capacity; lack of quality control, standards and codes; lack of skills and appropriate training; immature market development.

4.2.1 Policy, regulatory and institutional capacity barriers:

Despite the existence of domestic and international financial incentives, regulatory and institutional barriers prevent the utilisation of low carbon technologies in both grid-connected and off-grid applications [Gboney, 2009]. Interventions, such as international financial incentives, are only successful if they fit within national regulatory, legal and policy frameworks [Deutsche Bank, 2011]. Undoubtedly, inconsistencies in the nature of LCT and uncertainties in technological performance remain key concerns as policy makers engage in technology push but fail to interact with stakeholders in formulating and adopting the use of these technologies.

A renewed focus on supporting domestic policies to overcome domestic barriers is needed. Gboney [2009] describes how, despite the Ghanaian Government's commitment to the deployment of renewable energy, the absence of a legal and regulatory framework was a

major barrier to power producers wishing to invest in clean technologies. Haselip et al [2012], in analysing the pitfalls of policy implementation within the South African Feed-in-Tariff (REFIT), cited a lack of coordination and capacity at the policy making level, an unstable political environment and strong fossil fuel lobby groups as the main barriers to the implementation of the REFIT. This is further linked to technical barriers where a lack of appropriate skills in low carbon technology development was compensated for by impartial advice from energy experts in the fossil fuel industry.

Technical standards are limited within many developing countries, thereby negatively impacting on the deployment of LCT into markets. Rao and Ravindranath [2002] described how the Indian regulatory framework failed to enforce the use of renewable energy as a power option, thereby placing few incentives or obligations on utilities to deploy such clean technologies. Undoubtedly, the transfer of learning across jurisdictions can overcome regulatory barriers. From an EU perspective, the development of building codes and standards is one of the more successful policy tools that could be transferred and replicated. Such an approach, aimed at enhancing low energy building performance in China, is presented in section 4.4.4.

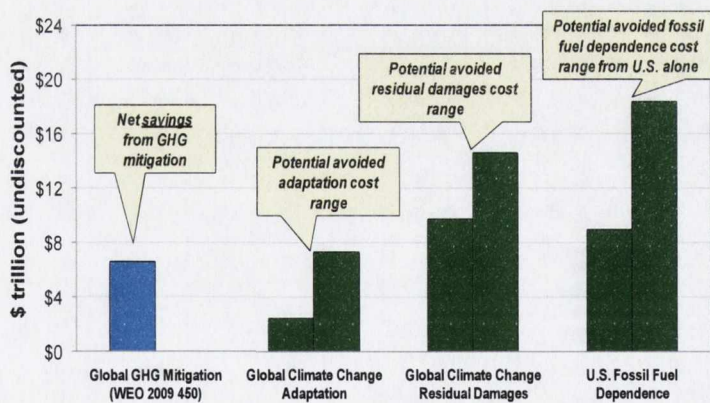
4.2.2 Investment and finance-related barriers:

A number of investment and finance-related barriers exist that could negatively affect the widespread deployment of LCT. Within developing country markets there is often limited knowledge and information concerning the benefits of investment and an overestimation of the initial investment costs. This impacts upon judgement and provides reluctance for initialising project development. The risk-to-reward portfolio of technologies often results in domestic financial institutions' reluctance to invest. This often arises from a lack of

understanding of risk assessment techniques by local institutions. The development of innovative financing mechanisms as an approach to overcome investment and finance related barriers in Mozambique and Uganda is presented in section 4.4.3.

The impact of ‘externalities’, in the form of global fossil fuel subsidies, should be incorporated into detailed energy system models and considered by policy makers when shaping policy. OECD modelling [2009] shows how the elimination of such externalities would result in a 6% reduction in global greenhouse gas emissions. Recent estimates present fossil fuel consumption subsidies as amounted to \$312 billion globally in 2009 [IEA, 2010] and value current fossil fuel subsidies as \$409 billion compared to \$66 billion for subsidies for renewable energy [Bloomberg, 2012]. OECD analysis [2012] valued fossil fuel support to the developed world amounted to \$45-\$75 billion in 2010, while clean energy subsidies amounted to \$44 billion in 2010. Figure 4.5 presents an economic value of renewable energy across two scenarios in the form of avoided cost that ranges from \$2 trillion to \$18 trillion.

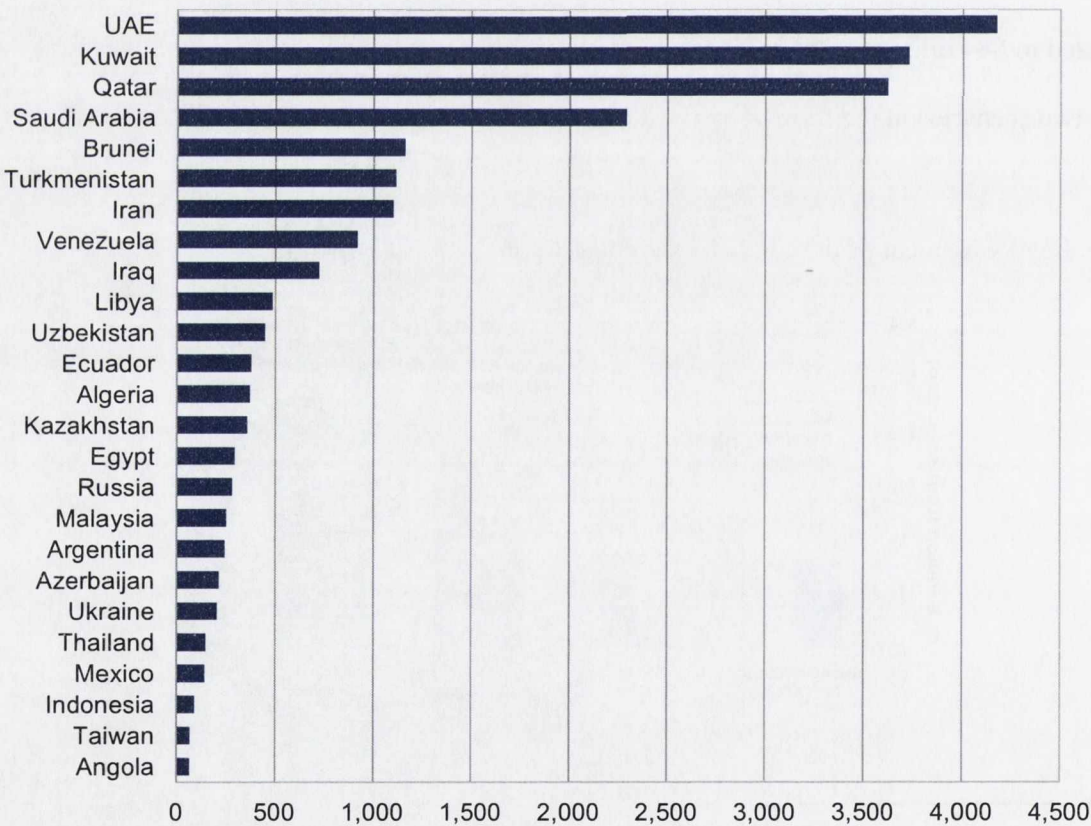
Figure 4.5: Assessment of the Cost of Externalities [IEA, RETD Project]¹²



¹² Analysis carried out by the IEA RETD have classified these externalities by (a) adaptation costs, the costs of measures taken by humanity to adjust to climatic change [Agrawala, 2011], (b) damage costs, the costs of residual damage produced by climatic change that cannot be eliminated via adaptation, and fossil fuel dependence costs, the externality costs (excluding direct costs of supply) beyond climate change that are associated with maintaining the energy system’s current dependence on fossil fuels.

The economic value of fossil fuel consumption subsidies by country [2009] is presented in Figure 4.6. Over 10 Sub-Saharan African countries are established oil producers with fossil fuel reserves and their major policy goal involves infrastructural development associated with supporting the oil and gas industry, even though the majority of the population has off-grid access or no access to electricity [Koskimaki, 2012]. From an Indian perspective, Rao and Ravindranath [2002], in analyzing policies to overcome barriers in the bioenergy sector, described how, due to subsidies provided to the agricultural sector, the conventional costs of energy are maintained at a low cost so they neither reflect the true environmental costs nor even long-term life cycle costs.

Figure 4.6: Fossil Fuel consumption subsidies (per capita) in U.S\$
[Earth policy, 2011]



4.2.3 Informational and technical barriers:

Informational barriers exist that reduce the ability to optimise energy use. The domestic capacities of local actors, coupled with a lack of information dissemination to enhance stakeholder awareness, often presents significant barriers to market uptake. In identifying barriers to the development of bioenergy in Thailand, Sajjakulnukit et al [2002] described a lack of awareness and confidence in available new energy technologies and applications, highlighting the requirement for extensive participation of stakeholders. The dearth of technical skills (for design, installation and operation, management and technology development) made many low carbon projects unsustainable in developing countries [Gboney, 2009].

Energy policies become successful when they interact with other policy fields. Societal engagement through education and information campaigns should be adjusted to local conditions [Koskimaki, 2012], enabling the dissemination of information relating to cost, performance, and maintenance of LCT systems. Indeed, Kaundinya et al [2009], in describing a shift in bioenergy technology policy toward demand-pull, cited key weaknesses arising from the Indian Government's failure to consider the requirement to coordinate local, institutional and government support. Rao and Ravindranath [2002], through their study of biomass system operation and maintenance in India, identified good practice actions, these include policies to promote a participatory approach in planning and technology management and a periodic assessment of technologies and instruments to promote the demonstration of technologies.

4.3 Project selection

This section describes the thesis' process for selection of a suite of project interventions within developing and emerging economies that are advancing the transfer of low carbon technologies. It outlines an approach to assessing project impacts and highlights the local challenges that LCT projects are experiencing.

4.3.1 Project selection methodology

The suite of developing and emerging economy projects presented have been individually evaluated and are supported by the Renewable Energy and Energy Efficiency Partnership (REEEP), an International UNFCCC Type II NGO. Each project was selected from a portfolio of projects that have been internationally evaluated by peer reviewers and funded by REEEP Government donors (see Figure 4.6). These projects have not been previously highlighted, collectively grouped nor have their impact been assessed or cited internationally. Each project confronts barriers and obstacles to the transfer and deployment of low carbon technologies. Additional selection criteria were applied to each project, namely the creation of an enabling framework for technology transfer and engagement in the process of developing Technology Action Plans within their needs assessment.

4.3.2 Project impact assessment approach

Technology impact assessment literature has identified various methods and tools to conducting thorough analysis and, over time, it has shifted in perspective, focus and approach. Significant debate [Pacala and Socolow, 2004, McKinsey, 2007, IEA, 2008] surrounds models, tools and scenario methods of measuring the impact of LCT in countries that are currently dependent on hydro carbon systems.

More effective methods of assessment are required and current prevailing approaches do not feature in many government policies [Tran and Daim, 2008]. Across international institutions, this thesis found that the impact associated with LCT projects is predominantly assessed by a logical framework or outcome mapping approach. This captures such criteria as energy savings, clean energy generation, GHG mitigation, and developmental impacts, including employment creation and industrial development. The institutions analysed include the Global Environmental Facility, Clean Development Mechanism, United Nations Development Programme, the World Business Council on Sustainable Development and the Climate Investment Funds.

This research found that policy makers often assess technology projects by means of cost-benefit and cost-effectiveness analysis, specifically in terms of employment creation, sustainability, environmental regeneration, trade and associated national development objectives. Accepting that technology assessment is an evolving area that continuously brings new challenges, it requires the invention of new methodologies and approaches to meet new demands [Tran & Daim, 2008]. Policy makers assess projects in terms of financial measures, including feed-in tariffs, related quantity based measures, subsidies, purchase agreements and publicly backed loan guarantees. The role of implementation actors that can transfer outputs into impacts and further adopt the use of these technologies is often diminished or not considered.

The variables analysed by the institutions within their impact assessment frameworks are often outside the sphere of control of the majority of international funding agencies. Such agencies are reluctant to discuss the 'attribution gap' and often include elements that are contributed to by a number of different funding agencies. When analysing the impact

assessment approaches applied by international institutions, this attribution gap often arises but is rarely considered.

Primarily, this chapter's assessment focuses on barriers to LCT deployment and transfer as expressed in section 4.2. In analysing the impact of such projects, the research discounts the logical framework and outcome mapping approaches in favour of a 'synthesis' approach. This highlights non-technical aspects of projects, considers the role of implementation actors, and highlights locally appropriate indicators and local market systems to assess impacts. It is about determining the widest scope of impacts in society, or better understanding the societal consequences of extending existing technology or introducing new technology [Coates, 2001]. Our synthesis approach places attention on the social and political context and participation and utilisation strategies [Ballard and Hall, 1984]. It identifies local implementation actors that can transfer outputs into impacts and considers their interaction in formulating and adopting the use of these technologies. The projects selected highlight actor engagement, and include a socio-economic impact of power systems on consumers, methodologies building capacity within developers' design decisions, and financing forums linking entrepreneurs with investors.

Local implementation actors can transfer outputs into impacts, and potentially avoid donors' multiple counting and duplication through outcome mapping. For example, the United Nations Development Programme financed a socio-economic and environmental impact assessment of a bioenergy project in 'Henchengli Village' in the Jilin province of China. Good practice within this project, as described by Fischer et al [2005], included attempts to develop locally appropriate indicators to assess impacts, and the articulation of lessons learned to facilitate success in replicating projects in the future. In assessing the impact, root

causes for project difficulties were blamed on ‘inherent local deficiencies’, including oversights in local capacity building, educational support, and failure to tap into local enthusiasm as local stakeholders were left without ‘decision-making authority, corrective voice, administrative capacity, or technical capacity’.

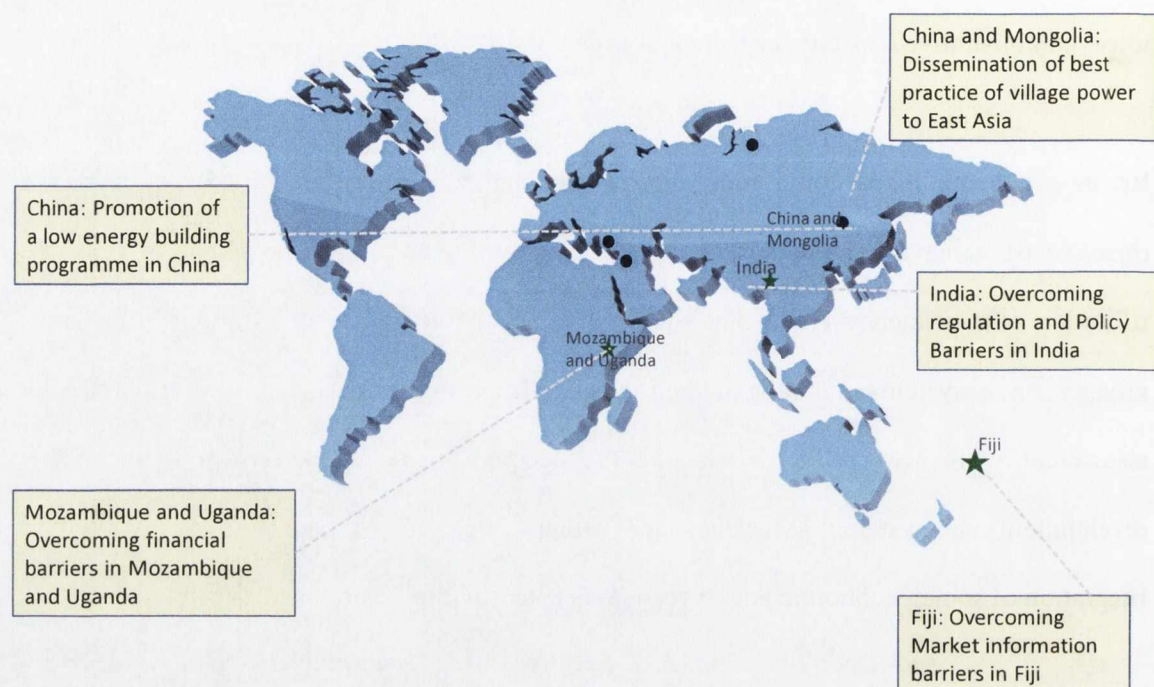
Strives are being made for a more integrated approach to project assessment with the objective of achieving more sustainable development goals. An assessment of resource utilisation and efficiency could place less stress on the environment. Authors often focus strongly on a systems dynamic modelling as a framework for technology sustainability assessment, while also calling for methods that account for the characteristics of sustainable development sub-systems [Musango and Brent, 2011]. This could often involve the integration of social, economic and environment issues within overall assessment.

4.4 Exploring the barriers to LCT deployment in developing and emerging economies

This section explores our understanding of barriers that hinder the accelerated deployment of LCT in five individual projects selected (See Figure 4.7). These case studies include:

- 4.4.1 Dissemination of Best Practice of Village Power to East Asia
- 4.4.2 Overcoming Regulation & Policy Barriers in India
- 4.4.3 Overcoming Financial Barriers in Mozambique & Uganda
- 4.4.4 Promotion of a low energy building programme in China
- 4.4.5 Overcoming Market Information Barriers in Fiji

Figure 4.7: Geographical distribution of case studies



4.4.1 Dissemination of best practice of village power to East Asia

This project's purpose is to transfer Chinese and international village power best practices to East Asian countries including Mongolia, North Korea, Korea and Japan via the establishment of a business model for PV village power in Mongolia. Achieving this purpose involves summarising village power experiences in China and Mongolia focusing on financial models used; developing and implementing a business model based on an installed village power system in Mongolia, and organising a regional workshop to disseminate project results and lessons learned.

Village Electrification in Mongolia and China is high on the governments' respective political agendas, implemented through the delivery of business models, such as Rural Energy Service Companies (RESCO). The introduction of new LCT to rural areas remains a

challenge as it generates changes in patterns of energy use that affect the demand of the system [Alvial-Palavicino et al, 2011]. The World Bank “Renewable Energy Development Programme” commissioned a team of Chinese and international experts to elaborate a RESCO model in 2007/08 concerning the Chinese Township Electrification Programme, with a budget of €172,000. The Township Electrification Programme is the largest worldwide with regard to village power electrification by means of decentralized renewable energy systems. The principal purpose of this project is to transfer Chinese and international best practices of village power to East Asia countries via the establishment of a business model for PV village power in Mongolia (See Figure 4.8).

Figure 4.8: Mongolian Village Power Participants [REEEP, 2013]



In assessing the impact of the project, consideration was placed on its main activities and outputs included:

- Sharing of local experiences gained in the course of the electrification of rural villages by means of decentralized low carbon technologies in China, Mongolia, North-Korea, and Japan.
- Summarising village power experiences in China and Mongolia focusing on financial models used;

- Development of a business model based on an installed village power system in Mongolia;
- Implementation of the business model produced; and
- Organisation of a regional workshop to disseminate lessons learning and study results.

4.4.1.1 Impact

Rural electrification by means of renewable energy has gained significant momentum in China and Mongolia, as verifiable by projects funded by World Bank, KfW Bank, and the UN Development Programme. Village power as an approach to supplying electricity to larger number of populations living in rural areas has become the favoured option under certain conditions. Village Electrification by means of renewable energy and the design of a sustainable business model, like RESCO, was a relatively new concept. The recipient of such systems expected the government to take full responsibility for operation and maintenance. The main project challenges related to methods to ensure a sustainable operation, issues relating to the transfer of ownership and the establishment of RESCOs, and undergoing the socio-economic impact on the rural population. As a result of this project, the Chinese Government is considering options to transfer the responsibility and ownership to state owned/private entities. This will enable state-financed, decentralized renewable energy systems to be commissioned, maintained and commercially operated in rural villages. Various recommendations and business models have been submitted to the National Energy Administration of China.

Assessing and measuring project implementation involved delivering a study focused on the *Status of Utilization of RE in Rural Areas* in China and Mongolia. The village power questionnaires targeted the socio-economic impact of such village power systems on the

consumers living and working conditions in these villages. In the past these ‘non-technical aspects’ were not considered when designing such projects. The bilateral exchange of information and experiences, training, elaboration of questionnaires has increased user understanding of aspects related to village power electrification by means of LCT. This is particularly the case in relation to the project’s operation and maintenance, socio-economic aspects, and service networks. Accumulated experience with renewable energy village power systems is now a reference used in the design of new projects planned by the Government.

4.4.2 Overcoming regulatory & policy barriers in India

This project’s purpose is to develop policies, regulations and guidelines to achieve energy efficiency and promote renewable energy in existing and new buildings in Bangalore, India. Achieving this purpose involves presenting a framework for policies, guidelines, and regulations to achieve energy efficiency at the building level. This included solar passive-design integration in new buildings; provision of roof treatment to cut heat gain; window design for day lighting, ventilation, energy-efficient artificial lighting design; energy-efficient air conditioning design, mandatory energy audit; and solar water heating systems for residential and commercial buildings.

Studies carried out by The Energy and Resources Institute [2010] show that more than 30% of Indian electricity can be saved in energy efficient buildings in comparison to conventional buildings. The City of Bangalore, India, is facing an enormous challenge to meet its ever growing demand of energy and water and to manage its ever increasing waste which is polluting the storm water drains and lakes in the city. There is a need to frame policies, regulations, guidelines, and develop financing instruments to achieve environmentally friendly, energy efficient buildings. The regulations need to be evolved to cover all aspects of sustainability and environment issues, including energy management, building materials and water/ waste management. It is anticipated that the integration of compulsory regulations in

the policy framework for buildings in the city of Bangalore will help conserve quantifiable tonnes of energy and abate CO₂ emissions.

In assessing the impact of the energy management policies to date, consideration was placed on the project's activities and outputs including:

- A framing of policies and regulations dedicated to energy management within Bangalore¹³; and
- The provision of a framework for municipal corporations, developers, builders, architects, technology providers, and financial institutions aimed at promoting, developing and evaluating urban house performance to meet sustainability goals.

4.4.2.1 Impact

This project resulted in (a) the growth in the market for products to achieve energy efficiency and integrate renewable energy in buildings; (b) a reduction of CO₂ emissions from the building sector and (c) the prediction of energy saving and CO₂ emissions arising once the policies and regulations (framed through this project) are legalised. It is expected that the building bye laws for the city of Bangalore will comprise of regulations and policies to integrate energy efficiency and renewable energy for both new and old existing buildings, thereby improving market demand for low carbon products. It is further anticipated that the policies and regulations developed to achieve energy efficiency and promote renewable energy in both new and existing buildings may be replicated by municipalities of other cities in India.

¹³ These policies and regulations include the following: energy demand reduction through appropriate architectural design features, energy efficiency in the cooling, heating systems and lighting, and appliances used in the building, integration of renewable energy to meet electricity demand in buildings, and energy demand reduction by meeting hot water demand in buildings through solar energy.

This project resulted in enhanced capacities of policy makers and practitioners. The developers are utilising economic appraisal methodologies and life cycle saving analysis and will document findings to help building professionals to make design decisions with regards to introducing energy efficiency measures. A few simple calculation and assessment methods are being developed and provided as part of the web based tool. These will help building professionals make informed decisions to integrate energy efficiency for new and existing buildings. Post project actions included a government mandate on energy efficiency in all public buildings in the state, and a mandate on the use of solar water heating. It concluded that compliance with the mandatory guidelines could result in mitigation of over 55% of emissions from Bangalore's building sector.

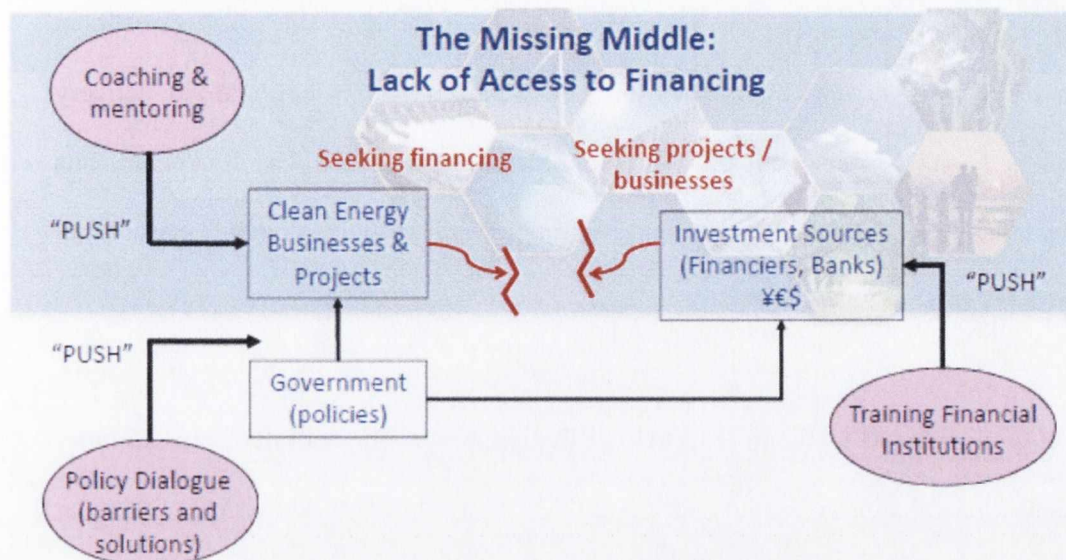
Pune, India, is a fast growing urban centre with increasing pressure on its resources. As a direct result of this project, policy recommendations were made to enable the government to implement the principles through regulations and byelaws. In order to incentivise eco housing in Pune, a set of technical criteria, with weighted point system, was established. TERI evolved the technical criteria for sustainable site planning and infrastructure planning, environmental architecture, energy efficient lighting, and renewable energy integration. The technical criteria and the weighting system have been developed through stakeholder consultation and an impact assessment was made at household, local, and global level of the adoptable measures.

4.4.3 Overcoming financial barriers in Mozambique and Uganda

This project's purpose is to establish a Private Financing Advisory Network (PFAN) in Mozambique and Uganda. Achieving this purpose involves the establishment of financial coaching and investor match-making services to guide renewable energy projects to a bankable financial close. It aims to reduce the perceived obstacles to the mainstreaming of financing for clean and renewable energy projects in Mozambique and Uganda, by increasing access to financing networks and investment for local clean-energy project developers and entrepreneurs and building local institutional micro-enterprise capacity.

While investments in low carbon projects have increased to a level of \$1billion annually in Africa in recent years, it is surprising that this accounts for only 1% of global total investment [Koskimaki, 2012]. Policies and programmes aimed at rural electrification (Uganda) and efficient lighting (Ghana) have been successful, yet financing has been a major bottleneck. In 2010, a Private Financing Advisory Network (PFAN) was established in Mozambique and Uganda, replicating an existing initiative in East Asia, aimed at 'bridging the gap' between low carbon project developers and investors. The main activities, utilising a budget of \$115,000, involved the screening of low energy business plans, selection of the most economically viable and environmentally beneficial projects, and provision of multiple rounds of coaching and guidance before projects are presented to investors. This involved development of a financing coaching and investor matchmaking service to guide low carbon projects to a bankable financial close (see Figure 4.9).

Figure 4.9: PFAN LCT guidance to overcome barriers to finance [CTI PFAN, 2013]



In assessing the impact of PFAN to date, consideration was placed on its main activities and outputs including:

- Identification of projects for inclusion in PFAN's development pipeline for receipt of guidance on project development and financing;
- Transfer of a scalable Brazilian model to Mozambique as a pilot project for the cultivation of high value-added crops at the family farm level;
- Provision of technical assistance and training to raise the ability of local market players to develop new projects;
- Achievement of financial closure on 4-8 medium scale low carbon projects (biomass-to-energy, solar, small-hydro, bio-fuels etc), raising a total of USD \$10-60 million;
- Engagement on more than 30 projects across Africa.

4.4.3.1 Impact:

An impact assessment of activities resulted in a significant reduction of the perceived obstacles to the mainstreaming of financing for clean energy projects in Mozambique &

Uganda. This was due to the provision of increased access to financing networks and investment for local project developers and entrepreneurs, enabling a scale up of investment in projects. Consideration was also made of the project impact in contributing to the delivery of Millennium Development Goals (MDG) and removal of barriers. The PFAN projects enabled the development of capability in local institutions and created sustainable agricultural microenterprises utilising LCT.

PFAN resulted in the development of an Africa Regional Network with dedicated Country Networks in Mozambique, Uganda and South Africa, enabling the transfer of a solar hydroponic project from Brazil to Mozambique. To January 2012, 21 LCT projects were 'closed' that account for USD\$232 million of investment. Over 240 MW of clean capacity was installed, resulting in 1.26 million tCO₂ reduction per annum. Seven LCT projects are currently in investor negotiations and an Africa Regional Clean Energy Financing Forum (AFRICEF) was delivered in 2010 and 2012, bringing together leading clean energy entrepreneurs in Africa with investors, fund managers and financiers that specialize in Africa's clean energy sector. Ten projects were selected for their commercial viability and environmental benefits from over 65 project proposals. All received intensive coaching on the preparation of their business plans from CTI PFAN professional advisors. Further project replication is anticipated in 2013 with the establishment of Sub-regional Networks in Africa. These include (1) Southern Africa / SADC (RSA, Mozambique, Tanzania, Botswana) (2) EAC: Uganda, Kenya, Rwanda and (3) West Africa (Ghana, Togo, Cameroon).

4.4.4 Promotion of a low energy building programme in China

This project's purpose is to reduce energy consumption in buildings through the adoption of new standards based on international best practices of energy efficiency and renewable energy technologies and use by the Chinese government. Achieving this purpose involves reviewing the major experience of energy use in Europe, estimating the energy savings achievable in China's building sector, and reviewing sustainable building best practices in European countries. The intent is to introduce European standards and develop policy recommendations for a sustainable building programme to China.

In China there was a significant lack of data concerning building energy performance throughout the 1980s and, over the past decade, energy consumption was growing at a much higher rate in the public sector than the residential sector. This led to questions about the existing buildings' compliance to current standards and the role of building controls and codes. Furthermore, questions were being raised about whether standards are appropriate and what "improvements could be made for enhancing the existing standards' availability and operability" [Jiang, 2011, p446]. Focus was also placed on the lack of skills in the sector and requirements for improving energy management standards through an effective enhancement of current policies and regulation. China's 12th Five Year Plan, (2011+) aims to reduce its energy intensity by 16% through projects including energy renovation and retrofitting, efficient product deployment and the use of performance contracting. The energy consumption in the building sector in China is 25% (around 4.5 billion CO₂e in 2007) of the nation's total energy consumption [Jiang, 2011]. The official promotion of low energy buildings contributes to an overall reduction of energy consumption and the protection of the local and global environment in terms of reduced CO₂ emissions. From a governmental perspective, promoting a low carbon building programme could provide a number of social, health and employment impacts. However, the prevailing price regime for electricity does not give sufficient financial incentives to developers due to the pay-back time for the additional investment required for such buildings being simply too long.

This project was developed to assist the continued concerted Government efforts designed to promote the construction of low energy buildings in China with the aim of contributing to a reduction of the overall energy consumption. Its purpose (utilising a budget of €120,000) was to reduce the energy consumption in buildings through the adoption of new standards based on international best practices of energy efficiency technologies and renewable energy use by the Chinese government.

In assessing the impact of the low energy building programme to date, consideration was placed on its main activities and outputs included:

- A review of the major experience of energy use in Europe and estimate of the energy savings achievable in China's building sector, with the assistance of European experts from the Netherlands, Germany and Austria;
- A review of best practices of sustainable building programmes in European countries, and introduction of European standards to China;
- An increased awareness of concepts for sustainable building development for several key stakeholder groups; and
- The development of policy recommendations for a sustainable building programme in China to promote the incorporation of energy efficiency and renewable energy technologies into the building sector.

4.4.4.1 Impact

The construction of low energy buildings has gained significant momentum in China, possibly triggered to some extent by the Olympic Games and the World Expo in Shanghai in 2010. This has led to an increased awareness among relevant stakeholders representing the Government, industry and public sector. The project enabled market development due to an

intensified encouragement of the Government via the enactment of stricter building codes and regulations, combined with financial incentives. In addition, the awareness was enhanced with regard to EU building standards among stakeholders representing the science, research, building sectors and the Ministries of Construction and Science and Technology.

The communication of this project was limited to the national level and involved experts only. It, unfortunately, avoided local authority engagement, achieved little involvement of stakeholders. This affected the overall impact that limited the scope and framework in which the results have been disseminated. An engagement of stakeholders on the provincial level would have facilitated an analysis of EU buildings standards and its relevance and applicable aspects to China would have been disseminated to concerned stakeholders. Provinces are authorised to endorse their own building codes as long as they do not contradict national regulations. Consequently, the potential to introduce new or amended building codes for low energy houses on the provincial levels was not addressed.

4.4.5 Overcoming market information barriers in Fiji

The purpose of this project is to develop a structured marketplace for energy efficiency and renewable energy services and technologies tailored to Fiji's hotel and resort sector, and provide instruction on the financing opportunities available under CDM for small-scale energy efficiency projects. Achieving this purpose involves creating a strategic plan for implementing a range of technology solutions in the Fijian hotel and resort sector through the establishment of a local partnership in Fiji to facilitate the project and provide long-term benefits to the community.

This initiative focuses on the market development requirements that will enable and assist Fijian hotels and resorts in meeting the United Nation's World Tourism Organisation target of 20% energy saving and a 10% increase in the use of LCT. A number of significant barriers have been identified within Fiji concerning the deployment of energy conservation measures

and efficiency technologies. Consumers, communities, entrepreneurs and NGOs require information to enable them to undertake analysis of available technological alternatives before making an uptake or investment decision. This project was established by Greenlight Technology as an attempt to reduce the informational barriers to energy efficiency and renewable energy technologies confronting Fiji's hotel & resort sector.

In assessing the impact of the promotion programme to date, consideration was placed on its main activities and outputs including:

- The development of a structured market place for LCT services and solutions tailored to Fiji's hotel and resort sector;
- A raising of awareness and creation of market demand for a range of small-scale LCT and services available to the hotel & resort sector;
- The development of a strategic plan for implementing a range of low carbon energy solutions in the Fijian hotel & resort sector; and
- The coordination of a collective reduction in electricity usage and CO₂ emissions.

4.4.5.1 Impact

The project has developed an energy efficiency and renewable energy programme for the Fijian Hotel sector. This includes a hotel LCT on-line 'market-place' bringing together technology and service firms and hotel owners and operators. Informational publications were provided to Fijian Hotel and Resort industry. Greenlight Technology established a local partnership in Fiji to facilitate the project and provide long-term benefits to the community that resulted in a reduction of the informational barriers to energy efficiency and renewable energy technologies confronting Fiji's hotel & resort sector. Importantly, from an industrial

voluntary agreement perspective, the project formed a strategic alliance of key stakeholder in the Fijian hotel and resort sector focused on LCT investment improvement.

4.5 Lessons learned

In considering the regulatory, institutional, financial and informational barriers that projects aimed at deploying low carbon technologies encounter in developing and emerging economies, this section draws a number of lessons for policy makers below. In our analysis of barriers across the suite of five projects analysed we found that:

- Domestic policies can facilitate the overcoming of domestic barriers and transfer learning across institutions and erode regulatory barriers;
- Local institutional and governmental support is crucial for technology demonstration and adoption and such institutions should improve their understanding of project risk assessment mechanisms;
- Local engagement with policy makers, developers and practitioners can aid project implementation and project design decisions and, through local alliances, can erode informational barriers;
- A lack of awareness and confidence in new LCT can be overcome through stakeholder engagement and enhanced participation;
- Bilateral information exchange, dissemination and sharing of experience can help project design and replication and should be adjusted to local conditions; and
- Initiatives that bridge the gap between investors and projects developers can overcome mainstream financing obstacles, scale up investment and build local capacity in institutions. These initiatives include entrepreneurship and investor brokerage, access to finance networks, and investor matchmaking.

Table 4.1 presents potential actions that can aid policy makers, market actors and technology innovators in their understanding of the transfer and deployment of low carbon technologies.

Table 4.1: Potential actions that can aid the deployment of LCT

Stakeholder/ Actor	Barriers		
	Policy, Regulatory and Institutional	Investment and Finance	Information and Technical
Government	Technical plan analysis, including understanding of the technical potential, leading to the development of support schemes and regulation. Replication/ consideration of EU best practice policies and regulations for energy use Establish new regulations to support small scale electricity generation.	Development of incentive schemes and support structures to assist with the roll-out of LCT and distributed energy schemes. Continued development, monitoring and analysis of support schemes and adjustment to support maximum potential uptake of measures.	Education of consumers to raise awareness of long term vision for energy and CO₂ reduction for LCT deployment Monitoring of progress in reducing energy and CO₂ emissions against targets. Continuation of education to support behavioural change.
Markets & supply chains	Development of technology performance standards to provide consumers with guarantees of minimum levels of performance.	Development of new business models to support uptake of low carbon technology measures/ installations.	Training and education of designers and installers of energy measures.
Technology & Innovation Actors	Development of LCT products, standards and materials for increased efficiency from building regulations. Continued integration of low carbon generation with the electricity grid.	Promotion of new business opportunities.	Continued RD&D of market specific LCT.

4.6 Conclusion

This chapter, through a case study exploration, highlighted a number of examples where LCT was being deployed and transferred within developing and emerging economies. It framed a number of barriers that hinder and constrain technology deployment and presented lessons aimed at advising future projects to overcome similar barriers.

Chapter 5

Political economy analysis of the climate change architecture: a game theory approach

Chapter 5 extrapolates the lessons identified within Chapters 2 and 4 and assesses potential LCT deployment in a global context with reference to the international UNFCCC architecture. Drawing upon economic game theory, this chapter interprets the latest developments within the international negotiations and provides a political economy analysis of the climate change architecture. Accepting that international co-operation is essential for collective action, achieving consensus around the climate architecture is more challenging than ever. At an international level, action depends strongly on the national decisions of countries where commitment to an agreement can result in an enhanced willingness and determination to meet climate obligations.

As countries strive towards the maintenance of national interest and the pursuit of international co-operation, the timing of a country's decision to abate, the level of such abatement, and the effect on the costs of delivering emissions-reduction targets is very relevant, especially as it impacts national competitiveness, development and growth. This chapter analyses the process of negotiation towards a second commitment period of the 'Kyoto Protocol', assesses the validity of a single agreement and reframes the climate agreement architecture by proposing new dimensions that add flexibility. Such dimensions include the need for national, bilateral and multilateral action, the adoption of a pledge approach that reflects national differences, the consideration of national competitiveness and a utilisation of incentives. Accepting that countries will reject an international agreement or

obligation that is seen as inimical to their economic competitiveness, the chapter analyses a number of existing game-theoretical models and their role in the climate negotiation process. It considers how learning from such models can influence agreement design and proposes a new approach from a non-monotonic polluting payoff function.

5.1 Introduction

Climate change, as a concept, is an important foreign policy for global leaders, where the power to make agreements often includes concerns that derive from individual nations. It is a collective action problem [Vogler, 2010] that represents a significant market failure [IPCC, 2007]. Achieving an international agreement can only happen if the various interests of individual nation states are met, while cost-effectiveness and overall national competitiveness is protected and maintained. Such economic considerations are very relevant as the only chance we have to curb climate change is to accelerate the growth of clean energy economies [Stern, 2013]. Progress and agreement depend on our understanding of how policy at a national level, and collective action at an international level, support and encourage each other [Stern and Rydge, 2012]. This chapter considers how to best achieve an agreement by reviewing existing game theory models in light of the climate negotiations, highlighting aspects to consider in framing a new agreement.

While climate change is an interconnected global problem where ‘conflicts of interest are international and intergenerational’ [Hepburn et al, 2008], it remains a geopolitical issue. Governments and policymakers are being urgently asked to act to reverse emissions growth trends and let scientific evidence inform their pathway. There is international acceptance that a response to tackling climate change requires international collaboration on a global scale that reflects the idea of a balanced and fair agreement. Achieving consensus surrounding

approaches to climate change is a significant collective action problem, where benefits are internalised within a country and the costs are evenly spread out globally. This raises issues concerning how best to reframe such an agreement, and what considerations to make in shaping its architecture. This is the key focus of this chapter as a successful framework of agreement would lead to a significant impact on the deployment of LCT globally.

5.2 Learning from game theory concepts

Throughout the past 50 years, game theoretical models have been applied to interconnected global problems, including financial markets, trade, biodiversity and, more recently, climate change negotiations. These models allow for the fact that individual decisions depend on the expected reactions of others, thereby allowing policy makers to form more effective and efficient policy mechanisms that focus on incentives. This had led Forgo, Fulop and Prill, [2005, p252] to comment:

“It is hard to find a better testing ground for various game theoretic models than climate change negotiations where the conflict character of the situation is apparent not only for the specialists but also for concerned citizens.”

A country's/ player's abatement decision is informed by the decisions of another player, as they aim to maximise their utility function, seek self-interest, and engage in 'free-riding'.

5.3 Applying game theory to the climate negotiations

Game-theoretical models provide an elegant formalisation of strategic interactions across the climate negotiations [DeCanio, 2010] whose application can inform parties' decisions given certain circumstances. A number of key assumptions surround the application of game theory

to the climate negotiations, namely that countries will act rationally and will all share the objective of climate stabilisation and protection. Table 5.1 outlines the various combinations of strategies that parties can pursue structured around three cases: compliance with agreement, continuing business as usual and applying self-interest strategies. Ciscar [2000] found that the emissions levels of parties were similar in cases in which a strategy of self-interest (*si*) and compliance (*c*) with a climate agreement were pursued. Furthermore, in scenarios where one party followed a Business as Usual (*bau*), the other party followed a *si* strategy. From a game theory ‘realism’ perspective and using 2x2 order games, each nation state ranks each of their expected outcomes and the resulting associated payoff(s).

Table 5.1: The Game Matrix [Ciscar’s multi-region exercise, 2000]

	c	bau	si
Comply with Climate Agreement (<i>c</i>)	c,c	c, bau	c, si
Business as Usual (<i>bau</i>) [i.e. continue to pollute and apply no new policies/ measures so maximises utility function without emissions reductions]	bau, c	bau, bau	bau, c
Self-Interest (<i>si</i>) [i.e. consideration of climate change in context of the impact on own economy so maximises own utility function]	si, c	si, bau	si, si

From a climate perspective, we apply the *Abate/ Pollute* strategy (Table 5.2) where two parties exist in the game: U.S. and China. There is considerable payoff for both parties as the costs of climate change exceed the costs of mitigation [Stern, 2006]. Both countries have openly expressed a fear of jeopardising economic growth and competitiveness that may be directly attributed to their abatement actions. The consequences of current and near-future actions are stimulated. They are based on projections of future costs and benefits as players undertake, or choose not to undertake, mitigation measures to reduce GHG emissions.

Table 5.2: Abate / Pollute Game [DeCanio et al, 2010]

		Chinese strategy	
		Abate	Pollute
U.S. strategy	Abate	a, w	b, x
	Pollute	c, y	d, z

Abate refers to early mitigation in current or near term, and Pollute refers to no mitigation.

In this game, *a* in the upper left hand segment is the payoff for the U.S., if the U.S. chooses the strategy *Abate*, and China chooses the strategy *Abate*. China's payoff is *w* from this pair of strategy choice. The payoffs to each of the players in the game are measured by order, so (*a,b,c,d*) and (*w,x,y,z*) can take on numeric values of (4,3,2,1), with 4 as the most favourable outcome reducing to 1 as the least favourable outcome. Let us first assume, that the *Abate: Abate* outcome is the preferred outcome for both parties, so no economic benefit arises if both *Pollute* instead of choosing *Abate*. Say, if the decision of neither party's pollution benefits the other party, then it is difficult to see if any benefit could be derived from emissions reductions resulting in either China or the United States [DeCanio, 2010].

The proposed approach then relaxes the assumption and we see how preferences change. The U.S and China agreed on an *Abate: Abate* as the dominant Nash equilibrium strategy leading to the rational pursuit of self-interest that encourages co-operative behaviour [Vogler, 2010]. In effect, neither party can improve their payoff by deviating away from their outcome if the second party also acts the same way and maintains the equilibrium (the maxi-min strategy). The payoff to the U.S. and China for choosing *Abate* is greater than their payoff for choosing *Pollute*.

5.3.1 Considering time and payoffs

Countries, such as U.S. and China, do not just make a decision about whether to pollute or not, they make a decision about how much and when to reduce their emissions [Wood, 2012]. If we apply a time horizon to our game (near and long-term), early abatement actions may affect later abatement costs. Late mitigation costs are assumed to be the lowest when both countries undertake early abatement, higher when only one country undertakes early abatement, and highest when neither country undertakes early abatement. Less abatement in the near term will have a significant impact, in cost terms, assuming that economies move towards a low carbon trajectory in the longer term. This asymmetric dilemma implies the less action that occurs in the near term to reduce CO₂ emissions, the more expensive in nominal terms it will be to implement similar actions in the longer term. This often results in countries observing and not acting while others bear the abatement cost: “if it is unclear who is going to pay the cost and it is not all that clear who is going to gain how much from acting, one has an energised set of opponents and a weak group of opponents” [Ellwood, 2009, ix].

We then apply the prisoner’s dilemma (PD) to study the complexity that arises when time horizons and costs are applied to the *Abate / Pollute* Game: as the financial costs associated with the time of abatement become significant, the opportunity cost of action is considered. All gains are forfeited if the co-operative arrangement benefits another party [Richardson, 2011] and complexity is added with a ‘wait and see’ abatement strategy [Hsu, 2010] where the early adoption of technologies may be more expensive than delaying to a time when costs have reduced and technologies have become more mature.¹⁴ The counterfactual is early abatement providing ‘first to market’ advantages. Table 5.3 presents a scenario where Nash’s equilibrium arises from both the U.S. and China maintaining a *Pollute* strategy. The real

¹⁴ There is little acknowledgement inherent in the Prisoner’s dilemma that a co-operative outcome could be reached if parties are permitted to signal to each other intent to co-operate [Hsu, 2010].

question is whether the payoff for exploiting one country's *Abate* co-operative strategy is better than their payoff for engaging in mutual co-operation (*Abate: Abate*) with another country.

Table 5.3: Nash's Equilibrium within the Game

		Chinese strategy	
		Abate	Pollute
U.S. strategy	Abate	3, 3	1, 4
	Pollute	4, 1	2, 2

Deviation from business as usual strategy (a Pollute to Abate Strategy) may have a more negative payoff

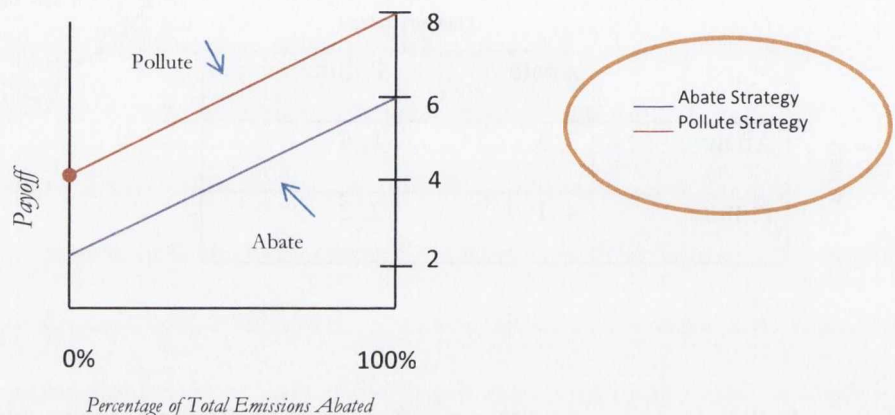
The *Pollute/ Pollute* strategy where the payoff is equal (2, 2) and a pareto superiority (3, 3) arises from an *Abate: Abate* strategy. However, if one of the parties deviates from the *Pollute* strategy, thereby moving to an *Abate* strategy, then the payoff (1) would be less than that of its original strategy of business as usual (*Pollute: Pollute*).

Countries must also consider a preference for delay in their *Abate* strategy, especially considering the possibility that future technological learning may indeed reduce the costs associated with abatement in the longer term. This increases the attractiveness of delayed abatement strategies. The negotiations do not reflect this two party power struggle as depicted in Table 5.2 as attention focuses on how one party's 'payoff' compares to what the second party has received, and vice versa.

In Figure 5.1 the percentage of emissions abated by one negotiation strategy is considered in terms of the potential strategy payoff. The PD logic applies as long as the pollute strategy line is above the abate line and one Nash equilibrium exists (represented by the dot in Figure 5.1).

The payoff to the polluting party increases as total emissions are abated, while the benefits from abating may also increase. However, the decision to *Pollute* has a negative externality as it results in pollution.

Figure 5.1: The classical game theory approach



[Figures 5.1 and 5.2 adapted from DeCanio [2010]: Prisoner’s dilemma and coordination in N-player games.]

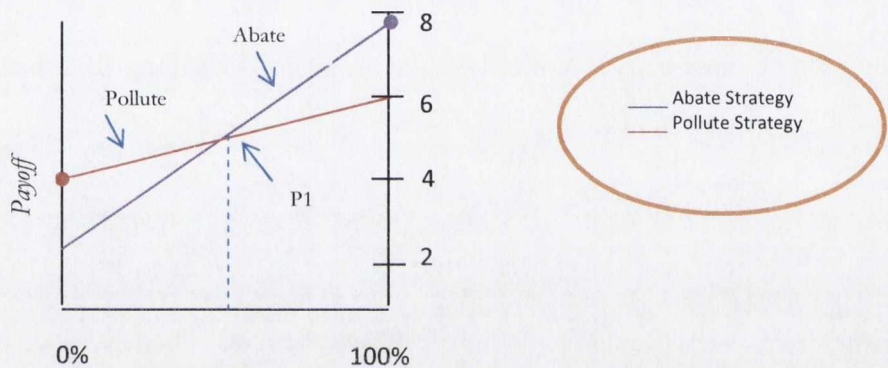
Figure 5.1 is the classical game theory approach incorporating the prisoner’s dilemma. The horizontal axis measures the percentage of emissions abated and the vertical axis measures the payoff per country following their decision. In Figure 5.1 the prisoner dilemma logic applies as long as the Pollute strategy line lies everywhere above the Abate strategy line, therefore it does not matter if the Abate line slopes upward or not. The one Nash equilibrium is represented by the heavy red dot.

When considering a single UNFCCC binding agreement, coordination games become more complex when more than two countries exist in the negotiation. Once the two lines cross with the abate line upward sloping (Figure 5.2), a coordination game commences as two Nash equilibria exist (as represented by two dots). In this two player dilemma, all countries can

Pollute and all can *Abate*. If fewer than the payoff point (P_1) of the pollution is abated, then the payoff to *Pollute* is greater than the payoff to *Abate*.

Figure 5.2 presents the coordination game, where the optimum strategy depends upon the actions of others within the game. It is reflected at the point of intersection between the two lines cross and the *Abate* line is upward sloping. It exhibits two Nash equilibria, one in which all countries pollute (red dot) and the other in which all abate (blue dot).

Figure 5.2: The coordination game



In Figure 5.2, if fewer than P_1 (payoff) percentage of total emissions is abated, then the payoff to abate is less than it is to pollute, and all countries will settle toward the equilibrium in which all pollute. Yet, if more than P_1 of the pollution is abated, then the payoff to Abate is greater than the payoff to Pollute, and the countries will settle toward the equilibrium in which all abate. In a multi-country negotiation setting, as a number of countries shift to an abatement strategy (from pollute), it entices other countries to also change their strategy in order to achieve payoff. Circumstances, such as an international climate treaty could transform a Figure 5.1 into 5.2, where a shift upward would increase the slope or change the shape of the Abate payoff function so that the strategy lines cross (DeCanio, 2010).

Rationally acting countries will settle toward the equilibrium in which all countries abate [De Canio, 2010]. Payoffs to abate could include avoidance of climate change effects, while payoff to pollute could include avoidance of investment costs required for emissions reduction. If the abate strategy line were moved up, the P_1 , pollution abated to induce cooperative equilibrium would shift to the left.

5.4 A critique of a centralised single agreement approach

This section identifies two main challenges with countries pursuing a top-down, harmonised climate change architecture. It analyses the appropriateness of such architecture with respect to the ‘global commons problem’ and in terms of the emerging ‘differentiation’ among developing countries.

5.4.1 The ‘global commons’ challenge

Applying a single agreement to curb climate change is an exceptionally challenging dilemma, at a political level, due to the ‘global commons problem’. For the majority of countries, the direct costs of action to curb climate change will inevitably be greater than the direct benefits that result, despite the fact that global benefits may be greater than global costs [Stavins, 2012]. Undoubtedly, seeking national self-interest could have positive ‘free rider’ effects as it is economically rational for each country to let another country lead and be first to abate CO₂ emissions. The continual struggle of nations to assert such national interest ends up hurting common interest [Ekman, 2010]. This analysis led the OECD to call for Governments to “break out of their national mindset and look at the global picture” and calling for “policies to build a low carbon, climate resilient economy” [McDonald, 2011]. Yet, the ‘early adopter’ country bears the full costs of its emissions reduction while only receiving a small fraction of the benefits. While agreement may be easier across countries that are artificially

symmetric, principles such as fairness and equity play a role. This reflects public choice theory where engagement by a country within the climate negotiations only occurs when the co-operation is associated with a net gain for that country [Svendsen, 2003]. Considering the majority of national action requires constituent support that a main challenge is that “climate change is essentially unobservable to the general population” [Gavel, 2013].

The IEA’s reference scenario [2008 and 2010] indicates that an 85% increase in global energy demand and a 97% of increase in energy related CO₂ emissions will come from developing countries by 2030. Such change and accompanying GHG emissions are projected to occur mostly in the developing world, particularly China, India and the Middle-East, with estimates indicating that India’s emissions could increase three to four fold by 2030, ranging from 4-7 billion tonnes [UNDESA, 2009]. Given their need for continued economic growth, it is unlikely that developing countries will agree to constrain emissions without compensation from developed countries [Popp, 2009]. The transfer of these technologies, typically from industrialised nations to developing countries, provides an avenue for ‘spillover’ effects, where compensation stimulates changes in flows of capital, production and trade between countries and regions.

5.4.2 Differentiation among developing countries

As long as CO₂ emissions accumulate within the atmosphere and its sources are greater than sinks, the historical responsibility of countries has a scientific basis in the climate change debate. Developing countries currently account for nearly 55% of GHG emissions, making a differentiation among developing countries a realistic proposition. This differentiation should be considered along a spectrum that emphasises the current capabilities of an individual developing country. Any new agreement architecture should consider the current

circumstances of developing and emerging economies, rather than views and categories held when the Convention was signed in 1992. The commitments to address climate change and the rules for counting and tracking emissions can no longer be handled on a bifurcated basis (based on 1992 categories) and “we should not have the same expectations for emerging powers like China, Brazil, Mexico or Korea as we have for countries of modest capacity just because all of them are developing” [Stern, 2013] The significant economic interests between different countries, that are partly diametrically opposed, has made the mission to negotiate such a single binding agreement ‘near impossible’ [de Coninck, 2009].

It could be argued that a number of such emerging economies should no longer be the beneficiaries from climate financing as, from 2009-2011, their GDP was higher than the average EU 27 states. Attention could focus on the circumstances of poorer countries that have made a minimal contribution to emissions growth thereby maintaining principles of equity across the architecture. When analysing incomes and emissions per capita of the US, EU and China (until 2020), it becomes clear that based on current business as usual scenarios, carbon emissions, in the form of CO₂ tonnes per capita, are practically the same for both the EU and China, but half those of the U.S. (Table 5.4).

Table 5.4: Comparison of CO₂ Emissions of major economies [UNEP and PBL, 2012]

	Emissions (including land use)/ capita, tonnes CO ₂ / capita			
	1990	2010	2020 BAU	2020 Pledges
EU-27	11.9	9.2	10	8.8 (20% reduction) 7.7 (30% reduction)
China	3.5	7.4-8.3	9.9	9.7
United States	24.3	21.5	21	17.7

Reverting back to game theory, accepting the costs of abatement outweigh the benefits, international co-operation is essential for achieving agreement. Negotiation positions return

to the economic benefit (or differential cost) of abating early, or abating late. The perceived ratio of benefit-to-cost is often dependent on the action of others: a country's failure to act can result in another country reconsidering its abatement strategy. Stern and Rydge [2012] describe how international action depends strongly on the national decisions of countries where commitment to agreement can result in an enhanced national willingness and determination to meet obligations. However, achieving consensus around structure is more challenging than ever, especially considering issues of equity ('common but differentiated responsibilities') and emerging vibrant emerging economies, such as Singapore and United Arab Emirates, that are classed as developing nations. These nations need to increase their level of ambition within any agreement.

Vogler [2010] describes how, once the U.S. failed to ratify the Kyoto Protocol, the main strategy from Russia, Japan and Australia was to maximise potential emissions while minimising all penalties resulting from non-compliance. This issue of growth and competitiveness is again central where the linking of growth to emissions productions may indeed be viewed by emerging economies as a form of punishment that would prevent certain countries from emerging to challenge the US and European economies. Strives toward co-operation and gaining trust bring a potential risk of exploitation [Kydd, 2010] as one country may feel vulnerable if the second country fails to reciprocate. Trust brings enforcement responsibilities: the Kyoto Protocol had few negative consequences, and the requirement for having clear binding commitments should be linked with the achievement of economic interests [Hare et al, 2010].

5.5 Designing a flexible architecture while maintaining ambition

Within the context of the UNFCCC, individual countries bargain within a group of 192 nations based upon a generally shared appreciation of the scale of the climate challenge, as GHGs continue to increase beyond the 1990 reference year. In reality, this reflects a multi stage game: a simultaneous negotiation at a national and international level where interactions occur across interest groups at a national level, while coalitions are built at an international level. The classic two stage game, outlined by Putnam [1988], Berk and del Elzen [2001] and Rong [2010], describes how the central government tries to alleviate domestic concerns without committing to any action that will have deleterious effects at home. Implications for competitiveness, development and growth are high on national agenda. Climate authors and policy makers [Stern 2007, 2012, Stern, 2013] have publicly debated on the arrangements required to solve the climate change dilemma. Achieving an all-inclusive top-down agreement that includes all country compliance with strict timetables and targets is perhaps overly ambitious. One single set of targets, applicable to all, may not be appropriate to the multiple interests of nation states. While such ambition may work on paper, demanding the achievement of, and policing compliance with, strict commitments through tough penalties may be viewed as undermining national competitiveness. A spectrum or range of targets (or negotiation points), possibly in the form of pledges or a hybrid portfolio approach, may indeed be a more flexible and acceptable strategy.

Establishing a flexible framework for policy implementation, at a nation state level, is perhaps more relevant and achievable than a harmonised climate change target. This needs to be conducive to broad country participation, and should encourage emerging economies to be ambitious and act, while achieving a level of differentiation among developing countries [Stern, 2013]. Mitigation commitments that focus on national planning add flexibility. For

example, at an EU level, countries had the opportunity, through national planning, to determine levels of ambition across heat and electricity within their National Renewable Energy Action Plans. Reframing the climate architecture can take this one step further by formally acknowledging key national action. This could include a country's investment in LCT, recognising energy efficiency gains or decreases in energy intensity across the economy. A reframing of the climate architecture will have a number of dimensions:

- 5.5.1 Embracing national, bilateral and multilateral action
- 5.5.2 Adopting a pledge approach that respects national difference
- 5.5.3 Considering national competitiveness
- 5.5.4 Utilising 'spillovers' as incentives
- 5.5.5 Analysing game theory and domestic action

5.5.1 Embracing national, bilateral and multilateral action

National action ultimately becomes the necessary instrument to fulfil whatever agreement is decided through international co-operation. There is general consensus [Barrett, 2003, Vogler, 2010, Richardson, 2011] that the inclusion of the large emitting countries in any agreement architectural design and ratification is essential in curbing future GHG emissions. Today, just 20 countries and regions account for nearly 90% of global emissions and so national, bilateral and multilateral action is required. Undoubtedly, the extension of the Kyoto Protocol commitment period was a critical bridge towards reaching a binding deal in 2015 (through the 'Doha Gateway') and in maintaining a rules-based and common accounting system. While it is extremely unlikely that a favourable outcome, in an emissions reduction sense, will arise from countries acting individually [IPCC, 2007], this second commitment

period achieved minimal signatories¹⁵ (representing 10-12% global emissions). This reflects the design inadequacies of the original Kyoto Protocol from a major emitter perspective. China, Indonesia, India and Brazil were not constrained due to a lack of commitments, while the US passed legislation to promote clean technology, improve efficiency and reduce GHG through regulation but ultimately failed to ratify.

Country-to-country arrangements have the potential to undermine future Kyoto model agreements, often in the pursuit of national interest or economic goals. For example, Bang et al [2007] have described how the U.S. engaged in a Partnership on Clean Development and Climate with global coal producers, including India and China, to exchange knowledge on cleaner coal technology and has also established bilateral science agreements to facilitate technology transfer. The EU has signed science and technology cooperation agreements with developed countries and has engaged in joint research (Framework 7 and upcoming Horizon 2020) calls with Brazil, Russia and India, while also signing an agreement with China on strengthened environmental technological cooperation. The IEA Committee on Energy Research and Technology (CERT) have openly engaged with non-OECD countries, including India, Brazil, China and Indonesia, enticing them to participate across the work of the IEA energy technology actions in an observer capacity. The UK established climate innovation centres in India and Kenya aimed at strengthening economic ties with its priority development countries.

¹⁵ This commitment period to 2020 will only include EU, Australia, Norway, Switzerland and a few smaller countries such as Lichtenstein and failed to include Canada, Russia, Japan and New Zealand.

5.5.2 Adopting a pledge approach that respects national difference

A ‘pledge and review’ approach to emissions reduction has long been debated [Bradley, 2005, Reddy, 2009, Hare et al 2010] as a viable approach in which bilateral and multilateral funding can enhance agreement success. This bottom-up perspective, ignoring the ‘free-rider’ problem, espouses the belief that climate change can be stabilised when effective change is driven by local action and driven by the attainment of domestic goals [Dubash, 2010].

Maintaining cost-effectiveness in attaining climate goals through a least cost means is critical. The ‘Kyoto model’ does not provide strong enough incentives for parties to participate or comply. The most prudent and cost effective path may require a slow ramp up of target severity for participating parties, and a phased approach that avoids unnecessary capital stock obsolescence [Stavins, 2011]. The ‘Cancun Agreement’, building upon the ‘Copenhagen Accord’, failed to deliver a global binding agreement. It enabled government pledges that included monitoring, reporting and verification of emissions reductions across all countries. At a general level, an agreement on commitments of the ‘Cancun Agreement’ involved an acceptance of the principle of GHG limits, voluntary pledges from parties to reduce emissions in the near term, and sectoral deliverables. While geopolitical uncertainty surrounds the ratification of the ‘Durban Declaration’ by key emitters, future arrangements may hinge on the national policies to curb emissions and the integration and alignment of such plans and co-operation into the international architecture. National interests and emerging political change may significantly impact the ratification of the ‘Durban Declaration’ post 2015. Indeed, as we get closer to ratification, the interests of individual nations may overpower the collective interest.

5.5.3 Considering national competitiveness

National interest is undoubtedly linked to economic wealth. Countries are subsumed by budgetary crises and political opposition has undermined strives towards achieving consensus while discouraging more ambitious commitments to reduce emissions. Government leaders are under increased demands. They have to respond to policy demands to secure indigenous sources of energy supply, constituent demands for more aggressive environmental policies, and the recognition that neither of these demands can be met without continued competitiveness and economic growth.

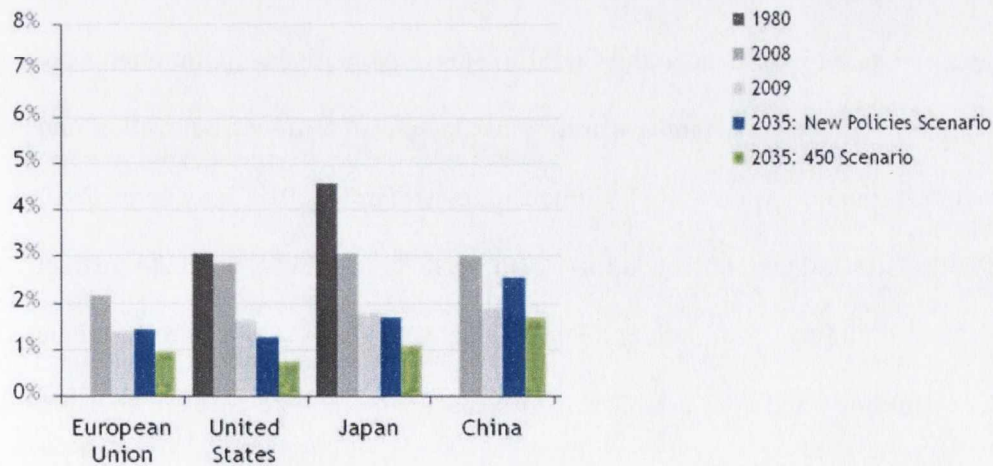
The choice of this 2°C or 450ppm stabilisation target has ‘a primarily environmental rather than an economic rationale’ and if the cost of achieving the goal exceeds the benefits, then the goals of benefit-cost optimisation and climate effectiveness would diverge [Bodansky, 2012]. With deeper interrogation, analysis of the cost implications on a countries’ national autonomy, versus the benefits of a global agreement, is a growing consideration for major economics. Larger parties, such as China and the U.S., do bear a small but non-negligible fraction of the costs of global CO₂ emissions and are also eager to placate public opinion at home and avoid international pressure [Tirole, 2012].

Grasso [2004], Brennan [2009] and Grundig [2009] argue that failures within the national market can be remedied by collective action. No single country, or group of countries can solve the climate change problem and coordinated action is absolutely necessary [Stern, 2007]. While the UNFCCC focuses on achieving climate effectiveness through reductions in net GHG emissions, little consideration is placed on factors, such as economic cost. The economic benefit that arises from curbing emissions should be made more explicit. The IEA’s 450ppm scenario to 2035 [2011] estimates that annual spending on oil imports by the

five largest importers is around \$560 billion, or one-third, lower than in the New Policies Scenario (see Figure 5.3). This analysis highlights the significant economic savings in the form of reduced oil-import dependency that can be achieved from pursuing a low carbon technology strategy.

Prior to UNFCCC Conference of the Parties in Durban, the expectation was that emerging economies, such as Brazil and China, in their pursuit of national interest, would be less likely to apply a voluntary commitment to place emissions caps on their respective economies. Any reframing of climate architecture should consider the inequalities of participating countries and recognise that countries are driven by domestic issues of competitiveness and political self-interest above climate consensus and GHG abatement. Indeed, Bang et al [2007] further observed that such agreement acceptability depends on the distribution of power, preferences and possible coalitions within each participating country. Rong [2010] illustrates such factors to influence policy response, including a country’s ecological vulnerability, mitigation capability, international financial and technological transfer and country pressure arising from growing GHG emission levels.

Figure 5.3: Oil-import bills as share of GDP in selected countries [IEA, 2011]



5.5.4 Utilising 'spillovers' as incentives

Authors, including Bazilian *et al* [2008] and DeCanio [2010], have argued that the deployment and transfer of LCT is essential to achieving participation from developing countries in a future agreement. These concessional mechanisms can bring beneficial effects in the form of technological knowledge enhancing the productivity and innovative ability of countries. Tirole [2012] outlines how a country's strategic positioning increases the cost of delay in choosing to abate emissions as future technological or societal choices will be linked to concession extraction arising from the negotiations. While it is challenging to reliably quantify the impact of such 'spillovers', they remain a significant negotiation incentive to attract parties toward a climate change agreement and valuable preconditions for long-term technical innovation [IPCC, 2007]. Examples of 'spillover' incentives include the instigation of fast-track financing, low-carbon technology transfers, reduction of intellectual property barriers or restrictions, enhanced trade agreements, technology innovation development and demonstration, regulations, standards or suitable instruments to induce the necessary required investment in technology transfer.

Spillovers are 'elaborate concessions' for participation in the climate architecture. They arise from economic and geopolitical relations and may provide a stimulus to national growth, resulting in increased emissions [Buchner and Carraro, 2005]. International commitments are obtained when countries perceive advantages from participation in terms of innovation and low carbon growth [Stern and Rydge, 2012]. Climate authors [Tirole, 2012, Beccherle, 2010 and Harstad, 2010] have argued how countries will bias their moves so as to extract concessions in future climate negotiations. For example, under the Poznan Strategic Programme, a \$50 million fund was established to scale up investment in LCT transfer. Beneficiaries included Brazil, Cambodia (technology transfer using agricultural residue

biomass for sustainable energy solutions), Chile (promotion of local solar technologies), China (green truck demonstrations), Kenya, Jamaica (introduction of renewable wave energy technologies for the generation of electric power), Thailand (overcoming barriers to support technological innovation and south-south technology transfer, ethanol production from Cassava), and Sri Lanka (Bamboo processing).

5.5.5 Game theory and domestic action

The climate change negotiations are a collective action problem where, similar to any game, focus is placed on cooperation and on the strategic interactions of individual countries. The welfare of an individual country depends not only on its own emissions of GHG, but also on the emission levels of all other countries. Game theory places focus on the mathematics behind the strategic behaviour of countries, or put another way, the tools to help them to determine what they perceive to be in their best interest. Game theoreticians model the climate negotiations as extensive games of perfect information, applying and analysing solution concepts such as Nash equilibrium and bargaining solutions.

A number of game theoreticians, from the classical co-operative [Barrett, 2007] to the non co-operative authors [Nordhaus and Yang, 1996, Buchner and Carraro, 1995], have applied game theory to the problem of international climate change negotiations given the strategic interdependencies among countries. Such models of climate strategies involved the creation of network incentives for adoption [Barrett, 2005], simulated country pathways for GHG abatement [Nordhaus and Yang, 1996], and explored coalition formation and its impact on outcomes as assumptions change. Such individual game models are based on decisions around different levels of mitigation efforts and are useful for showing what happens to the probability of co-operative outcomes once assumptions are relaxed. Of course, the UNFCCC

negotiations themselves are not a prisoners' dilemma, but addressing GHG in the absence of international coordination is very similar to a prisoners' dilemma, possibly leading to a sub-optimal outcome.

Free-rider effects emerge through voluntary cooperation and influence the negotiations. These effects have a negative impact if one country emits more CO₂ within a commitment period than agreed, and another country could then deviate from their agreed targets to a particular degree in the following commitment period. Attention is being placed on incorporating the appropriate incentives that will get nations to cooperate. This achieves a linking of cooperation on climate change with cooperation on other issues, such as trade ('border tax adjustment') and adaptation finance.

Even with the concentrated effort of country negotiations throughout the past two decades, some game theoreticians argue how governments will most likely fail to conclude a major international treaty to reduce atmospheric concentrations of GHG and, even in the unlikely event of achieving such an agreement, believe it most likely will not work. Universal treaties will either (a) not demand countries to change what they're doing or (b) demand fundamental changes in behaviour without applying credible monitoring and sanctioning provision [Gronewold, 2010].

The climate negotiations pose challenges for game theoreticians as no single model can be readily applied that captures all players' strategic behaviours at play. Game theoreticians find it easier to reach an agreement through modelling artificially symmetric countries rather than modelling agreement as a dynamic process. Achieving agreement on climate change and associated global warming is a "tragedy of the commons" problem and it assumes countries

are symmetric. The effect of climate change unequally impacts upon countries. As Eyckmans [2012] puts it, more research is needed to understanding the heterogeneous players within the negotiations instead of focusing on the symmetric players. This will require other methods beyond the standard analytical tools that are being applied by game theoreticians.

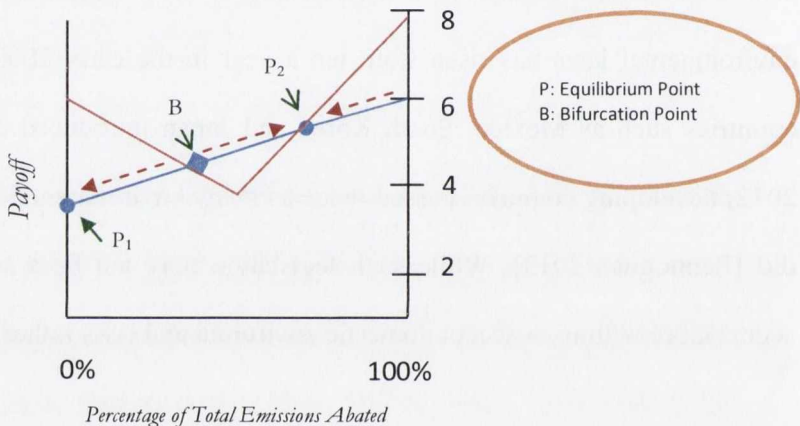
Global problems do not always require global solutions. As key countries are deemed unwilling to take on burden-sharing the validity of such an international approach to agreement is being questioned. National policy makers are arguing that legal activism through domestic laws, rather than a global agreement, is the approach to fight negative effects of climate change. In a Globe study of 33 countries, the number of new domestic environmental laws has risen from ten a year in the early 2000 to twenty in 2012. While countries such as Mexico, South Korea and Japan introduced environmental legislation in 2012, developing countries passed twice as many environmental laws as developed countries did [Economist, 2013]. While such legislation may not be a suitable measure, the public seems more willing to accept domestic environmental laws rather than international ones.

5.6 Proposing a more flexible approach

This section of the chapter reframes the UNFCCC architecture by proposing a portfolio approach. This represents a hybrid [Rajamani, 2010] between a ‘pledge and review’ (type) bottom-up approach to emissions reduction and top-down targets and timetables (as seen in a second commitment period Kyoto type model). It tailors targets to the needs of countries and so reflects the complexity and uncertainty of projecting emissions for developing countries [Neuhoff, 2009]. It adopts a pledge and review approach, reflects differentiation across developing countries and applies a new spectrum of emissions whereby national competitiveness can be maintained.

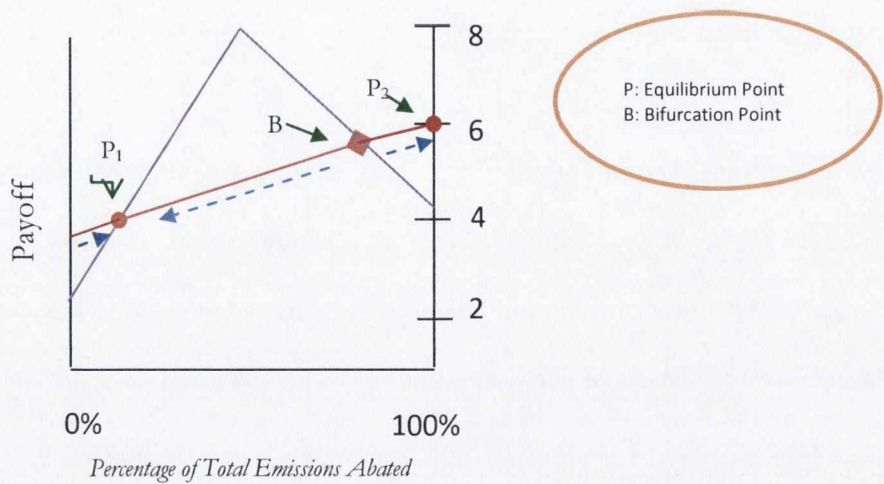
Figure 5.3 (expanding 5.1 and 5.2) outlines this new flexible approach, presents the implications of a non-monotonic function, and illustrates the payoffs for a single country. The optimal portfolio may depend on the risk in climate damages, and this does not change monotonically in risk. Considering the international climate negotiations at a global level, the incentive for parties to abate increases, their negotiation strategy is pushed to the right (to P_2) and their percentage of emissions abated increases.

Figure 5.4: A model with a concave non-monotonic polluting payoff function



Figures 5.4 and 5.5 present two negotiation points or mitigation policy options with non-monotonic payoff function. The figures have a dashed red line to represent the payoff under a 'pollute' strategy and a blue line to represent the payoff ('y axis') under an 'abate' strategy. These lines are functions of the percentage of total emissions abated, the 'x axis'. P_1 and P_2 reflect the two equilibrium points.

Figure 5.5: A model with a convex non-monotonic polluting payoff function



Conversely, as the pollute payoff increases (or abate payoff decreases) the strategy is pushed to the left (to P_1) and the country's percentage of emissions abated decreases. Considering the negotiations from a nation state perspective, countries will act differently depending on the payoff that they perceive from their chosen strategy. For example, a country would move from bifurcation point (B) toward either P_1 or P_2 depending on what positive or negative payoff or 'spillover' they can gain. This is often based on socio economic perceptions and perspectives of entry, such as positive gains in terms of jobs, carbon credits, tax incentives or negative gains in terms of increased climate financing.

It may cost more for a major economy, such as Germany, to continue to pursue an emissions abatement strategy, given the competitiveness focus being driven by industry. Germany, as a large producer of photovoltaics, biomass and wind energy, could exceed its emissions target of, say 40%, by say 2016, and could then choose, for competitiveness reasons, that it is no longer feasible (from a payoff perspective) to follow its existing strategy and so moves to a polluting strategy (see Figure 5.4). This decision would require consideration of the political implications [Vogler, 2010] of LCT growth on its economy in the context of the cost of

potentially continuing to abate for little reward or payoff. The domestic landscape is important as countries assess what can be agreed in the context of what can be ratified by their government at home [Putnam, 1988].

Figure 5.5 presents another new scenario with a convex non-monotonic polluting function and a new game in the context of non-monotonic payoff function is incorporated. It highlights when a bilinear polluting function, the bifurcation point (B) exists as countries can select their strategy based on perceived 'spillover' advantages. Spillovers incentivise strategy choice through enhanced investment in new frontier LCT. For example, a country may revert to a pollutant strategy if they deem it more economically advantageous than following a course of emissions abatement. A country would be pushed to the left (away from B) and towards P_1 . In such a model, rather than having a harmonised global goal of emissions reduction, (say 20%), we could apply a country based pledge approach, say 15% and 20%.

5.7 Conclusion

Chapter 5 analysed the latest developments within the international negotiations. It acknowledged the challenge of defining the required architecture to curb the imminent impact of growing CO₂ emissions. It identified a number of challenges that could hinder the achievement of a strategy based on the objective of achieving a single harmonised top-down agreement, similar to the Kyoto Protocol type model. The chapter suggests that a reframed architecture could consider the role of national, bilateral and multilateral action and the importance of incentives, such as spillovers, to entice the engagement of countries. It incorporated a new game theory model and presented a new scenario with a non-monotonic polluting function. It reframed the climate agreement architecture by proposing new dimensions that could add flexibility.

Chapter 6

Conclusions

Global environmental, energy security and competitiveness challenges are influencing decision-making by politicians, policy makers, industrialists and consumers. Society is aware of the importance of reducing fossil fuel dependence in light of finite fossil fuel reserves and increasing energy bills. This realisation is underpinned by an austere economic environment where the achievement of affordable energy and delivery of sustainable employment are key drivers. A combination of these aspects has contributed to a search for alternative energy means that has resulted in an accelerated deployment of low carbon technology.

Clean and efficient energy technologies have the ability to meet emerging societal challenges that range from enhancing competitiveness, to limiting vulnerabilities associated with fossil dependence, and addressing the threat of growing emissions. An accelerated growth and deployment of low carbon technologies has the potential to reduce global carbon emissions by a third and would benefit 1.4 billion people who currently do not have access to the grid. The utilisation of such LCT can mitigate the negative climate effects in countries and regions that are currently dependent on hydro carbon systems. They can facilitate an exploitation of existing and new sources of energy by allowing cheaper, cleaner and efficient ways of converting energy into desired end use services.

Scientists have estimated that two thirds of this century's warming is dependent on what is discharged in the coming two decades, leading energy commentators to highlight the significant role that developing and emerging economies will play in our future energy

systems. Such growth provides opportunity for investors in clean technologies, especially aware that technology leapfrogging can enable wider deployment of LCT as developing nations learn from the deployment experiences of developed nations. A number of barriers and obstacles are encountered that hinder this deployment, while the tools to enable full transfer of LCT differ significantly across countries. Government action or inaction will play a vital role in determining success.

Through an exploratory approach and a methodological analysis, this thesis focused on the deployment and acceleration of low carbon technologies. This analysis was placed in the context of meeting climate stabilisation objectives, developing pathways to meet future energy demand while ensuring security of supply, and, indirectly, strengthening the competitiveness of industry and business that benefits from wider LCT deployment. It involved a multi-scale analysis of the international acceleration and deployment of low carbon technologies. The research presented the importance of LCT in terms of an emerging energy revolution where clean technological sources can minimise fossil fuel dependence and address the threat of climate change.

6.1 Methodological review

The thesis began by setting the context and tracing the progress of low carbon technology as a key building block within the international climate regime. It provided an analysis of the growth of technology as an emerging force under the UNFCCC architecture. It acknowledged the challenge of agreeing the required architecture to curb the imminent impact of growing CO₂ emissions.

The thesis' exploratory analysis had two components: it considered the factors that influence low carbon technology take-up in a developed market (Chapter 2) and identified a number of barriers that could hinder such LCT deployment within developing and emerging markets (Chapter 4). The deployment and acceleration of LCT was explored within a mature technology market (Ireland) and in less mature markets (5 developing and emerging economies). The factors that influence the proliferation of technologies and those that may restrict the international deployment of LCT at a global level were determined.

This analysis highlighted the anticipating increase in demand for energy services across developing and emerging economies. While such development brings opportunities for low carbon growth and the acceleration of advanced technologies to meet emerging needs, it also brings challenges to the countries' regulatory, legal and policy frameworks. Through an exploratory analysis of five developing and emerging countries, the thesis showcased the financial, regulatory and institutional barriers that may prevent the utilisation of low carbon technologies. Uncertainty exists within these countries government policy makers incentivise technology push but fail to interact with stakeholders in formulating and adopting the use of these technologies. The research extrapolated a number of lessons resulting from this exploratory analysis.

Chapter 3 proposed a procedure to analyse and predict customers' choice of low carbon technologies using artificial neural networks. Through a modelling-based contribution, it analysed two case studies of domestic dwelling heating in Ireland, utilising the data set of 31,560 technology choices that formed the exploratory analysis within Chapter 2. The results indicated that an artificial neural network (ANN) model can be successfully implemented to predict consumers' choices of low carbon technology. This procedure serves as a framework

for better understanding the various factors that influence consumer selection of one low carbon technology over another.

Finally, the thesis considered the mechanisms, institutional arrangements and international architecture, required to facilitate international LCT acceleration and deployment (Chapter 5). A political economy analysis of the climate change architecture was conducted, including the process of negotiation towards a second commitment period of the 'Kyoto Protocol'. As a mechanism to establish an environment for accelerating LCT on a global scale, the thesis assessed the UNFCCC's current approach and reframed the climate agreement architecture by proposing new dimensions that add flexibility and so could encourage a faster deployment of LCT.

The thesis analysed a number of existing game-theoretical models and considered if they had a role in the climate negotiation strategies. The intent was to use various game theoretical tools as an approach to position an architecture where agreement could be more easily achieved and LCT deployment could be enhanced. It involved developing a new model based on game theory learning and reframing the climate agreement architecture by proposing new dimensions that could add flexibility.

6.2 Chapter review

Chapter 2 began with an exploration of the factors that may influence the choice, take-up and acceleration of LCT. It identified the action that is required to erode barriers to deployment, thereby stimulating low carbon growth. It reflected the findings from research commissioned by the IEA [2008] where non-economic barriers impact on the success of policy incentives

irrespective of their design, and draws attention to the importance of the country-specific contexts.

Through an exploratory analysis of renewable heat deployment policies in Ireland, the thesis found that government energy policies tend to target GHG emission reductions and the achievement of energy savings. They fail to exhibit a full understanding of the determinants that consumers consider when making technology choices. Such determinants influence consumers' decision-making as they attempt a transition from fossil to low carbon technology. They also determine what influences their selection of one LCT above other technology types.

The results of the quantitative analysis (Chapter 3) reiterated the complexities of consumer choice as it tested a variety of determinants by analysing and predicting the process of LCT selection.

Chapter 4, through an exploratory analysis of five projects within developing and emerging economies, categorised a number of barriers that are hindering the deployment and acceleration of LCT. Findings mirror those of the UNDP Technology Needs Assessments Synthesis Report [2010], where economic and market conditions, information and awareness were identified as key barriers to LCT transfer. Methods to overcome financial barriers were identified that included strengthening local capability, making financing schemes available, and utilising economic appraisal methodologies that enhance the capacities of policy makers and practitioners.

Chapter 5 identified a number of challenges that could hinder the achievement of a single harmonised top-down agreement, similar to the Kyoto Protocol type model. In analysing the latest developments within the international climate change negotiations, a number of potential obstacles were presented that stem from the ‘global commons problem’ to the enhanced economic ‘differentiation’ among developing countries. Accepting that countries will reject an international climate agreement or obligation that is seen as inimical to their economic competitiveness, the chapter framed the importance of such considerations within an international agreement or obligation.

The chapter found that the cost implications on a countries’ national autonomy versus the benefits of a global agreement remain a key and growing consideration for major economics. It reflects progress made within the ‘Doha Gateway’ deal, acknowledging that future climate agreements must consider country differentiation across their emission profiles and changing economic circumstances.

6.3 Key Findings

- While economic factors are important with regard to technology deployment, a much broader variety of determinants is required when analysing the process of adoption of technology.
- Policy makers often misunderstand the heterogeneity of actors and their preferences and fail to exhibit a full understanding of the determinants that consumers consider when making technology choices. They also under appreciate the multi-agent decision nature of technology choice and interaction, as well as the complexities of consumer choice and household behaviour.

- An artificial neural network (ANN) model can be successfully implemented to predict consumers' choices of certain low carbon technologies with high accuracy.
- Local stakeholder engagement, training and experience exchange are often underestimated by implementers and are significant barriers to LCT deployment.
- National interests remain active considerations for major economies in determining their approach to emissions reduction and they will ultimately determine a country's future emissions abatement strategy. As countries assess and determine various negotiation positions (chosen abatement strategy), they consider economic benefit, or differential cost, of abating early, or abating late. This includes the perception of benefit-to-cost in relation to the action, or failure to act, of other nations..
- A new scenario with a non-monotonic polluting function can reflect country differentiation and present a new flexible architecture. Such flexibility could enable a consideration of a country's political and economic circumstances and capabilities.

6.4 Recommendations

In their attempts to make energy policy and establish technology related goals across sectors, policy makers should consider both economic and non-economic determinants when delivering technology deployment schemes. The thesis identified a broad variety of variables and determinants that may be required when analysing the process of technology adoption. While financial determinants are important, policy makers should consider the influence of social determinants, product reliability, product support systems, consumer confidence, environmental awareness and impact assessment in determining consumers' low carbon technology choice.

Previous researchers have written extensively about the unrealistic representation of consumers when both choosing technologies and ascertaining the impact of different policy instruments. Policy makers should consider how consumers will respond to certain technologies over others. As a result, future Government policies aimed at accelerating the deployment of LCT should consider how household behaviours, decision making choice frameworks and associated barriers result in consumer uncertainty. Indeed, a questionnaire survey targeting consumers could be considered to assist in determining the various influences on consumers' decision to deploy low carbon technologies.

In identifying the impact of various barriers that are encountered when deploying low carbon technologies, the thesis discounted the logical framework and outcome mapping approach and recommended the application of a 'synthesis' approach. Extending the findings regarding the impact of non-economic determinants in consumer low carbon technology selection, the thesis recommended that project assessors and policy makers consider the non-technical aspects of projects. It highlighted the role of implementation actors and championed the requirement for locally appropriate indicators and engagement with local market systems in impact assessment.

A number of potential actions were recommended that could aid policy makers, market actors and technology innovators. These include the replication of EU best practice policies and regulations for energy use, the development of incentive schemes and support structures to assist with the roll-out of LCT, the education of consumers to raise awareness of LCT deployment and the development of technology performance standards to provide consumers with guarantees of minimum levels of performance.

In reframing the international climate architecture, the thesis recommended that any future agreement should consider the role of national, bilateral and multilateral action and incentives, to entice engagement of all countries. Determining the cost of first mover abatement advantages versus the cost of delaying their emissions abatement strategy has implications for the impact of LCT at an international level. The thesis recommended a reframing of the UNFCCC climate agreement architecture by proposing new dimensions that could add flexibility through adoption of a 'pledge and review' approach. This involves accepting differentiation among countries when setting targets, enabling a more speedy acceleration of low carbon technologies.

Flexibility should feature within a country's emission reduction commitments, enabling a consideration of a country's political and physical circumstances, capabilities and legal systems. Such flexibility considerations involve equity principles, such as the concept of 'progressivity' where emissions can be adjusted based on per capita income alongside targets becoming more stringent as countries become wealthier.

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