Report No. **196**

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Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Climate Technology - Realising the Potential

Authors: Fionn Rogan, Paul Bolger and Brian Ó Gallachóir.

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

www.epa.ie

ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA) is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

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Regulation: *We implement effective regulation and environmental compliance systems to deliver good environmental outcomes and target those who don't comply.*

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- large scale industrial activities (*e.g. pharmaceutical, cement manufacturing, power plants)*;
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- the contained use and controlled release of Genetically Modified Organisms *(GMOs)*;
- sources of ionising radiation *(e.g. x-ray and radiotherapy equipment, industrial sources)*;
- large petrol storage facilities;
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The EPA is managed by a full time Board, consisting of a Director General and five Directors. The work is carried out across five Offices:

- Office of Environmental Sustainability
- Office of Environmental Enforcement
- Office of Evidence and Assessment
- Office of Radiological Protection
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet regularly to discuss issues of concern and provide advice to the Board.

EPA Research Programme 2014–2020

Climate Technology – Realising the Potential

(2012-CCRP-FS-10)

EPA Research Report

Prepared for the Environmental Protection Agency

by

University College Cork

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ACKNOWLEDGEMENTS

This report is published as part of the EPA Research Programme 2014–2020. The programme is financed by the Irish Government and administered by the Environmental Protection Agency, which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to thank the members of the project steering committee (Frank McGovern, Gemma O'Reilly, Ian Hughes, Matthew Kennedy, Orla O'Brien and Phil Hemmingway) for their guidance and feedback during all stages of the project. Special thanks are also due to Mark Sweeney, Enterprise Ireland, and to the many researchers and staff at all the research organisations, agencies and institutes cited in this report who were very generous with their time. Thanks to the Sustainable Energy Authority of Ireland for hosting the Climate Technology Conference and Stakeholder Event in November 2014, and to all the speakers and the audience who participated in that event. Finally, thanks are due to the staff in the Department of Jobs, Enterprise and Innovation who provided feedback on an earlier version of this report.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholers on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA RESEARCH PROGRAMME 2014–2020
Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-84095-676-4 September 2016

Price: Free Online version

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Executive Summary

Climate technology has been defined as "technologies of relevance to climate change mitigation and adaptation" (Ockwell *et al*., 2014). The term has commonalities with "cleantech", "green technology", "low-carbon technology" and "environmental technology", and also includes adaptation technology and technology for understanding climate change dynamics and impacts. Ways for the world to limit future global warming to below 2ºC rely on the large-scale deployment of many existing and new climate technologies far beyond current deployment trends. The economic impact of such deployment is generating a growing body of research, which organisations such as the Global Commission on the Economy and Climate say has a strong positive economic impact.

In 2012, the EPA funded the Climate Technology Fellowship with the aim of investigating the potential for climate technology in Ireland. Analysis was based on a broad survey of current and recent climate technology research in Irish tertiary education organisations and institutes, and of climate innovation and technology use in the private sector. A technology innovation system framework was employed to explore strengths and weaknesses in climate innovation across sectors.

This report groups climate technology opportunity areas into the following categories: agriculture and land use; climate services; water and wastewater; smart buildings; marine sector; and transport and air quality (Figure ES.1). It focuses on the opportunities such as reduced emissions and energy consumption, value chain economic opportunities and co-benefits.

Agriculture and Land Use

A range of agriculture technologies being developed in Ireland could both reduce the country's carbon footprint and emission intensity and have potential environmental co-benefits on water, air and land use. The agriculture sector is also the source of a great variety of bioenergy feedstocks that could be exploited for all types of energy use. Sufficient government incentives (e.g. renewable heat) could make a positive contribution to this opportunity. Mitigation of greenhouse gas emissions through land use management (e.g. peatlands management, rewetting) is an active research area, as are space technologies combined with on-the-ground sensors to generate information products that help improve management and adapt to short-term weather shocks and long-term climate trends. While some of these technologies have been deployed by agriculture companies (particularly efficiency technology), the sector's climate technology potential remains underdeveloped. New business models are required. There have been a number of sector-wide successful management and accreditation schemes (Origin Green, the Carbon Navigator), which could be readily adapted to new business models that emphasise sequestration. Sequestration is likely to gain more emphasis in future, driven by domestic legislation and European policy. For new land use technologies and methodologies, the business models for companies remain uncertain and the sector is dominated by the large state companies Coillte and Bord na Mona. Leadership from the government can play a crucial role here.

Climate Services

The opportunity for Ireland is two-fold, comprising both *need* (such as improved climate resilience of Ireland's agriculture and land use) and *capability* (from internationally renowned centres such as Mace Head, together with a host of other research units in Irish universities and colleges, as well as a vibrant and active information and communication technology sector) for solutions. Research and commercial activity are evident. However, a disconnect between the two is leading to lost opportunities. While there are some climate services technology companies, they have little connection with innovative research. Many climate services applications will require either innovative business models or new types of markets (e.g. local emissions trading markets). Some research is already finding users (and a market) outside Ireland. A national strategy for development of this sector is needed.

Whereas climate services research tends to focus on innovative use of earth observation data and ground measuring devices, climate services companies tend to focus on established data sets and client-focused advice. There is a great opportunity for fruitful collaboration between research units and companies. National

Figure ES.1. Wordle summary of the climate technologies investigated.

or local government entities are very likely to use climate services technology, because it can be used for climate adaptation. Therefore, government policy and resources for climate adaptation will be a key enabler for this industry.

Water and Wastewater

Research in Ireland includes projects on individual technologies and projects focused on the integration of technologies into an effective smart water management system. Data from the USA has shown that water and wastewater utilities use 2% of generated electricity. The potential for new technology to reduce the energy intensity of wastewater treatment in Ireland arises from technologies such as anaerobic digestion, applying energy efficiency principles, application of sensors, use of nano-materials and recycling of sludge. There is significant research activity on water and wastewater in Ireland, with a high degree of collaboration with the private sector. Despite being identified as an opportunity area in the literature, water-related technology was not cited as an explicit priority area in the Research Prioritisation Report (Forfás, 2011a). Innovative climate technology has been deployed in the agri-food sector, in which large volumes of water are used; these are largely efficiency solutions. Other potential users of water technology are utilities and local authorities responsible for water management. The water sector in Ireland is applying technology solutions to many climate adaptation challenges. Again, many of the most innovative solutions are emerging from collaborative projects of teams from different types of organisations. Green public procurement is expected to be the main user of climate technology, so its role in supporting technology diffusion is important.

Smart Buildings

Smart buildings are an enormous opportunity area owing to the number of buildings and the increasingly urgent need to decarbonise the buildings (and heat) sector. Ireland has a thriving information and communication technology sector, and many researchers and companies are developing technologies that will optimise the use of energy in buildings. There is good collaboration in this sector between researchers and private companies. Many companies are active in this field, although the more innovative technologies tend to be for industry and to a lesser extent for the commercial sector. For the commercial and domestic sectors, a much larger cohort of companies is active, with pre-existing energy-efficient technology.

Linking information and communication technologies (such as sensors and control algorithms) to energy services in buildings presents an opportunity to optimise the energy use of new and, more importantly, pre-existing buildings. However, it is questionable if more advanced technologies will make a major breakthrough. Established building technologies have not been deployed at the expected rates, even when the technology is economically viable. Despite many demonstration buildings, building users have been slow to adopt the optimising technology. This is a challenge that technology researchers need to address in collaboration with industry partners. Government policy on procurement and standards could play a key role.

Marine

The marine sector provides opportunities for climate technologies such as energy device design, mooring anchors and foundations, device materials and marine bioenergy. There is also a range of climate service adaptation technologies such as those that make use of earth observation of coastal areas to help prediction of storm swells, provide decision support for the Irish Coast Guard and monitor other coastal parameters. There is a diversity of climate technology – both mitigation and adaptation – for the marine sector. Through research centres (such as Marine Renewable Energy Ireland), collaboration between research and industry is taking place and research capacity is growing. A research centre approach particularly helps international collaboration, which, in a sector such as marine renewable energy, is particularly important for scaling up technology development.

Transport

The transport sector is one of the most challenging parts of the energy system to decarbonise. One of the main co-benefits of a decarbonised transport sector is improved air quality. Ireland's air quality is generally good in comparison with other European countries and EU limit values. In 2014, World Health Organization guideline values for protection of human health were exceeded at several sites for ozone, particulate matter (fine dust) of 10 µm or smaller and particulate matter of 2.5 µm or smaller.[1] Modifying existing technologies to be less damaging to air quality presents an opportunity for both transport research and air-quality monitoring research.

A broad range of technology is being researched at Dublin City University, University College Cork, the National University of Ireland Galway, Dundalk Institute of Technology and elsewhere. Topics include fuel cells, hydrogen cars, nano-electronics for electric vehicles, compressed natural gas, photovoltaic charging for electric buses and biogas. However, unlike similar research in the UK, there does not appear to be large-scale engagement with industry. This is arguably in large part because of the different traditions in transport engineering manufacturing. Ireland's transport sector is dominated by a number of state-owned companies, which are slow to change to new technology. These are predominantly service companies rather than technology producers. There is very little indication that Irish transport companies are trialling new technologies that are being developed in Irish research institutes. Government leadership and resourcing could enable and encourage innovation in this sector.

Government

The government has a key role to play in supporting climate technology innovation, enterprise and deployment. For many climate technologies, national or local governments and even state-owned companies are key customers, so government procurement policy can have a great impact. Given the current emphasis on cost in public procurement and the weakness of "green-directed" government procurement, there may be potential for government policy to support the young climate technology sector more carefully.

These opportunities are in areas in which climate change challenges and climate change research strengths are aligned. They are also opportunities in that the technologies are not fully developed (i.e. market ready) yet. Technology improvement and cost reductions happen for a number of related reasons, including research and development, learning by doing and consistent policy, which supports a growing market. While there is consensus that both technology-push and market-pull dynamics are required to achieve successful innovation, the precise contribution from each will vary according to the technology and local conditions.

A very broad range of companies in Ireland are developing, or working with, technology that has a direct relationship to climate change. While certain companies and sectors (e.g. power generation companies) are more directly engaged with climate change than others (e.g. pharmaceutical companies), more and more types of companies are bringing climate change into their business models. To capture and describe the diversity of these companies, a climate technology company catalogue was prepared that categorised 261 companies into seven sectors and described each with one or more tags. These climate technology companies are actively

1 In 2014, no levels above the EU limit values were recorded at any of the ambient air quality network monitoring sites, but the tighter World Health Organization guideline values for protection of human health were exceeded for ozone and particulate matter (fine dust) at several sites. The European Environment Agency reference levels for polycyclic aromatic hydrocarbons were also exceeded at several sites.

involved with different parts of the value chain and with different products and services.

In terms of location, most of the climate technology companies in the catalogue are indigenous Irish-founded companies. While a map of these companies by location shows a concentration in the cities (Dublin, Cork and, to a lesser extent, Limerick and Galway), they are broadly spread across the country; see Figure ES.2.

Technology Innovation Systems

Innovative technologies arise from technology researchers, technology companies and the policies that enable their dissemination. The integration of these dynamics can be readily examined with an innovation system framework. Such a framework helps to systematically identify the innovation management ingredients that are required for innovation. A climate technology innovation system will include all the necessary actors, put a price on externalities (e.g. carbon emissions) that can act as a market signal (i.e. market pull), align long-term targets with short-term policies (i.e. consistency in policy), focus on investment and be locally focused and driven.

Some insights can be derived from benchmarking Ireland internationally against key countries, for example, the importance of long-term policy, consistent innovation policy, the importance of co-operation and the potential of the cleantech and green economy sectors.

Ireland has been cited as a country with better green performance than perception, which points to an "urgent need for better strategic communications and information exchange of their green merits and associated investment opportunities" (Tamanini *et al.*, 2014). This has implications for the marketing of Irish products and the ability of Irish researchers to collaborate internationally. The government could assist with better communication in this regard.

For Irish companies in general, a number of indicators show lower levels of collaboration (1) between industry and university (for indigenous firms, that is 99% of firms in Ireland), and (2) between universities and government bodies, as measured by joint publications and joint patents. For better collaboration nationally, building coalitions around climate change challenges could be a forum and a mechanism for enabling engagement.

International collaboration opportunities lie with Climate-KIC (Knowledge and Innovation Community) and the United Nations Framework Convention on Climate Change (UNFCCC). Climate-KIC is Europe's climate innovation laboratory and was set up by the European Institute for Innovation and Technology. While there is no Climate-KIC centre in Ireland, a regional implementation scheme was launched in 2014 and there is now potential for involvement via Sustainable Nation and Energy Cork.

There are opportunities for international activity through participation in the UNFCCC technology activities, which arise from some of the activities mentioned at the start of this report and through engagement with the UNFCCC Green Climate Fund. These can offer a stepping stone to the growing market for climate solutions in developing countries. The main UNFCCC technology transfer mechanism is the Climate Technology Centre & Network (CTCN). The CTCN is currently fielding requests for assistance from developing countries and the number of requests is expected to grow over time. There are opportunities for Irish companies, universities, non-governmental organisations and firms to participate by becoming members of the network. On 8 February 2016, the Environmental Research Institute at University College Cork became the first Irish member of the CTCN.

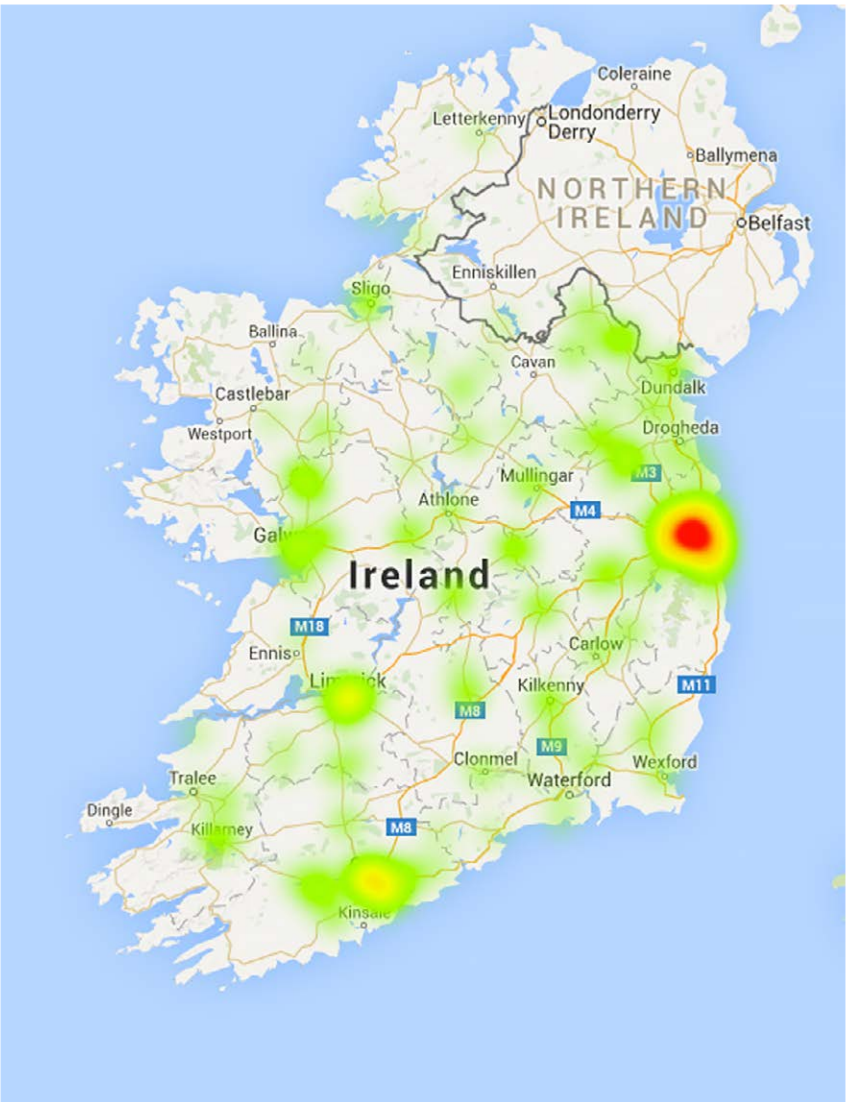

Figure ES.2. Heat map of a sample of climate technology companies in Ireland.

1 Background and Project Description

1.1 Climate Change

In its latest assessment report (AR5), the Intergovernmental Panel on Climate Change (IPCC) clearly articulated the consequences of climate change arising from the world's current pathway of development: "It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise. Climate change will amplify existing risks and create new risks for natural and human systems" (IPCC, 2014a).

Another AR5 headline statement says: "Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term, and contribute to climate-resilient pathways for sustainable development". Thus the IPCC reaffirmed the potential to address the two broad challenges of climate change mitigation and adaptation through widespread deployment of mitigation technologies and adaptation technologies (IPCC, 2014b).

The IPCC notes the very high confidence (95–100%) that humans are responsible for current climate change, but it does not predict how likely humans are to take appropriate mitigation or adaptation action. That is up to the world's citizens.

In December 2015, delegates representing 196 countries finalised the text of the Paris Agreement, which described a wealth of mechanisms for "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C". Central to the mechanisms in the Paris Agreement is the role of "technology transfer" and "technology research, development and demonstration", which together affirm "the importance of fully realizing technology development and transfer in order to improve resilience to climate change and to reduce greenhouse gas emission" (UNFCCC, 2016). This report examines the role that both developing and deploying technology can have in Ireland's response to climate change.

1.2 Climate Technology

Climate technology has been defined as "technologies of relevance to climate change mitigation and adaptation" (Ockwell *et al*., 2014). As a category, it overlaps with cleantech, green technology, low-carbon technology and environmental technology. In addition to these, it also includes adaptation technology, together with technology for understanding climate change dynamics and impacts. In terms of usage, the category *climate technology* is most prevalent at meetings of the United Nations Framework Convention on Climate Change (UNFCCC), which hosts country-to-country discussions and negotiations on technologies to help achieve climate targets and on technology transfer needs between countries. The UNFCCC envisages future pathways whereby the world limits global warming to 2°C. These rely on ambitious levels of large-scale deployment of many existing and new climate technologies far beyond current deployment trends. This in turn will require much technology transfer, which the UNFCCC also facilitates through its various partnership mechanisms.

The impact of technology on productivity has long been a driver of economic growth. It is therefore uncontroversial to say that the widespread diffusion of climate technology (i.e. low-carbon technology), above and beyond a business-as-usual rate of diffusion, will have major implications for global economic growth. There is a growing body of research on the economic impact of such deployment. High-profile projects such as the New Climate Economy have recently argued that there is a strong positive economic argument in favour of climate technology (Global Commission on the Economy and Climate, 2014).

1.3 Climate Technology Fellowship

As one of the government agencies responsible for leading and co-ordinating Ireland's response to climate change, the EPA has a remit to fund climate change research under a number of themes. Under the theme "Socio-Economic and Technological Climate Solutions and Transition Management", the EPA funded the Climate Technology Fellowship in 2012 with the specific aim of investigating the potential for climate technology in Ireland. The Climate Technology Fellowship has four goals: (1) assemble a database on climate technology research in Ireland, (2) carry out a multi-criteria assessment (MCA) of this research, (3) identify technologies at the concept and commercialisation stages, to analyse barriers to success, and (4) conduct outreach with stakeholders. The overall aim of this work is to map the opportunity space for climate technologies in Ireland.

Clear communication of both the climate change challenges and the opportunities is important and necessary. In 2014, the Global Green Economy Index evaluated 60 countries for green economic *performance* and *perception.* Using data from published reports and surveys with key practitioners, the report ranked how countries *performed* as well as how they *perceived they performed*. While some countries performed well and perceived themselves as doing well (e.g. Sweden, Denmark, Germany) some countries performed poorly yet at the same time perceived that they were doing well (e.g. Australia, the USA, Japan). Ireland was one of the exceptions in scoring much better in performance than in perception. According to the report authors, there is an "urgent need for better strategic communications and information exchange of their green merits and associated investment opportunities". The report authors note that Ireland "performs respectably" and has "room for improvement"; more importantly, there are investment opportunities in the green economy that are not fully appreciated (Tamanini *et al.*, 2014). This report intends to explore these opportunities in more detail.

1.4 Climate Change Challenges in Ireland

Climate change presents an array of specific and general challenges for Ireland, which vary according to geography, location, the structure of Ireland's economy and society, and the timelines of the short or long term. Climate change trends in Ireland, such as temperature increase and sea-level rise, are in line with global trends. In the short term they are relatively small and incremental, but in the longer term they are both more uncertain and potentially more damaging. While the mitigation challenge for Ireland is in line with globally agreed targets, it is arguably greater than the challenge posed by adapting to climate change. Many of these mitigation challenges arise from the nature of Ireland's economy and the source of our greenhouse gas (GHG) emissions; for example, Ireland's agriculture sector is responsible for 32% of all GHG emissions, our electricity system is a small poorly interconnected island grid with large amounts of intermittent wind power, and our settlement patterns are distributed and non-concentrated.

Climate change is a global challenge, but its manifestation as a threat is inherently local, with the nature of the danger varying to a great extent with location. For example, if the global average temperature increases by 1.5°C, many small island nations are faced with a sea-level rise that threatens their existence, but most countries are not similarly threatened with extinction from sea-level rise; in contrast, many countries in the Mediterranean face drought from lower levels of rain. Ireland, for example, faces risks to coastal communities from the increased storm surges associated with sea-level rise; recent record-breaking volumes of winter rain (and associated flooding) are consistent with climate change predictions for this country.

1.5 Opportunity Mapping

In outlining Ireland's climate change challenge areas and the associated technology-based solutions, this report maps the climate technology opportunity space for Ireland. Opportunities are understood in terms of both the effectiveness of mitigating or adapting to a particular challenge and also the accrued knowledge from developing a solution that can be turned into an economic activity or product. While a given matrix of challenges will not necessarily map neatly onto a given matrix of solutions, there are sufficient technologies that can contribute to climate change for a mapping exercise to be useful. This project will also prepare and publish a database of what research is being done in Irish universities, colleges and companies.

For Ireland, the opportunity space for cleantech and environmental technologies has been mapped by at least 11 reports since 1999. A Wordle summary of these reports is shown in Figure 1.1. A full list of all the reports cited is in Appendix 1. Many of the technology areas covered in the reports overlap, although there are differences and changing trends over time. The analysis in this report covers some of the previous areas and excludes some of the others. In part this is because of

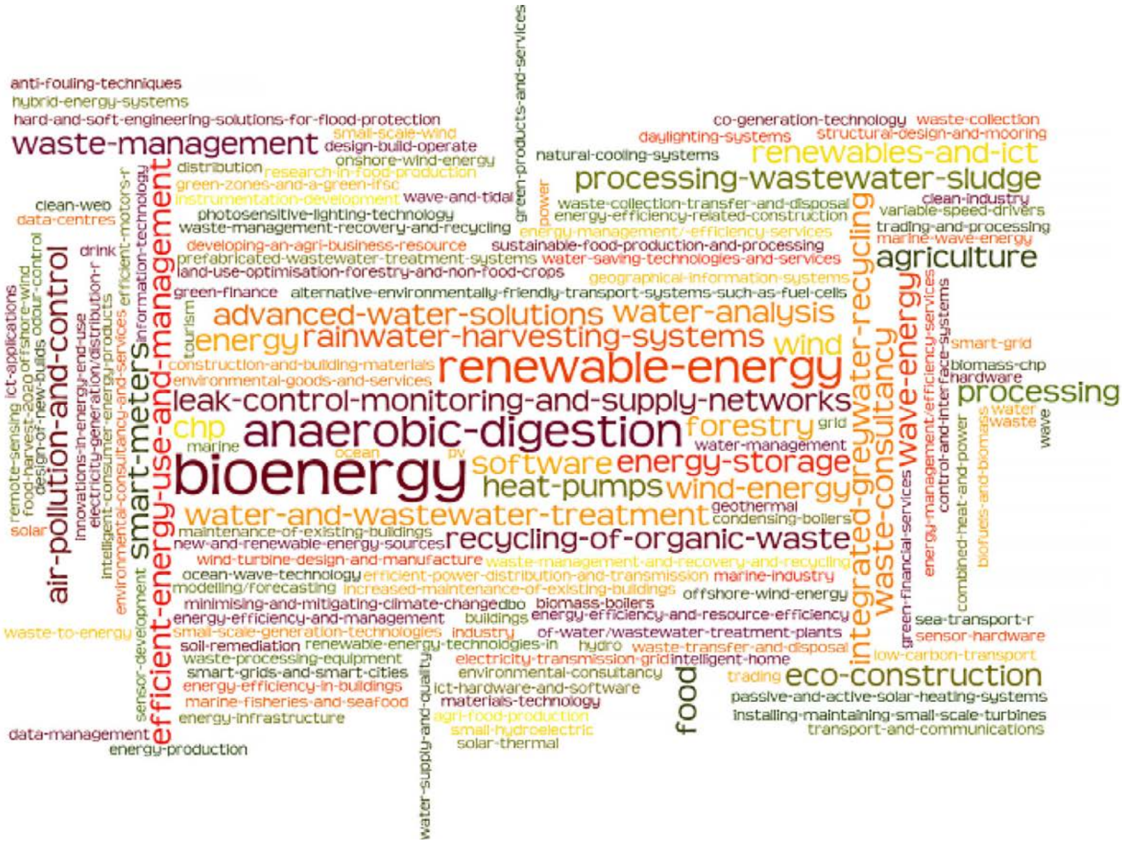

Figure 1.1. Opportunity space.

the time period covered, since some of the opportunity areas (e.g. wind energy) have developed stable and established markets; in other words, wind energy is now a mature industry, and most of the innovation is at the marginal end and in the business model and ancillary services (e.g. forecasting wind speeds). The overlaps and differences between this report and the 11 previous reports will be elaborated on at the end of the report.

2 Climate Technology Opportunities

This report focuses on climate technology opportunities in Ireland that arise from technology development in either tertiary education or private research institutes. The opportunities arise because the technology developed (1) is more effective in addressing particular climate change challenges and (2) accrues associated economic advantages at either national or international level. The areas of opportunity are organised into general technology categories, which encompass specific technology projects, research groups and (in a small number of cases) company collaborations. More specifically, what is meant by opportunity is captured by the range of headings in the MCA, which are listed below. These headings include both economic and environmental criteria.

2.1 Multi-criteria Assessment

Multi-criteria assessment is an established analytical technique useful for (1) understanding issues that are subject to numerous competing and conflicting goals and (2) choosing between alternatives when there is more than a single criterion of importance. For a given project, for which there are a range of alternative options, MCA can formally incorporate the many criteria by which each option is assessed and therefore help the decision-maker to (1) understand how the options compare and rank and (2) make a decision on an objective or data-derived basis. MCA operates by (for a given set of options) attributing a score to each criterion and then (for the chosen array of criteria) assigning a weight to each criterion. This latter feature is useful when technical information is mediated by the values of different stakeholder groups, for example for environmental issues, which by definition will have a range of impacts and stakeholders.

Multi-criteria assessment is a powerful analytical methodology and is appropriate for technology assessment for the following reasons: it can capture a diverse range of data fields, including both quantitative and qualitative metrics and data of diverse levels of certainty; it allows trade-offs between potentially conflicting objectives, especially for environmental and climate-related problems, which tend to be complex and involve multiple trade-offs (Munier, 2011); and it can accommodate broad stakeholder engagement. Its use has been documented in environmental fields (Huang *et al*., 2011), integrated assessment of climate change (Bell *et al*., 2003) and sustainable energy planning (Pohekar and Ramachandran, 2004) and it has been used by such organisations as the World Bank (World Bank, 2010), the Global Environment Fund (GEF, 2012), the US Environmental Protection Agency (Julius and Scheraga, 1999) and the International Institute for Applied Systems Analysis (McCollum *et al*., 2012).

In terms of technology assessment, MCA has been recommended by the UNFCCC (UNFCCC and UNDP, 2010) as part of the technology needs assessment handbook, included in an Energy Research Centre of the Netherlands paper that outlined possible approaches for China in undertaking a technology needs assessment (Wurtenberger *et al*., 2010) and used in a host of other studies (Grafakos and Huijsman, 2010). Some examples from the literature include evaluations of energy technologies in Iran (Talaei *et al*., 2013), domestic energy options in Ireland (Browne *et al*., 2010) and climate change adaptation options in the Netherlands (de Bruin *et al*., 2009).

The analysis presented in this report uses the TOPSIS (Technique for Order Preference by Similarity to Ideal Situation) method. TOPSIS facilitates different scoring methods, finds optimal solutions and is the most objective method (Munier, 2011). Guidelines for including criteria were that they be independent, measurable, non-redundant, operational and manageable. These guidelines were distilled from a number of sources (de Bruin *et al*., 2009; Dolan *et al*., 2001; Wang *et al*., 2009). The criteria selected for the analysis are shown in Table 2.1. Even weighting was adopted for each of the criteria, i.e. each of the 10 criteria was given a 10% weighting in the final assessment.

2.2 Technology Areas

Based on a knowledge of climate impacts in Ireland (EPA, 2009, 2010, 2012; Dunne *et al*., 2009), and a broad survey of climate technology research being carried out in Irish research organisations and institutes, this report groups the climate technology opportunity

Table 2.1. List of mitigation and adaptation criteria

Mitigation
GHG reduction
Energy sustainability
Resource sustainability
Co-benefits
CO_2 cost
Business case
TRLs
Risk
Public acceptability
Value chain
Adaptation
Importance
Resilience
No regrets
Co-benefits
Sustainability
Cost of penalty
Cost of action
TRLs
Information dissemination
Value chain

TRL, technology readiness level.

Table 2.2. Number of adaptation and mitigation projects examined in each category

Category	Adaptation	Mitigation
Agriculture and land use	8	14
Climate services	15	–
Water and wastewater	9	9
Smart buildings	–	18
Marine sector	5	23
Transport and air quality	8	6

areas into the following categories: agriculture and land use; climate services; water and wastewater; smart buildings; marine sector; and transport and air quality. The section about each technology area presents the findings of the MCA together with a summary of who is active in this space, what levels of support currently exist and the status of the technology area compared with the previous reports. A summary of the number of projects is shown in Table 2.2 and a Wordle summary of the climate technologies is shown in Figure 2.1.

2.2.1 Agriculture and land use

Ireland has one of the largest agri-food sectors of any developed economy; it accounts for approximately 7% of gross domestic product (GDP) and 8% of employment in Ireland (DAFM, 2015). This large economic footprint has a parallel in terms of research: agri-food research is carried out in nearly all universities and colleges, as well as the national agriculture and food development agency, Teagasc. Although the agriculture sector alone is responsible for 32% of Ireland's GHG emissions (EPA, 2014a), Ireland's carbon footprints for beef production and dairy production are the fifth- and second-lowest in the world, respectively (Leip *et al.*, 2011). Part of the reason is the predominance of grass (as opposed to feed) in the cattle's diet. However, raising cattle on grass is a weather-dependent activity and as such is vulnerable to the vicissitudes of a changing climate. This was particularly apparent during the weather-induced silage and fodder crisis of 2013 (Kavanagh, 2013), which led to a weather conference that examined lessons from the crisis (Teagasc, 2013).

The mitigation challenges for Irish agriculture are significant. In a detailed survey by Teagasc of existing mitigation technologies, it is very apparent that a "silver-bullet solution" to reduce agriculture emissions does not exist, but a range of "silver buckshot" technologies is required (Schulte *et al.*, 2012). A range of technologies are being developed in Ireland that could reduce agriculture's carbon intensity and footprint.

This review identified a range of technologies in development that could reduce emissions and energy use through increased efficiency, such as using anaerobic digestate as fertiliser, algorithms for managing energy in dairy plants, nitrification inhibitors, sexed semen DNA analysis and genetic analysis of various bovine parameters (see Table 2.3). Most of the technologies have environmental co-benefits for water, air and land use, although, because of the potential for intensification, this finding is dependent on the level of activity.

The agriculture sector is also the source of a great variety of bioenergy feedstocks (cereal grains, crop residues, willow, *Miscanthus*, sugar beet, straw, winter wheat) that could be exploited for all types of energy use types (e.g. electricity, heat and transport), both in the agriculture sector and elsewhere. This finding echoes a consistent finding in the 11 domestic opportunity reports that bioenergy is a major opportunity for Ireland. In addition, because the supply chain is within Ireland, the value chain opportunities from this are significant. Ireland is in the top five countries in the Organisation

Figure 2.1. Wordle summary of the climate technologies investigated.

for Economic Co-operation and Development (OECD) whose energy patents specialise in bioenergy (Hascic *et al*., 2012).

A wide range of technologies are being developed in Ireland for mitigation of GHG emissions through land use management (e.g. peatlands management, rewetting). These range from relatively low-tech management strategies to the high-tech employment of sensors to monitor fluxes in different land types. These high-tech solutions present significant value chain economic opportunities for Ireland, especially through the new sensor technologies that they include. They also assist GHG accounting tools that could enable "new business models for land use sequestration" (Edenhofer, 2014) as part of the broader climate services technology paradigm, which is discussed in section 2.2.2.

Adaptation technologies have the potential to make a real impact on Ireland's adaptive capacity. They build on a number of strengths [information and communication technology (ICT) expertise, agriculture] and bring together a broad grouping of stakeholders [universities, the Irish Centre for High-End Computing (ICHEC), Teagasc]. That area was not highlighted in any of the earlier reports (prior to 2011), although the Research Prioritisation Report does cite "land-use optimisation, forestry and non-food crops" as a critical area (Forfás, 2011a).

Many technologies being developed in Ireland enable improved adaptation for increased resilience to short-term weather shocks and long-term climate trends. While variable weather rather than climate change is often the main driver of the research, in most cases there are multiple benefits. These technologies employ space technologies and ground-based sensors to generate information products for better management. Some examples of these technologies are landcover mapping, monitoring of vegetation seasonality, soil moisture and peatlands subsidence, compiling the national grassland database and mapping grass growth trends (see Table 2.4).

2.2.2 Climate services

In a recently published European Commission "Roadmap for Climate Services", climate services were defined as "the transformation of climate-related data – together with other relevant information – into customised products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large" and were interpreted as having a supportive role in adaptation, mitigation and disaster risk management (EC, 2015a). There is a growing level of interest in the opportunities from climate services and there is significant capacity in Ireland. The technologies in this opportunity area do not, generally speaking, have a mitigation aspect; rather, they are about building strong adaptation capacity through timely generation and delivery of important information. Their information

Table 2.3. Agriculture and land use mitigation projects

Name	Institute
Metagenomic understanding of enteric methanogenesis	UCD
Low particulate and NO_x biomass combustion	Teagasc, Graz University of Technology
Dairy farm energy management	Teagasc, Cork Institute of Technology, Wageningen University
Anaerobic digestate as fertiliser	Teagasc, UCD
Energy crops	Teagasc, Institute of Technology, Carlow, UCD
Cereal grains and crop residues as biomass feedstock	Teagasc, UCD
Biomass combustion of pellets from straw and energy crops	Teagasc
Sexed semen DNA analysis	Teagasc
Genetic analysis of cow parameters	Teagasc
Nitrification inhibitors as soil additive	Teagasc
Willow and miscanthus for electricity production	Teagasc
Winter wheat to bioethanol	Teagasc
Sugar beet to bioethanol	Teagasc
Anaerobic digestion of pig slurry	Teagasc
Carbon restore: the potential of restored Irish peatlands for carbon uptake and storage	UCD
Celticflux: measurement and modelling of greenhouse gas fluxes from grasslands and a peatland in Ireland	University College Cork
Formation for quantifying the influence of disturbance, land use change, soil type and forest age on carbon budgets	UCD

UCD, University College Dublin.

Table 2.4. Agriculture and land use adaptation projects

Name	Institute
EO landcover mapping	UCC
EO peatland subsidence	UCC
EO vegetation seasonality	UCC
Improving grassland inventories	UCC
Global soil moisture product	UCC
National Grassland Database	Teagasc, ICHEC
Management guidance and forecast	Teagasc, UCC, IBM, ICHEC
Trend map	Teagasc, UCC

EO, earth observation; UCC, University College Cork.

value is high for resilience and, in many cases, they cost less than doing nothing.

The climate services opportunity area for Ireland can be outlined in terms of *needs* (such as improving the climate resilience of Ireland's agriculture and land use sector, as outlined in section 2.2.1) and *capability* (from internationally renowned centres such as Mace Head, together with a host of other research units in Irish universities and colleges, as well as a vibrant and active ICT sector). In previous opportunity area reports, climate services were cited (although not by name) for use in various sectors that are in this report (e.g. marine, agri-food, forestry) and were also cited as an opportunity area in terms of ICT hardware, software and sensor development.

Ireland's location on the edge of the Atlantic Ocean is advantageous, and underpinned advances in expertise and technology for atmospheric remote sensing at Mace Head. The resultant increased understanding of climate and atmospheric dynamics helped map the movement of the ash cloud from Eyjafjallajökull. This technology has also contributed to regional climate modelling to quantify and understand the interactions and impacts of many atmospheric variables, and the impact of air pollution such as from ozone and particulate matter of 2.5 µm or smaller ($PM_{2.5}$). The potential for GHG measurement reporting and verification (MRV) can be seen in a collaboration involving Mace Head [National University of Ireland Galway (NUIG)] and the Climate Knowledge and Innovation Community (Climate-KIC), which used atmospheric remote sensing data to inform a simple, online CO_2 indicator.[2] There is potential to use this data to manage adaptation area plans; see examples such as the Adaptation Tool for Local Authorities (ATLA) project[3] and the Open Access Catastrophe Model (OASIS)[4] from the Climate-KIC catalogue of projects .

The building blocks and enabling technologies of an effective climate services infrastructure include data-gathering capabilities, expertise in sensor development and deployment, data-analysis tools and ICT infrastructure. All of these elements are present in Irish universities [National University of Ireland (NUI) Maynooth, University College Cork (UCC), NUIG, Trinity College Dublin (TCD)], specialised organisations (e.g. ICHEC, Teagasc) or private companies (e.g. IBM) (see Table 2.5). However, despite world-class facilities, there is no national strategy for this area.

2.2.3 *Water and wastewater*

Although Ireland is one of the least water-stressed countries in the world (EEA, 1999), the impacts of climate change on the water cycle have already been recorded (EPA, 2009): rainfall has increased (EPA, 2010) and damaging flood events are probably worsening (Adamson, 2014). While the future magnitude of the impact of climate change on rainfall and associated water events remains uncertain (Dunne *et al.*, 2009), there is a clear role for technology both to improve Ireland's capacity to adapt to water-related climate-change events and to contribute to mitigation through more efficient water and wastewater treatment. Water-related technology was not cited as an explicit priority area in the research prioritisation report, but it was highlighted as an opportunity area in nearly all other previous reports.

2 http://co2.climate-kic.org/#Climate%20KIC%20CO2%20Indicator (accessed 15 September 2015).

3 http://www.climate-kic.org/projects/adaptation-tool-for-local-authorities-atla/ (accessed 15 September 2015).

4 http://www.climate-kic.org/projects/open-access-catastrophe-model/ (accessed 15 September 2015).

Table 2.5. Climate services adaptation projects

Name	Institute
Impact of biogenic versus anthropogenic emissions on clouds and climate: towards a holistic understanding	NUIG
Pan-European gas–aerosol–climate interaction study: air pollution–climate interactions	NUIG
Ground-based remote-sensing and in-situ aerosol–cloud synergy for hemispheric trans-boundary air pollution studies	NUIG
OceanFlux: sea spray source function	NUIG
Greenhouse gas and CFC/HCFC trends	NUIG
Monitoring atmospheric composition and climate	NUIG
Air quality – aerosol mass spectrometry	NUIG
Ozone levels, changes and trends over Ireland: an integrated analysis	NUIG
Elucidating the impact of aerosols on cloud physics and the North Atlantic regional climate	NUIG
Quantification of marine aerosol flux and its biological content	NUIG
Modelling the role of clouds in forming $PM_{2.5}$ aerosols	NUIG
CO_2 flux detector	NUIG
CO_2 and ocean acidification	NUIG
Atmospheric chemistry: secondary organic aerosols	UCC
Atmospheric cryochemistry of acid rain	UCC
In-port emissions	UCC
Particulate matter in urban and rural residential areas	UCC

CFC, chlorofluorocarbon; HCFC, hydrochlorofluorocarbon.

This survey of adaptation water technologies found a range of Irish research projects: some focused on individual technologies and others focused on the integration of technologies into an effective management system. Individual technologies include tracing groundwater movements, machine vision in analogue meters, sensors and water quality monitoring devices (see Table 2.6). The integration of these technologies and others that use wireless networks, monitoring regimes and earth observations can help monitor and manage water as a resource, for example within an Irish regional authority (Regan *et al.*, 2013). This system has been called a smart water system and a water-focused climate service. Active tertiary education researchers come from TCD,[5] the Tyndall National Institute (TNI) at UCC,[6] the Marine and Environmental Sensing Technology Hub (MESTECH)[7] at Dublin City University (DCU) and the Nimbus Centre at Cork Institute of Technology (CIT).[8] A number of private research units, such as IBM Research Labs,[9] are active in the area and it is to be expected that the recently announced Irish Water Innovation Fund will soon support the sector.

Figures from the USA indicate that water and wastewater utilities use 2% of all electricity generated (EPA, 2008). This is particularly pertinent to the wastewater sector; many reports point to the potential for technology development to reduce the energy intensity of wastewater treatment in Ireland (EPA, 2011) and to reduce the overall energy consumption and associated emissions. This potential arises from different technologies such as anaerobic digestion, applying energy-efficiency principles, application of sensors, use of nano-materials and recycling of sludge. They can be applied by water utilities, wastewater treatment centres or high water users such as dairy producers and slaughterhouses. Work in this area has been undertaken by NUIG, TCD, the University of Limerick (UL), Queen's University Belfast (QUB) and UCD, and these institutes are scaling up wastewater treatment pilot projects (see Table 2.7).

There have been a number of successful new companies in the water sector, such as the recent UCD spin-off company OxyMem, which uses an aerated filtration system to reduce the energy requirements for wastewater treatment.

2.2.4 Smart buildings

In Ireland, 41% of primary energy use is in buildings (Howley *et al.*, 2014), for heating and services such as lighting and ventilation. Decarbonising these energy services is a central part of mitigating energy-based GHG emissions, and a multitude of technologies already exist, from supply-side to demand-side, that contribute to this mitigation effort. The linking of the latest ICT technologies (such as sensors and control algorithms) to building energy services presents an opportunity to optimise the energy use of new and, more importantly, existing buildings. The opportunity associated with smart use of energy in buildings through energy management, efficient use of materials or ICT controls has been cited in many of the opportunity reports. Smart buildings are also an intrinsic part of smart grids and

5 https://www.tcd.ie/environment/research/overview.php

6 http://www.tyndall.ie/content/water-quality-monitoring

7 http://www.mestech.ie/

8 http://nimbus.cit.ie/water/

9 http://www.research.ibm.com/labs/ireland/applications/water_quality.html

Table 2.6. Water adaptation projects

Name	Institute
EO and geochemical tracing for groundwater detection	TCD
Machine vision monitoring of analogue meters	CIT
Water quality monitoring system	UCC
Novel environmental water quality monitoring system	DCU
Real time monitoring of river catchment	DCU/UCC
Novel continuous water monitoring system	DCU
Contactless oxygen sensor	TNI
Integrated monitoring	DCU
Water system pressure analyser	IBM

TNI, Tyndall National Institute.

Table 2.7. Wastewater mitigation projects

Name	Institute
Activated sludge control	TCD
Improved energy efficiency of waste water treatment	NUIG
Improved energy efficiency of water treatment	UL
Low temperature anaerobic digestion treatment of waste water	NUIG
Waste water treatment	QUB
Waste water treatment	NUIG
Waste water treatment – small scale	UCD
Water treatment sludge usage	TCD
Nano materials for water pollutant treatment	UCC

smart cities, which are cited as technology opportunity areas in other reports, such as the research prioritisation review.

A smart building might rely on sensors that harvest energy from ambient light or building vibrations to power a wireless network that then provides autonomous control of a range of aspects of the building. This could help run a building management system, which would enable the building's energy to be optimised according to algorithms or user requirements. Additional aspects of a smart building might be the ICT architecture that enables integration with a smart grid that then manages the inflow and outflow of energy. The industry sector also uses smart technologies in data centres, heating, ventilation and air-conditioning (HVAC) diagnostics and production systems.

From a climate-technology perspective, the key to smart buildings as an opportunity area is the energy and emission savings and the associated reduced throughput of resources and waste. In addition, smart building technologies have great potential for the value chain, particularly in terms of the services provided, and the co-benefits in comfort and health are also substantial, particularly from warmer and better-sealed buildings with less indoor air pollution.

The possibility of retrofitting existing buildings with smart technologies makes the opportunity particularly significant, because it could affect so many buildings. Many of the projects to date (either in new builds or in existing buildings) have been demonstration projects or pilot projects; this fact emphasises the many challenges in getting beyond the demonstration project stage. One challenge, for example, is accommodating the full range of building occupants and users.

The participants in this include all the major universities [UCC, CIT, Dublin Institute of Technology (DIT), UCD, Limerick Institute of Technology, UL) and a number of private companies, with a particular cluster of activity in Dublin (see Table 2.8). Smart buildings are an evolving climate technology opportunity area, which builds on Ireland's strong ICT sector and diversity of research on energy use in buildings.

2.2.5 *Marine sector*

The impacts of climate change on the coastal area of Ireland have already been recorded, both gradual sea-level rise (EPA, 2009) and record storm surges (Matthews *et al.*, 2014). Current predictions for Ireland's climate are that not only will the sea level continue rising but storm frequency, sea-surge height and extreme wave height will also increase (Dunne *et al.*, 2009). This makes Ireland's marine sector a critical sector in which both climate change mitigation and adaptation technology will be needed.

The Forfás 2011 Research Prioritisaton Report cited marine renewable energy as an opportunity area (Forfás, 2011a) on the basis of criteria that gave importance to areas that are "associated with a large global market or markets in which Irish-based enterprise [...] can realistically compete". It said that marine renewable energy "represents an appropriate approach to a recognized national challenge and/or a global challenge to which Ireland should respond". That conclusion echoed earlier reports from 2009 back to 1999, which cited the marine renewable sector as an opportunity area (DETE, 2009; ICSTI, 1999; InterTradeIreland and Forfás, 2008). The definition of marine sector in these reports was often broader than in the research prioritisation report. This broader definition reflects the level

Table 2.8. Smart buildings mitigation projects

Name	Institute
Appliance load monitoring by power load disaggregation	UCD
Autonomic Home Area Network Infrastructure (AUTHENTIC)	UCC/CIT
Data centre energy usage optimisation system architecture	CIT
Electromagnetic energy harvesting from vibrations	UCC
Embedded systems architecture	CIT
Energy efficient miniature sensors	UCC
Energy harvesting powering sensors	UCC
Energy monitoring and targeting system	DIT
HVAC system monitoring	UCC
Improved building energy management system	CIT
Optimised building operation	UCC
Retrofitting existing infrastructure with sensors	UCD
Sensor architecture	UCC
Sensor control algorithms	UCC
Wireless energy monitoring system	UCD
Wireless sensor networks	International Energy Research Centre
Production floor energy management	International Energy Research Centre

of activity. A notable addition (especially in the context of impacts of climate change) is adaptation, although it is still starting from very little and faces considerable ongoing challenges.

The marine sector presents opportunities for climate technologies such as wave energy, energy device design, array design, offshore wind power, moorings, anchors and foundations, device materials, marine bioenergy, power systems, remotely operated vehicles, sensors and Wi-Fi earth observation (see Tables 2.9 and 2.10). The potential economic opportunity along the value chain for these technologies is high, although the potential energy and GHG savings need to be quantified in the context of complete energy systems. Many of the new power devices present high risks, in contrast with the lower risks of supporting technologies, such as composite materials and remotely operated vehicles. As marine energy is at the pre-commercial stage of marine sector energy [i.e. the technology readiness levels (TRLs) are low; see Appendix 4], collaboration with industry is important. An example of a large-scale collaboration between industry and research is Leanwind. More collaboration should be encouraged.

In addition to the high-profile climate mitigation technologies, there are a range of climate service adaptation technologies, such as those that make use of earth observation of coastal areas to help predict storm swells, provide decision support for the Irish Coast Guard and monitor other coastal parameters. These technologies are particularly important for Ireland given that the sea level is expected to rise and climate change will have other impacts on the coast.

2.2.6 Transport and air quality

Approximately 40% of final energy use in Ireland is in the transport sector (Howley *et al.*, 2014). It is one of the most challenging parts of the energy system to decarbonise, and the analysis from the Irish TIMES (The Integrated MARKAL-EFOM System) energy system model has confirmed this for Ireland. To date, there has been some progress towards Ireland's renewable energy in transport (RES-T) target, but this has been achieved largely due to blending and a double credit. In 2005–2012, just 2.5% of energy research, development and deployment (RD&D) spend in Ireland was in the transport sector, compared with 40% of final energy use (source: SEAI RD&D inventory database).[10]

The transport sector did not featured in the early reports on the potential for green growth, although it has featured in some of the most recent reports (Curtin, 2014; Government of Ireland, 2012). This section outlines

10 http://inventory.seai.ie/ (accessed 23 November 2014).

Table 2.9. Marine mitigation projects

Name	Institute
Optimal design tools for ocean energy arrays	MaREI
GeoWave (moorings, anchors)	MaREI
Develop and optimise carbon-fibre reinforced composite materials	MaREI
Ocean energy supply chain refinement	MaREI
Biogas supply chain	MaREI
Bluepower	Start-up
High-end computational modelling for wave energy systems	UCD
The development of offshore foundation systems for wind energy platforms	UCD
Wave energy device design innovation and optimisation	MaREI
Marine electro-gas	MaREI
Marine renewable energy informatics tools	MaREI
Marine renewable energy devices	MaREI
Novel materials for MRE systems	MaREI
Power take-off and energy storage for MRE	MaREI
Operations support engineering	MaREI
MRE decision support and data management	MaREI
Towards ocean wave energy-potential quantification from a terrestrially-based seismic observation system (Wave-Obs)	UCD
Airborne wind energy using automated parafoil	UL
ROV	UL

MaREI, Marine Renewable Energy Ireland; MRE, marine renewable energy; ROV, remotely operated vehicle.

Table 2.10. Marine adaptation projects

Name	Institute
Use of radar data in flood forecasting and warning in Ireland	UCC
CommonSense: marine sensors	UCC
SAFI (Supporting our Aquaculture and Fisheries Industries)	MaREI
Development of a decision support environmental tool for the Irish Coast Guard	UCC

MaREI, Marine Renewable Energy Ireland.

some of the technologies that are being developed in Ireland. It also finds that the air quality co-benefits from low-carbon transport are substantial.

A broad range of technology is being researched across all of Ireland's tertiary education research institutes. These include technologies such as fuel cells, hydrogen cars, nano-electronics for electric vehicles, compressed natural gas (CNG), photovoltaic (PV) charging for electric buses and biogas (see Table 2.11). This research is taking place in DCU, UCC, NUIG, Dundalk IT and elsewhere. However, unlike similar institutes in the UK, there does not appear to be large-scale engagement with industry. This is arguably in large part because of the different traditions in transport engineering manufacturing.

Although climate mitigation technologies are being developed in Ireland, the TRL distribution in this sector in Ireland is quite low. Ireland has lagged behind in diffusion of established transport technologies that use non-oil-based energy, for example CNG, electricity and biofuels, so there is clearly a need for more policies to help reduce inertia in the transport sector in Ireland.

One of the main co-benefits of a decarbonised transport sector is improved air quality. Ireland's air quality is generally good in comparison with other European countries and EU limit values. In 2014, no levels above the EU limit values were recorded at any of the ambient air-quality network monitoring sites; however, the tighter World Health Organization (WHO) guideline values for protection of human health were exceeded at several

Table 2.11. Transport mitigation projects

Name	Institutes
Nanoporous gold fuel cell	UCC
Construction of a hydrogen car	DCU
CNG vehicles	GNI
Nanoelectronics for an energy efficient electrical car	TNI
Optimal production of renewable gas	UCC
Modelling and design of electric vehicle charging systems that include on-site renewable energy sources	NUIG

GNI, Gas Networks Ireland; TNI, Tyndall National Institute.

Table 2.12. Air-quality adaptation projects

Name	Institutes
Analysis of the development and occurrence of biological and chemical aerosols	UCC
An integrated source apportionment and climatic implications of $PM_{2.5}$ and PM_{10}	NUIG/UCC
Measuring in-port emissions	UCC
Monitoring of gas emissions at landfill sites using autonomous gas sensors	DCU
Air quality–cloud–climate interactions	NUIG
Quantifying trans-boundary air pollution	NUIG
Black carbon	NUIG
Ozone deposition flux to ocean waters	NUIG

sites for ozone, particulate matter (fine dust) of 10 µm or smaller (PM_{10}) and $PM_{2.5}$. The European Environment Agency reference levels for polycyclic aromatic hydrocarbons (PAHs) were also exceeded at several sites (EPA, 2013, 2014b). In addition, driven largely by activity in the transport sector, nitrogen oxides have been rising in the past few years (EPA, 2015). Modifying existing technologies to be less damaging to air quality presents an opportunity for research into both transport and air-quality monitoring (see Table 2.12).

2.3 Summary

Climate technology offers many opportunities to reduce emissions and energy consumption (smart buildings, bioenergy, land use sequestration, marine energy), and opportunities to increase adaptation and climate resilience (earth observation of agriculture, land use, the marine environment and water). The value chain opportunities of climate technology are significant: it can be commercialised, there is demand for it in both domestic and foreign markets and it can provide employment in services, manufacturing and the supply chain. There are multiple co-benefits of climate technologies (land use, water, air quality, biodiversity). Some areas have been included within others; for example bioenergy is included within agriculture (in terms of feedstocks) and transport (in terms of application).

The agriculture and land use sectors offer many opportunities for mitigation and adaptation technology, but in many cases the business models are underdeveloped. Innovative technologies are being developed for the climate services sector in collaborations that are the key for this sector's further development. The water and wastewater sectors present opportunities from both technology development and technology integration, but the new technologies need to move beyond demonstration scale. In the smart buildings sector there are considerable opportunities for deploying new technologies in existing buildings, although these new technologies face the same barriers that existing technologies encounter. The marine sector presents a range of opportunities, although many of the technologies are at an early stage. Technology development in the transport sector is limited, but its deployment could be improved by boosting the visibility of co-benefits such as air quality. Spider diagrams summarising the results for mitigation and adaptation technologies are shown in Figures 2.2. and 2.3. Note that, due to data availability, there are a number of gaps in the figures; however, this does not undermine the underlying analysis.

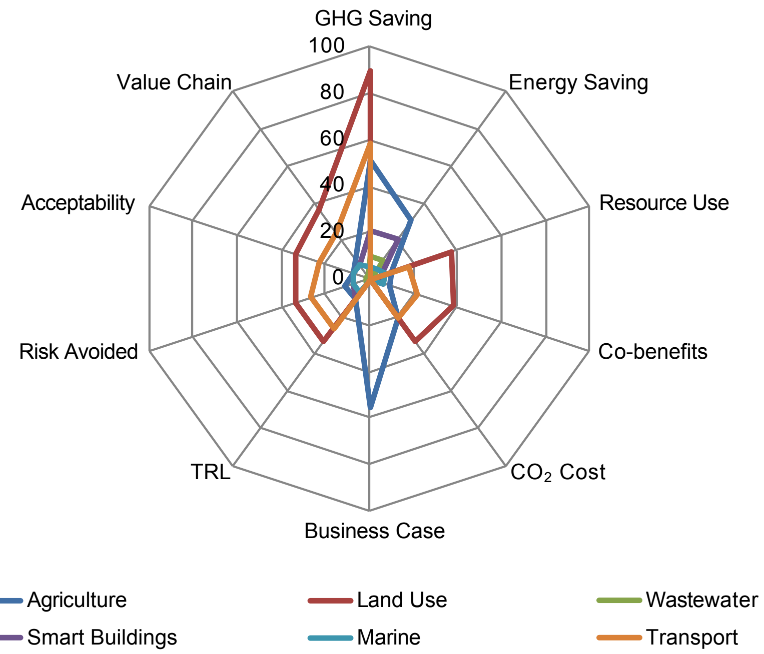

Figure 2.2. Mitigation projects (graph based on maximum score per metric for each technology area).

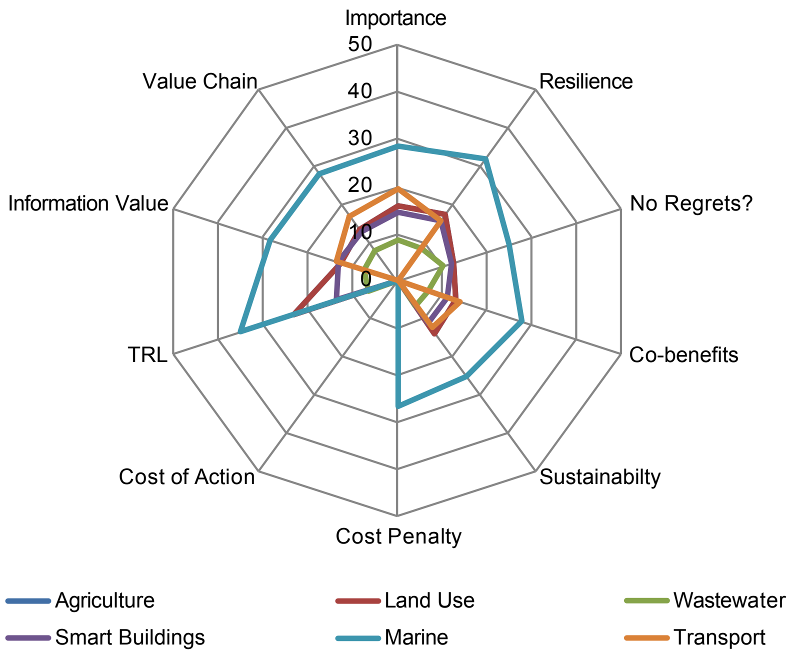

Figure 2.3. Adaptation projects (graph based on maximum score per metric for each technology area).

While all the technology areas have been mentioned in at least one of the 11 domestic reports cited earlier, and often in more than one, the analysis diverges in places from the recent high-profile research prioritisation exercise (Forfás, 2011a). In part this is because of the focus on climate technology, and in part because of the different understanding of technology development, which is underpinned in this analysis with an innovation systems approach. This analysis points to a need to allocate resources and policy efforts better to different classes of technology.

Research and development (R&D) is vital to improve technologies and bring their costs down sufficiently for them to become competitive; however, it is not the case that sufficient R&D will always lead to cost reduction, or that it is the only route to cost reduction. Learning by doing can contribute to reducing technology costs, although there are also exceptions to this, for example as happened with nuclear power in France (Grübler, 2010). As has been shown with solar PV costs, which have dramatically fallen in price in recent years, technology improvement and cost reduction happen for a number of related reasons, including R&D, learning by doing, and consistent policy that supports a growing market.

While many press releases cite green technology areas in which Ireland can become a world leader, the challenges of this approach must be emphasised. Irish government spending on R&D is 1.58% of GDP, well below the EU average of 2.08% (Eurostat, 2015a) and the OECD average of 2.36% (OECD, 2015). Ireland has had success stories (e.g. installation of wind power capacity, CO_2-based car tax), although the lessons from these successes are general rather than specific, for example Ireland is capable of designing and implementing specific programmes of policy and action. While Ireland has made significant advances, it is still lagging behind targets for converting innovation goals into innovation results, and in comparison with competitor countries.

This report has so far outlined the climate technology opportunities associated with technology development that is taking place mostly within research institutes at universities and colleges. Private companies and firms have a crucial role in bringing technology to commercial development status. Therefore, an understanding of the profile of climate technology companies in Ireland is essential. The next section describes a newly developed catalogue of climate technology companies in Ireland, which contributes to this profiling.

3 Climate Technology Companies in Ireland

This chapter describes a catalogue of climate technology companies in Ireland that has been prepared and published separately from this report. The first such catalogue published in Ireland, it is an introduction to the many Irish companies that are building climate change into their business models. The catalogue conveys the breadth of Irish companies that, through their products and services, are developing, deploying or advising on climate change and climate technologies in Ireland and abroad. The catalogue lists 261 companies and includes sector and activity descriptions for each company. Nearly all the companies were founded in Ireland and both large and small and medium-sized enterprises (SMEs)[11] are included.

The data were collated from diverse sources including web searches, online catalogues, industry open days, existing catalogues, published reports and catalogues (particularly from Enterprise Ireland), all of which are in the public domain. Although every effort was made to capture as many companies as possible, it is important to note that this catalogue is not 100% comprehensive; the Irish climate technology sector is too dynamic for this catalogue to be able to account for them all, with new companies being set up every day. This is good news, for the number of companies in this catalogue is only the minimum and it gives a strong indication of the diversity of climate technology companies that currently operate in Ireland.

3.1 Climate Change and Companies

Climate change has become a mainstream issue for businesses. The Paris Agreement endorsed this at the international level and the simultaneous passing of Ireland's Climate Bill was an endorsement of climate change at the national level. While governments will be expected to continue to lead with policy and legislation underpinning both the Paris Agreement and Ireland's Climate Bill, the role of companies and businesses in the day-to-day transactions that will make climate change a truly mainstream issue has to date been underestimated.

Businesses respond to climate change in ways that reflect their global or local footprint. Climate change is a global issue for companies such as Nike and Coca-Cola that have large global supply chains and factories in locations that are particularly vulnerable to climate change; both these companies have restructured their businesses to be more resilient to the impacts of climate change. While the developing world is expected to bear the brunt of climate change, the World Bank has estimated that there is a US$1.6 trillion market for SMEs in the developing world in challenge areas such as water, wastewater, onshore wind power, hydroelectricity, bioenergy and many more.[12]

3.2 Climate Technology Companies in Ireland

A broad range of companies in Ireland are developing technology or working with technology that is directly relevant to climate change. While certain companies and sectors are more directly engaged with climate change than others – e.g. power generation companies compared with pharmaceutical companies – more and more types of companies are bringing climate change into their business models. To capture and describe the diversity of these companies, the climate technology catalogue categorised each company into one of seven broad sectors (Table 3.1) and described each company with one or more tags (Table 3.2).

There are a number of differences between the climate technology research categories in Chapter 2 and the climate technology company categories in this chapter (see Table 3.3). The climate technology research areas are discrete sectors that are aligned with a climate change challenge and are associated with clusters of research (in terms of volume); the climate technology company categories tend to reflect currently existing sectors, in terms of both activity and data categorisation.

11 The SME sector accounts for 99.7% of enterprises in Ireland: http://www.cso.ie/en/media/csoie/releasespublications/documents/multisectoral/2012/businessinireland2012.pdf

12 https://infodev.org/infodev-files/green-industries.pdf

Table 3.1. Climate technology company sectors

Sector	Number of companies
Climate services	25
Energy efficiency	116
Energy storage/supply/generation	8
Renewable energy	58
Transport	5
Waste management	24
Water/wastewater	30

Table 3.2. Climate technology tags

Agrifood
Bioenergy
Building and materials
CHP
Climate services
Ecosystem services
Electrical power conversion
Energy management and services
Energy storage
Heat boilers
Hydro
ICT/Smart grids/smart cities
Land use management
Marine
Marine renewable energy
Smart buildings
Solar
Technology transfer
Transport
Waste management
Wastewater
Water
Wind energy

CHP, combined heat and power.

It is therefore unsurprising that there are differences, since the company categories represent the past and present, whereas the research categories are a non-exclusive potential view of the future.

While there is a range of technology research in agriculture and land use, for example, companies in the agriculture sector tend to focus not on climate change but on output and productivity. Agricultural climate technology companies focus on energy efficiency (e.g. production efficiency, efficient equipment and material design), develop water and waste management technology or are engaged with bioenergy. While many of the newer technologies being developed are not being trialled, two exceptions, which are being implemented, are the Carbon Navigator (Teagasc) and Origin Green (Bord Bia), which are activities driven by government agencies. This shows that the priorities of research (especially if government led) are not fully shared with the companies in the sector. Similarly, for new land use technologies and methodologies, the business models for companies remain uncertain and the sector is dominated by the large state companies Coillte and Bord na Mona.

While *climate services* is a new research area, it has such a broad definition that many existing companies could be described as climate services companies; however, there is minimal overlap between technology research and company activity. The research tends to focus on the physical artefact, either the technology hardware or software, but for companies the technology tends to come second to the service. Many companies that in other catalogues would be called consultants can be here called climate services companies because of their work with information and analysis. Whereas climate services research tends to focus on innovative use of earth observation data and ground-based measuring devices, climate services companies tend to focus on established data sets and client-focused advice. There is much opportunity for fruitful collaboration between research units and companies.

In the water sector, a diversity of companies are active across a range of sub-sectors. There is some overlap between the research and the companies, particularly for the wastewater sector, although most of the research on wastewater remains small in scale. There is not a clear cohort of companies exploiting the research being done on smart water management; it remains to be seen if the new water utility company, Irish Water, will drive research into smart water management and associated technology.

Table 3.3. Climate technology research categories and climate technology company categories

Research category	Company category
Agriculture and land use	Climate services
Climate services	Energy efficiency
Smart buildings	Energy storage/supply/generation
Marine sector	Renewable energy
Transport and air quality	Transport
Water and wastewater	Waste management
	Water/wastewater

A full list of climate technology company sectors and tags is shown in Appendix 3.

Smart buildings is framed as a new research area to highlight the opportunity. It includes a number of existing energy companies. Many companies are active in areas that align with the research focused on smart buildings, for example building energy management and energy-efficiency devices, although the more innovative technologies tend to be for the industrial and, to a lesser extent, commercial sectors. For the commercial and domestic sectors, a much larger cohort of companies uses pre-existing energy-efficient technology; the slow take-up of new technologies for these sectors could be related to the relatively slow take-up of existing energy-efficient technologies.

Energy companies are often established companies using existing technologies, rather than contributing to research for new technologies. The exception is the marine sector, which has a large volume of research and many companies, although the existence of a lot of companies is consistent with the market cycle for underdeveloped technology (Grubler *et al.*, 1999).

In the marine sector, Ireland has a number of small indigenous marine energy companies and a number of foreign companies, which are predominantly focused on research, although some of the larger companies have other energy portfolios. In addition, a number of non-energy start-up companies support them. Non-energy marine companies are also engaged in climate services consultancy (e.g. sonar, navigation aids, mapping) and marine water monitoring.

The transport sector highlights the small volume of research and the small number of companies that focus on climate technology. Ireland's transport sector is dominated by a number of state-owned companies, which are slow to adopt new technology. There is very little indication that companies are trialling new technologies that are being developed in Irish research institutes, although there are trials of more established technologies (e.g. CNG buses in Cork). The innovative transport sector companies in the catalogue are more information-/service-type companies that are making innovative use of information or software rather than hardware.

In terms of location, most of the climate technology companies in the catalogue are indigenous Irish-founded companies. While a heat map of a sample of these companies by location shows a concentration in the cities (Dublin, Cork and, to a lesser extent, Limerick and Galway), they are broadly spread across the country; see Figure 3.1. This map also shows the potential for regional development from the climate technology sector.

3.3 Summary

This chapter has outlined the range of climate technology companies in Ireland. Successfully responding to climate change will require large-scale deployment of *existing* low-carbon technology, and large-scale development and deployment of *new* low-carbon technology, i.e. RD&D. Companies and businesses have a critical role in RD&D, particularly at the later stages of technology development and deployment. Collaboration between research units and industry is important to technology development and deployment. While Ireland has growing levels of engagement between tertiary education research institutes and private sector entities, this has been led by multinational companies (MNCs) and universities; the SME sector still has room for improvement. It is hoped that, by outlining the companies active in climate technology, the catalogue can contribute to increasing the scope of research institute and private sector collaborations.

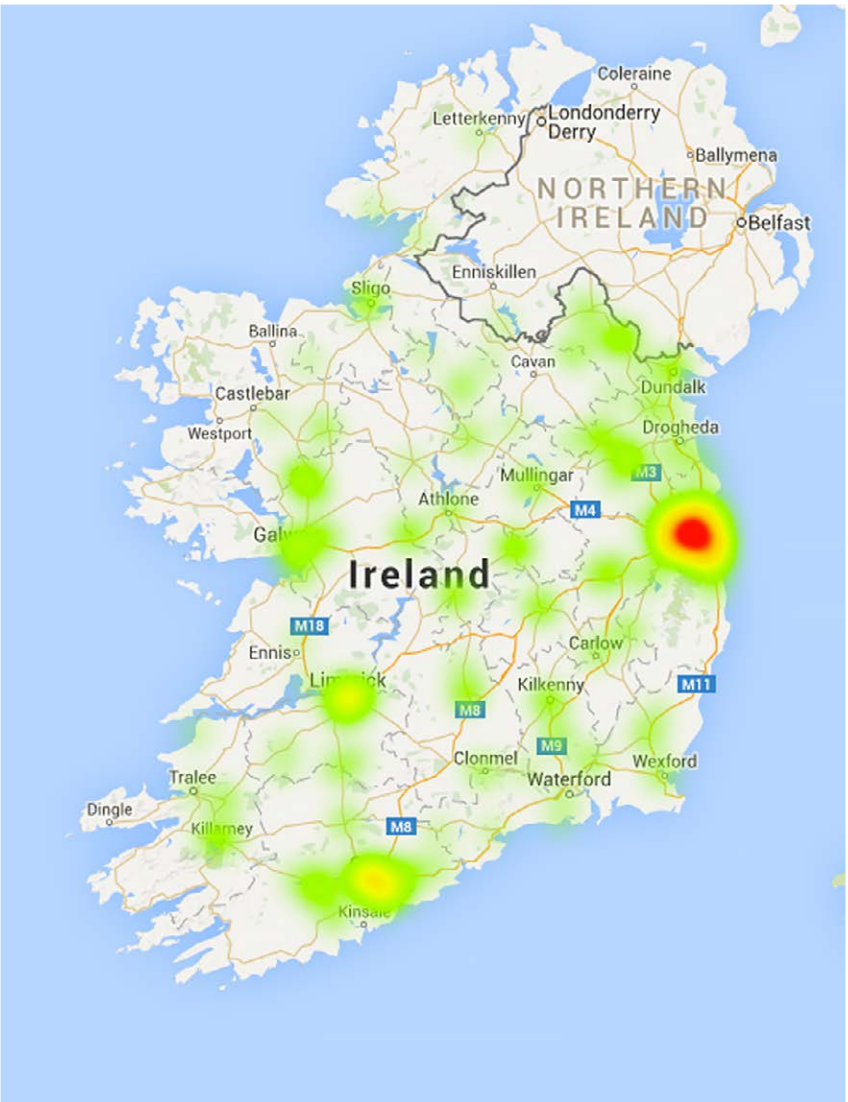

Figure 3.1. Heat map of sample of climate technology companies in Ireland.

There are areas where the research and the companies overlap (marine, water and wastewater) and areas where they do not (transport, climate services, agriculture and land use). These point to opportunities for better engagement. Compared with technologies deployed by companies, climate technology research tends to be more novel and unique; many of the climate technology companies are simply using existing technologies or improving them incrementally (e.g. making them more energy efficient). While markets alone tend to reward incrementally better technologies, broader support and landscape changes are necessary for more innovative technologies to be developed through to dissemination.

4 Climate Technology Innovation System

Climate change is a grand societal challenge that will require levels of technology deployment, government leadership and societal engagement above and beyond business-as-usual norms. It will require a coherent response from a very wide and diverse set of individuals, organisations and sectors of society. The climate change challenge is system-wide and will require a systematic and innovative approach.

The lifecycle of technology development from invention to deployment does not happen in a vacuum. Technology development and innovation are influenced by markets, policy supports, the environment, user preferences and networks. The innovation system framework illustrates the systematic interactions of all these elements. Climate technology policy will be formed from a mix of technology policy, innovation policy, climate policy and development policy.

This chapter uses a number of frameworks from economic development studies, innovation studies and environmental studies to develop a *climate technology innovation system* framework to outline solutions to the challenge of climate technology diffusion. The previous two chapters discussed climate technology research and companies; this chapter examines both within the broader framework of innovation systems.

4.1 Innovation System

The innovation system is an analytical framework defined as "the system of actors, institutions, networks and processes that result in innovation taking place. [It] covers *research, development, demonstration* and *commercial* activities leading to *deployment*, and can be used in reference to countries, sectors or technologies. Formally, [it] covers processes that lead to early deployment but can also be used in an extended sense to include processes leading to *commercial* or *full-scale deployment*" (Hannon, 2014).

Schemas that describe the structure of an innovation system show the *who*, i.e. the organisations that contribute to or are necessary for innovation, and the *how,* i.e. the stages of the innovation process such as different technology development steps and market diffusion steps. The national system of innovation illustrated in Figure 4.1 shows the breadth of actors, conditions and institutions that are necessary for successful innovation. This framework could be applied to a particular country to identify deficiencies, gaps or weaknesses in its national system of innovation. Shortcomings could be identified as the absence of key actors, framework conditions or links between key actors and organisations.

Because of the central role of technology in innovation, innovation systems that emphasise the *how* are often framed in terms of the key stages of technology development and diffusion. They are often described in terms of their technology-push and market-pull dynamics. The innovation system schema in Figure 4.2 shows the various stages of technology development: (1) research, (2) development, (3) demonstration, (4) niche markets, (5) diffusion and (6) phase-out. This schema shows that, while these stages are broadly sequential, there is also extensive feedback between the stages, making it more non-linear than linear. This schema also highlights the role of technology-push and market-pull forces, which can be linked to broader values of societal actors, such as entrepreneurial values, shared expectations and adopter preferences.

An example of the successful application of a systematic approach to innovation comes from Denmark, which grew a successful wind power industry in response to the energy crisis of the 1970s. Many other countries also initiated policies attempting to grow a wind power industry, notably Germany, Sweden and the Netherlands. However, whereas the latter countries all focused R&D on large-scale projects in order to maximise efficiency, Denmark focused on smaller turbines. At the same time, it worked with expected users of the technology, so they had higher deployment rates. The Danish approach proved to be less risky and ultimately more successful (Wilson *et al*., 2012). In innovation system terms, Denmark applied its R&D efforts across the full innovation system spectrum: from technology-push to market-pull. This is not just a simple matter of spending more on R&D than others, or being the origin of the most important early-stage ideas; a patent analysis has shown that, while most of the most important wind turbine patents came from California, this did not prevent Denmark's success (Nemet, 2009).

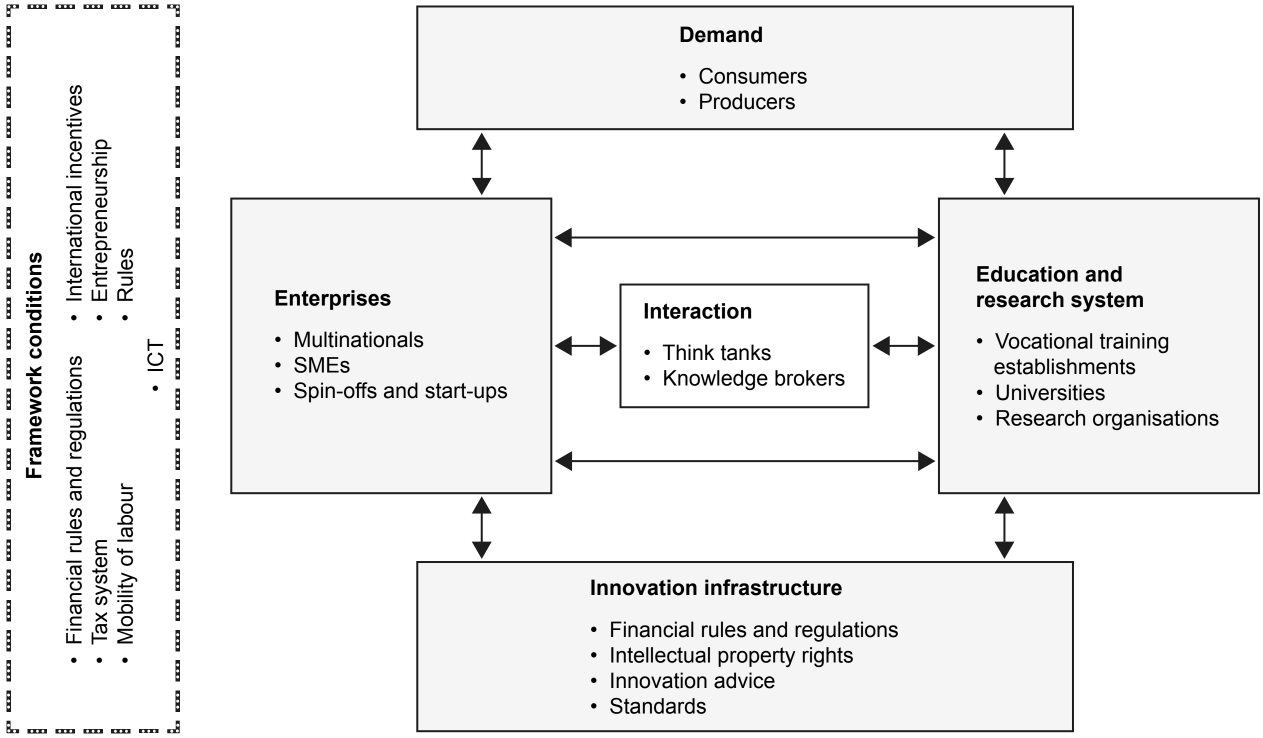

Figure 4.1. National system of innovation. Adapted from Branstetter (n.d.) and Bremer *et al.* (2001).

4.1.1 Energy innovation system

The representation of the energy innovation system for the UK in Figure 4.2 includes the stages of technology development and also shows the roles (and relative weightings) that various agencies should have at successive stages.

Recently, there has been a lot of research on innovation systems in the energy sector. Until the 2000s, the global energy system had been largely mature and stable, investing relatively little in R&D compared with other industries (Skea, 2014). However, the energy sector is the largest contributor to GHG emissions globally; it was responsible for 65% of global GHG emissions in 2010. It has become acknowledged as the most important sector to decarbonise in order to address climate change. While there is agreement that far-reaching technological change is required for the energy sector, agreement is far from being reached about the best way to achieve this (Grubb, 2005). Historically, energy transitions have taken a long time: in the case of coal, it took over 100 years (Grübler, 2012). A timeline of centuries does not align with the 2°C pathway, nor does the historical rate of innovation in the energy sector. However, although large-scale energy transitions take a long time, many smaller-scale energy transitions have happened at a much faster rate and one of the critical factors in these fast transitions has been the role of innovation (Sovacool, 2016).

A world-wide interdisciplinary research project on the energy technology innovation system included the findings that (1) “Large, early, and sustained investments, combined with supporting policies, are needed to implement and finance change. Many of the investment resources can be found through forward-thinking domestic and local policies and institutional mechanisms that can also support their effective delivery” and (2) “The use of appropriate policy instruments and institutions can help foster a rapid diffusion and scale-up of advanced technologies in all sectors to simultaneously meet the multiple societal challenges related to energy” (Banerjee *et al*., 2012). This alignment between policies and technologies is particularly important for the energy technology innovation system.

Relevant insights from the energy technology innovation system literature include the finding that, while a combination of the two dynamics of technology-push and market-pull is required to achieve innovation, the precise role and relative contribution of each will vary with the technology and context in question; for example, a guideline that technology-push is more important for non-incremental technology changes, while market-pull is more important for incremental technology changes, is qualified by whether the industry in question has settled on a final design or is still experimenting with alternatives (Nemet, 2009). This finding implies different innovation system and policy needs for a technology such as wave energy, which is still experimenting with device designs, compared with the wind energy sector, which has largely settled on a final design.

4.2 Green Growth

Green growth seeks to align ecological sustainability with economic growth. According to the OECD, policies for green growth must (1) integrate the natural resource base into the same dynamics and decisions that drive growth, (2) develop ways of creating economic payoffs that more fully reflect the value of the natural resources base of the economy and (3) focus on mutually reinforcing aspects of economic and environmental policy (OECD, 2011). In an example of applying green growth to the energy sector, its list of recommended policy outcomes is (1) rationalise and phase out inefficient fossil fuel subsidies, (2) set a price signal to value externalities, (3) establish sound market and regulatory frameworks, (4) radically improve energy efficiency and (5) foster innovation (OECD and IEA, 2011).

As a way to achieve increased valuation of the natural resource base and to help mainstream green growth policy and analysis, the OECD has started designing indicators to help track the trajectory of the green economy, such as carbon productivity, material productivity, environmentally adjusted multi-factor productivity growth, a natural resource index, changes in land use and cover, and population exposure to air pollution (Upton, 2015).

In outlining the challenges for innovation systems in general, but for green growth in particular, Botta *et al*. (2015) note that "in addition to the issues typical of innovation generally (such as market failures related to limited appropriability of economic benefits of

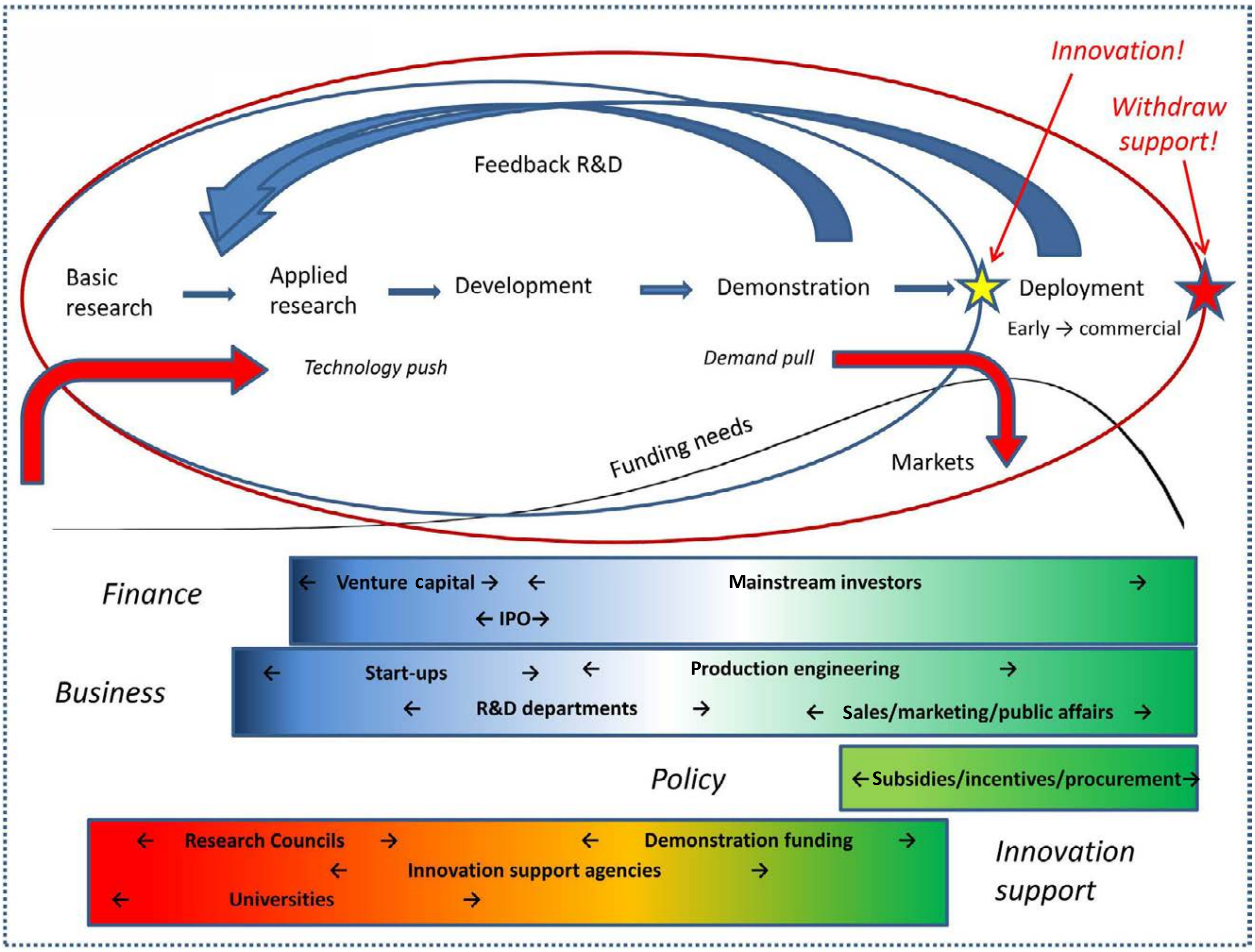

Figure 4.2. Energy innovation system. Source: Imperial College London.

knowledge), green growth innovation is also hindered by market failures related to the environment (pollution externalities)". The World Wide Fund for Nature (WWF) undertook an extensive study of innovation systems in the context of climate innovation. While stressing the need for a harmonised approach, it notes that the challenges vary in different countries; it undertook case studies in a range of countries, including Kenya, Uganda, India, the Netherlands and Sweden (WWF, 2011). Prior to the 15th Conference of the Parties (COP15), in 2009, many governments joined together to make a statement on the positive impact that green growth could bring to addressing environmental and climate change related problems (OECD, 2009). A number of green growth initiatives were launched at COP21, including Mission Innovation and the Inclusive Green Growth Partnership.

In Ireland there has not been a climate technology innovation system analysis, but a report by the National Economic and Social Council (NESC) reiterates some of the above green economy points in an Irish context: environmental concerns must be integrated into core policy; the ability to capture the full potential of the green economy would be enhanced by further developing an Ireland-specific cleantech 'green' enterprise strategy; and it is important to explore ways in which green economy development can most support employment and local economic development (NESC, 2013; Renwick *et al*., 2014).

4.3 Smart Specialisation

Although climate change presents grand challenges that require big collaborations, including between nations, climate change will also be local in its impact. The smart specialisation framework, which is becoming widely used in the EU to guide national innovation policies, is a useful framework to align regional development with addressing climate change challenges. Regional development has been central to EU development policy, as EU regions have very different rates of development and the aim is to counteract this. Recent EU policy has aligned regional development and innovation-driven economies with the smart specialisation framework, to make the Research and Innovation Strategies for Smart Specialisation (RIS3) platform.[13] The RIS3 platform is a "place-based approach to policy design and delivery", which works on the basis that "regions can only acquire a real competitive edge by finding niches or by mainstreaming new technology into traditional industries and exploiting their 'smart' regional potential" (EC, 2014). RIS3 allows regional benchmarking, thematic analysis, and competitor analysis.

The RIS3 method is organised into the following broad stages:[14]

1. analysing the innovation potential;
2. setting out the RIS3 process and governance;
3. developing a shared vision;
4. identifying the priorities;
5. defining an action plan with a coherent policy mix;
6. monitoring and evaluating.

The relevance of RIS3 to climate technology is that smart specialisation "can also be a powerful instrument to tackle social, environmental, climate and energy challenges, such as demographic change, resource efficiency, energy security and climate resilience" (EC, 2014).

4.4 Climate Technology Innovation System

Based on the principles of green growth and smart specialisation, a climate technology innovations system should:

- *Be comprehensive and include all relevant actors.* This will include all relevant departments, state agencies, private companies, research entities and community organisations. Government policy can have a strong role in helping all these entities cohere and work together. In Ireland, a number of government policy documents, such as the National Climate Change Adaptation Framework and the Climate Action and Low Carbon Development Act 2015, have already published frameworks showing how key parts of climate change relate to broader societal and economic sectors (transport, infrastructure, residential, agriculture, etc.).

13 http://s3platform.jrc.ec.europa.eu/home

14 http://s3platform.jrc.ec.europa.eu/s3pguide

- *Find a way of valuing natural resources and putting a price on environmental externalities.* Aligning economic development with true wealth and true costs.
- *Align economic development and climate change challenges.* Addressing climate change in the context of economic development means bringing in robustness and resilience.
- *Have sound and consistent market and regulatory signals.* For example, a price on environmental externalities (e.g. carbon tax) will act as a strong market signal (i.e. market pull) for the direction of climate technology development.
- *Align short-term policy measures with long-term policy.* While climate change is already happening, its full manifestation will be over longer time cycles than a typical business cycle and/or election cycles. Longer timelines will also be more common for climate technology development (especially for the energy system), which will have lead times measured over generations. This also means being investment focused.
- *Emphasise the importance of local context in framing economic and societal challenges.* As already stated, climate change is a global challenge but one with great variation in its local manifestation. This leads to two dynamics: one is internationalisation (e.g. calls for international strategies towards funding and co-ordination of RD&D (Milford, 2007), announcements at the recent COP21 meeting in Paris such as Mission Innovation, the EU Strategic Energy Technology (SET) Plan whereby EU countries work together on development of energy technologies (EC, 2015b) and the IEA Technology Collaboration Programmes). The other is localisation, for example organisations within a country working together to co-ordinate their efforts, such as Climate-KIC Regional Implementation Centres and, in Ireland, the Green Way and Energy Cork.

4.4.1 International context

There are a number of organisations actively assisting collaboration in the climate technology area. The Climate Technology Centre and Network (CTCN) and the Green Climate Fund (GCF) are two of the most prominent.

Climate Technology Centre and Network

The CTCN is the operational arm of the UNFCCC Technology Mechanism, hosted by the UN Environment Programme (UNEP) and the UN Industrial Development Organization (UNIDO). The Centre promotes the accelerated transfer of environmentally sound technologies for low carbon and climate resilient development at the request of developing countries. The CTCN provides technology solutions, capacity building and advice on policy, legal and regulatory frameworks tailored to the needs of individual countries.[15]

Green Climate Fund

The Green Climate Fund was established with a mission to advance the goal of keeping the global temperature increase below 2 degrees Celsius. The Fund is a unique global initiative to respond to climate change by investing into low-emission and climate-resilient development in developing countries. GCF was established by 194 governments to limit or reduce greenhouse gas emissions in developing countries, and to help adapt vulnerable societies to the unavoidable impacts of climate change. More than $10 billion has been pledged to the GCF over the 2015–2018 period and the first projects worth approximately $250 million were approved in 2015. The Irish government pledged an initial allocation to the GCF of €2 million.[16]

4.5 Climate Technology Opportunities: Innovation System Analysis

The following is a preliminary analysis of the climate technology opportunity areas using the innovation system framework.

15 Text from website: https://www.ctc-n.org/

16 Text from website: http://www.greenclimate.fund/

4.5.1 Agriculture and land use

Many of the more advanced and innovative technologies described in Chapter 2 were the result of collaborations between a number of organisations. The role of Teagasc in these collaborations is important, since it typically works closely with the expected final user (e.g. the farmer). While some agriculture technologies are high-tech, their use will be challenging for some users, as acknowledged by a Teagasc researcher who described the use of cultural scripts for developing technology. Many biofuel technologies developed in tandem with the agriculture sector suffer from a lack of clear incentives and clear trajectories for medium- to long-term policy.

Land use technologies are being developed, but the business models for companies are uncertain. There is now a small community of companies developing sequestration technologies, some of which are low-tech and not in need of huge funding, but there is no market-pull mechanism yet. A strong market signal could involve an appropriate carbon price.

4.5.2 Climate services

In terms of technology development, climate services are currently in receipt of very clear and strong policy signals coming from the European Commission (EC, 2015a). The catalogue of climate technology companies shows that, while many companies could be described as climate services companies, many of them are still described simply as consultants. There is a wealth of strong research, which tends to focus on the use of earth observation data in various innovative ways; however, apart from a number of leading technology developers, most so-called climate services companies do not see the potential that exists in this area. While there are strong technology-push dynamics in this sub-sector, they do not connect well with the market-pull dynamics.

4.5.3 Water and wastewater

As shown in the climate technology opportunity analysis and the catalogue of climate technology companies, there is a lot of research activity in water testing and wastewater management, much of it at demonstration level, and a lot of companies are engaged in this area. However, there is a lack of policy targets and policy goals for the water sector. Most of the research in the water sector is focused on wastewater and remains small in scale. The technology TRLs could benefit from strong policy to stimulate the market.

4.5.4 Smart buildings

While many companies focus on building energy management and energy-efficiency devices, the slow take-up of new technologies could be related to the relatively slow take-up of existing energy-efficient technologies, which continue to face a wide range of non-economic barriers. Research by Peter Taylor (University of Leeds) highlights that energy efficiency on the demand-side is a huge opportunity area but that much of its potential remains untapped (Taylor, 2009); in a separate analysis he concluded that a systematic approach is needed to surmount the multiple barriers that continue to impede the deployment of energy-efficient demand-side technologies (Taylor, 2014).

The smart buildings opportunity area somewhat reflects the distinction between indigenous firms and non-Irish multinational firms. Many of the ICT companies in Ireland are large MNCs and will not necessarily have the same priorities as indigenous firms. Many of the opportunities for retrofitting exist in small firms, whose cost base and business cycles are different from those of large MNCs. A key challenge for smart building research is to progress beyond demonstration projects.

4.5.5 Marine sector

The marine sector in Ireland has many opportunities and there are many analyses of its potential; the Irish government currently has a plan to double the proportion of GDP from the marine sector from 1.2% to 2.4% by 2030. The marine sector (and the marine energy sub-sector) could usefully benchmark itself against other technology development sectors with data, such as patents. For example, data from the OECD (Hascic *et al*., 2012) give an insight into how much Ireland, compared with other countries, has specialised in each type of renewable energy patent as a proportion of overall renewable energy patents: in this analysis, hydro/marine is relatively popular, but so are biofuels.

Figure 4.3 compares wind energy patents in Denmark and marine energy patents in Ireland.[17] It shows that, while Ireland is relatively highly specialised in marine energy patents, the total number is an order of magnitude below that of Denmark's wind energy patents. The market is completely undeveloped at present. Although many small indigenous marine energy companies are actively developing new technologies, the number of companies may be expected to decline once the industry settles on a few designs, as consolidation occurs.

Marine energy technology has a long development cycle, which meants that it might not be commercial for a generation. By that time, it could be locked out of the energy market by developments in other technologies.

4.5.6 Transport and air quality

As described in Chapter 2, research on climate technology for the transport sector is on a small scale. The transport sector has a small number of private companies, but is dominated by mostly state-owned companies, which are less dynamic and are more bound to infrastructure restrictions.

The transport sector is similar to the smart buildings sector in that neither new technologies nor existing technologies, that are less damaging to the climate, are trialled or used. More attention is required in achieving new uses of existing technologies. Insights may be derived from the fact that the climate technology companies that are active in the transport sector are predominantly services companies, rather than technology producers.

Transport climate technologies could make a positive contribution to improving air quality. Research on air quality in Ireland is developing mechanisms to better monitor the drivers and causes of poor air quality. This could help build demand for cleaner transport technologies.

4.6 Summary

For new and innovative climate technologies to be deployed, there need to be synergies between the interests of the researcher and those of the commercial sector. Owing to the risks involved, the commercial sector will tend to prefer less innovative but more efficient technology. The innovation system puts a frame around both the research and the companies and helps analyse the potential synergies. It can be used to identify gaps, innovation needs, etc. The climate technology innovation system has a number of special characteristics (shared with green growth), such as protecting the environment, monetising externalities, developing

17 The comparison used F1 and F2 patent categories. F1 patents are all patents whereas F2 patents are those that have been cited. The F1/F2 distinction captures the difference between all patents (most of which are never cited) and more important patents, which are cited.

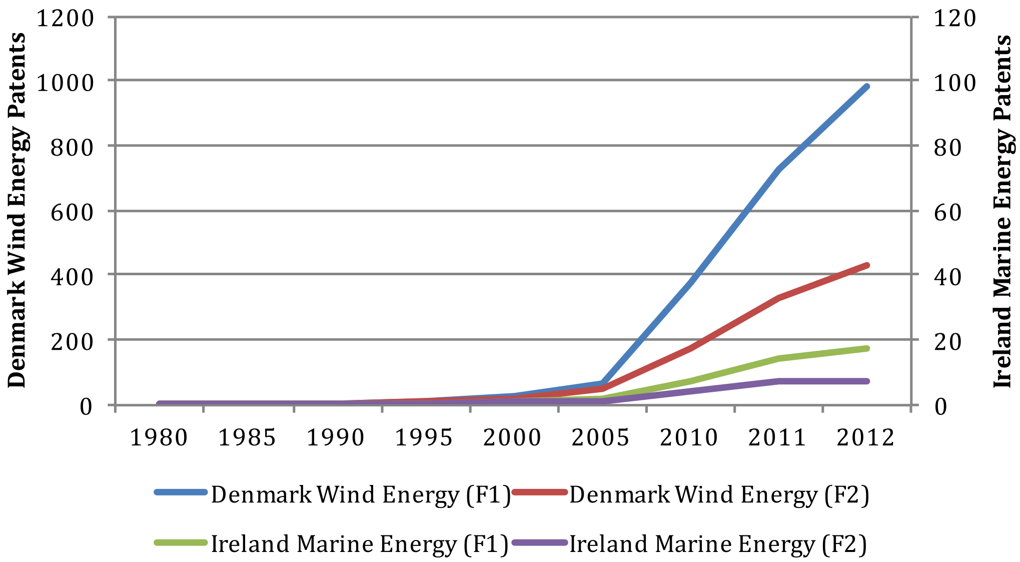

Figure 4.3. Cumulative number of wind energy patents (Denmark) and marine energy patents (Ireland), by year of registration, 1980–2012. Source: OECD.

consistent policy and longer time-scales. There is a synergy between the smart specialisation framework and climate technology innovation.

Owing to recent developments in Ireland's economy, innovation system (Innovation 2020 report; DJEI, 2015), energy policy (Energy White Paper, "Ireland's Transition to a Low Carbon Energy Future 2015–2030"; DCENR, 2015) and climate legislation (Climate Action and Low Carbon Development Bill 2015), Ireland's climate technology innovation system is itself in transition. While the smart specialisation framework was said to be aligned with the recently launched Innovation 2020 report (DJEI, 2015), its treatment of climate change is largely cursory.

Ireland's climate technology innovation system should comprise the following four groups of stakeholders:

- universities, colleges and research units;
- firms, companies and businesses;
- government and public bodies;
- citizens and communities.

Universities, colleges and research units were discussed in Chapter 2, and firms, companies and businesses were discussed in Chapter 3. All arms of government should be involved, including national agencies [such as EPA, the Sustainable Energy Authority of Ireland, Teagasc, Enterprise Ireland and Science Foundation Ireland (SFI)] and local (or equivalent) bodies (such as county and city councils, energy agencies and local enterprise offices). The challenge for all these entities will be in working together on clear short-term policy that is aligned with long-term policy. Ireland's new climate legislation has a number of mechanisms to address this challenge.

Citizens and communities have a key role on the market-pull side of the innovation system, as do citizens and communities. The nature and suitability of technology being developed needs to be fed back through the technology development stage.

5 Benchmarking Ireland

What conditions are needed for effective climate technology innovation? This chapter investigates the relationship between general macro-economic indicators and climate technology indicators for a number of high-performing countries; the analysis includes Ireland, to benchmark Ireland's performance on general innovation and climate technology innovation. Since the purpose of this analysis is to identify insights for Ireland, the five countries chosen are both more successful (according to the metrics chosen) and usefully comparable. The five countries chosen are Israel, Denmark, Finland, the United Kingdom and Switzerland. These other countries all perform better than Ireland (on some, most or all of the 10 indices) and are either broadly comparable to Ireland in size (Denmark, Finland, Israel, Switzerland) or directly relevant to Ireland in terms of proximity (United Kingdom).

5.1 Overview of Indices

The data used are a set of 10 independent indices that measure the world's countries for their performance on innovation, competitiveness and entrepreneurship metrics, and on environmental performance, energy sustainability, cleantech innovation and green economy metrics. The indices are all from either 2014 or 2015 and come from a variety of global consultancies and firms, which either develop their own data sets or assemble them from existing country or intergovernmental organisation data sets.

The 10 indices are:

1. Global Innovation Index (2014);
2. Global Competitiveness Index (2014);
3. IMD World Competitiveness Scoreboard (2014);
4. EC Innovation Union Scorecard (2014);
5. Global Entrepreneurship Index (2015);
6. Environmental Performance Index (2014);
7. Energy Sustainability Index (2014);
8. Cleantech Innovation Index (2014);
9. Green Economy Index (2014);
10. Climate Change Performance Index (2014).

The *Global Innovation Index (2014)* "is the result of a collaboration between Cornell University, INSEAD [the European Institute of Business Administration, a high-profile business school], and the World Intellectual Property Organization (WIPO)" and "covers 143 economies around the world and uses 81 indicators across a range of themes" that include institutions, human capital and resources, infrastructure, market sophistication, business sophistication, knowledge and technology outputs, and creative outputs (Cornell University *et al.*, 2014).

The *Global Competitiveness Index (2014)* "is published by the World Economic Forum". With input from "over 160 Partner Institutes worldwide", it measures the "competitiveness performance of 144 economies" under a range of indicators including institutions, infrastructure, macro-economic environment, health and primary education, higher education and training, goods market efficiency, labour market efficiency, financial market development, technological readiness, market size, business sophistication and innovation (Schwab, 2014).

The *IMD World Competitiveness Scoreboard (2014)* is produced by the IMD World Competitiveness Center (a research centre in the Swiss business school the International Institute for Management Development). It "ranks and analyzes the ability of nations to create and maintain an environment in which enterprises can compete" by using the following four main factors: economic performance, government efficiency, business efficiency and infrastructure (IMD World Competitiveness Center, 2014).

The *EC Innovation Union Scorecard (2014)* was prepared for the European Commission by the Maastricht Economic and Social Research Institute on Innovation and Technology, and for each EU Member State uses "eight innovation dimensions [human resources; open, excellent and attractive research systems; finance and support; firm investments; linkages and

Table 5.1. Rankings for all countries for the 10 indices

Index	Israel	Denmark	Finland	UK	Switzerland	Ireland
Global Innovation Index (2014)	15	8	4	2	1	11
Global Competitiveness Index (2014)	27	13	4	9	1	25
IMD World Competitiveness Scoreboard (2014)	–	9	18	16	2	15
EC Innovation Union Scorecard (2014)	–	2	4	8	–	9
Global Entrepreneurship Index (2015)	22	6	14	4	9	17
Environmental Performance Index (2014)	39	13	18	12	1	19
Energy Sustainability Index (2014)	66	5	8	4	1	22
Cleantech Innovation Index (2014)	1	5	2	6	8	10
Green Economy Index (performance) (2014)	33	5	8	20	6	11
Green Economy Index (perception) (2014)	24	2	9	8	10	33
Climate Change Performance Index (2014)	–	1	32	2	5	9

Performance and perception are sub-indices of the Green Economy Index.

entrepreneurship; intellectual assets; innovators; economic effects] and 25 indicators [to] analyse the performance of the EU innovation system" (Hollanders and Es-Sadki, 2014).

The *Global Entrepreneurship Index (2015)* is published by the Global Entrepreneurship and Development Institute to "measure the quality and the scale of the entrepreneurial process in 130 countries around the world" by gathering data under the broad headings of entrepreneurship attitudes, abilities and aspirations (Ács *et al*., 2015).

The *Environmental Performance Index (2014)* is a "joint project between the Yale Center for Environmental Law & Policy and the Center for International Earth Science Information Network at Columbia University" that "scores country performance in nine issue areas": health impacts, air quality, water and sanitation, water resources, agriculture, forests, fisheries, biodiversity and habitat, and climate and energy (Hsu *et al*., 2014).

The *Energy Sustainability Index (2014)* is published by the World Energy Council and "provides a comparative ranking of 129 countries" that "highlights how well countries manage the trade-offs between the three energy sustainability dimensions" of energy security, energy equity and environmental sustainability (Wyman, 2014).

The *Cleantech Innovation Index (2014)* is published by the Cleantech Group and the WWF; in the words of the report, "40 countries were evaluated on 15 indicators related to the creation, commercialisation and growth of cleantech start-ups" (Cleantech Group, 2014).

The *Green Economy Index (2014)* is published by Dual Citizen LLC. It measures "the performance of 60 countries and 70 cities in the green economy and how experts assess that performance" (Tamanini *et al*., 2014).

The *Climate Change Performance Index (2014)* is "published annually by Germanwatch and CAN (Climate Action Network) Europe [and] evaluates and compares the climate protection performance of 58 countries" (Burck *et al*., 2013). Country ranking results for 10 indices for the six countries in this analysis are shown in Table 5.1.

5.2 Country Analysis

5.2.1 Israel

Israel has singular strengths in early-stage climate technology innovation, but because it lacks well-integrated macro-economic supports (long-term policy goals, accessible markets, consistent pro-innovation policy) it struggles at the later stage of commercialising climate technology innovation.

Israel has a GDP of US$257 billion (2012), a population of 7.8 million, a high proportion of high-tech industry driving its economic growth and a world-leading output of scientific knowledge (as measured in RD&D expenditure as a percentage of GDP and in patents). However, its position in the innovation, competiveness and entrepreneurship indices is in the middle tiers (15th, 22nd, 27th). For environmental performance, energy sustainability, green economy and climate change performance, Israel scores in the lower tiers (24th, 33rd, 39th, 66th). However, for cleantech innovation, Israel is in the top position (first); in the 2012 version of the cleantech index it was placed second.

Israel's high scoring in the Cleantech Innovation Index is the main reason it was included in this analysis. The high ranking is due to excellent scores for the earlier phase of the innovation lifecycle (i.e. patents and start-ups) rather than commercialisation and initial public offerings (IPOs). In the words of the 2014 cleantech report, Israel has "strong VC [venture capital] activity, the greatest density of high-impact cleantech start-ups, and a good score for environmental patents", as well as "a high level of business sophistication and entrepreneurial attitudes" (Cleantech Group, 2014). The role of government in Israel's high ranking for cleantech is less equivocal; for instance, the 2012 Cleantech report declared that "the country lacks cleantech supportive government policy" (Cleantech Group, 2012), whereas the 2014 Cleantech report said that "[Israel has] increased its supportive government policies" (Cleantech Group, 2012). While part of the success of Israel's innovation capacity comes from the government's public procurement policies (Schwab, 2014), there is an uncertain climate policy landscape in Israel, which continues to undermine the country's ability to address climate change in a co-ordinated and successful manner (Michaels and Tal, 2015).

Overall, while Israel invests heavily in R&D and has a dynamic start-up culture, the country lacks a fully developed national innovation system. Owing to its small size and geography, Israel has low levels of internal competition, and a number of large firms dominate certain sectors (Ács *et al.*, 2015).

5.2.2 Denmark

Denmark has singular strengths in early-stage climate technology innovation (especially, and famously, wind energy) but, thanks to a comprehensive and well-functioning innovation system across the entire economy and society, it has also had singular success in commercialised climate technology innovation.

Denmark ranks high in nearly all categories and indices, and is one of the most consistently high-scoring countries. It is rarely outside the top 10 for any index. For environmental and energy indices, it scores highly and is consistent, with high ratings across all categories (Burck *et al.*, 2013; Hsu *et al.*, 2014). In innovation and entrepreneurship indices, it scores well (6th to 13th) and, in specialised indices of cleantech and green economy, it scores higher (second to fifth), reflecting national specialisation in this sector.

In the energy sector, Denmark has a clear long-term policy (Wyman, 2014) and has had a long-term energy policy for some time. This is reflected in the metrics that help Denmark score well for energy security: a well-diversified electricity mix, low fuel imports, and a high-quality transmission and distribution system. These achievements did not happen overnight. Denmark's high energy security (sixth) and environmental sustainability (ninth) rankings have not been entirely without trade-offs: owing to the cost of energy security and environmental sustainability, Denmark has relatively high energy costs, which manifest as a lower ranking for energy equity (47th). In contrast, while Ireland is ranked 69th for energy security and 13th for environmental sustainability, at 39th it ranks marginally better than Denmark for energy equity.

Denmark's cleantech sector is ranked very high (first and second), which reflects strengths across the full cleantech innovation system, from inputs to outputs. Examples of strengths include "ambitious green energy provisions until 2020" (Cleantech Group, 2014), "a number of high-impact cleantech start-ups, and a relatively high number of investors", together with a "thriving clean economy, and density of publicly traded cleantech companies". However, the authors of another report note a "stagnant number of environmental patents and a decreasing amount of venture capital compared to prior years" (Cleantech Group, 2012), indicating both the competitive nature of the cleantech industry and the relative shift of the Danish economy away from start-up-driven growth. Some of these shortcomings are reflected in other indices, which show that Denmark scores relatively poorly on entrepreneurial culture and values (Ács *et al.*, 2015; Cleantech Group, 2012) and that its SME sector is falling behind in terms of support (Hollanders and Es-Sadki, 2014).

Denmark's relatively high taxes are seen by some as a barrier to doing business (Schwab, 2014); however, the country has high levels of transparency and very low levels of corruption (Schwab, 2014) and also scores well on government effectiveness, regulatory quality and the rule of law (Cornell University *et al*., 2014). Some of the results of the high level of taxation can be seen in Denmark's high ranking in the R&D sector (fourth; Cornell University *et al*., 2014) and its patent count and international scientific co-publications metrics, which reflect this (Hollanders and Es-Sadki, 2014).

However, these shortcomings point to the role of deliberate and consistent policy. For example, in terms of the green economy, Denmark scores high on communication, both domestically (with a highly engaged population) and internationally, where "Denmark relentlessly communicates its commitment to green growth through a variety of strategies and tactics, and global practitioners continue to signal the positive impact of these efforts" (Tamanini *et al*., 2014).

Denmark's strengths are in metrics associated with a mature and steady economy, for example it scores well for business sophistication metrics such as "local supplier quantity and quality", "state of cluster development", "value chain breadth", "control of international distribution", "production process sophistication" and "extent of marketing" (Schwab, 2014). The country also gets a first-rate assessment for its higher education and training system (10th), which has provided the Danish workforce with the skills needed to adapt rapidly to a changing environment and has laid the foundations for high levels of technological adoption and innovation; in addition, "Denmark continues to distinguish itself as having one of the most efficient labor markets internationally, with flexible regulations; strong labor–employer relations; and a very high percentage of women in the labor force" (Schwab, 2014).

In summary, Denmark has a healthy national innovation system: there is investment and an active venture capital presence, strong early scientific activity (i.e. R&D, patents, collaboration), clear policy goals and targets, excellent training and job prospects, a self-image as green, and transparent and effective government. Potential road-bumps come from indications that some of the economic success of the incumbents is preventing new business and new ideas from being fully developed.

5.2.3 Finland

Finland is a country in transition. It has developed strengths on the innovation input side and is building capacity through high investment in R&D and facilitation of collaboration between industry and academia; however, it has had limited success to date with commercialising climate technology because of challenges on the macro-economic side: low levels of competition, little internationalisation and lack of risk capital. Finland has similar scores to Denmark, with slightly higher rankings for innovation and competitiveness, but with slightly lower rankings for cleantech, energy and environmental criteria.

In energy indices, Finland ranks eighth overall, with a well-balanced energy system of energy equity, energy security and environmental sustainability (in descending order of scores). Finland has a diversified electricity mix and a coherent range of pro-renewables policies (e.g. it recently streamlined the approval of wind farms; introduced tax hikes on fossil fuels in heat generation, which will mainly affect light fuel oil in domestic heating and other fossil fuels in district heating and industrial co-generation; and has nuclear, biomass and combined heat and power, and wind power high on the agenda; Wyman, 2014).

Internationally, Finland and Ireland have the largest proportions of peat in their primary energy mix: 5.8% (IEA, 2013) and 5.4% (Howley *et al*., 2014), respectively. Peat has a low calorific value (7.8–18.5 GJ/t), making it the least efficient fuel; however, Finland compensates for this by using combined heat and power, which is one of the most efficient energy-conversion technologies. Finnish energy policy is in line with EU target settings, but, unlike Denmark, Finland does not have a long-term energy policy (e.g. up to 2050).

In the two cleantech indices, Finland ranks very high (second and fourth), with the greatest strengths on the innovation input side, i.e. cleantech development-friendly policy and evidence of emerging cleantech innovation. In more general indices, Finland scores very well for general innovation inputs, such as cluster development, public and private sector spending on R&D, quality of scientific research institutions, university–industry collaboration in R&D, and government procurement of advanced tech products. However, despite some high-profile cleantech companies and many new environmental patents, Finland is not as successful in commercialising cleantech innovation; cleantech companies' revenues are only average and there are few mergers, acquisitions and IPOs (Cleantech Group, 2012, 2014).

Finland has a highly transparent government and very high levels of public and private investment in R&D (third), with very strong linkages between universities and industry (first) coupled with an excellent education and training system (first) (Schwab, 2014).

Overall, Finland's innovation system is strong on the earlier, developmental, stage of innovation, but commercialisation remains a challenge, which could be linked to the limited competition scores, low level of internationalisation and lack of risk capital.

5.2.4 United Kingdom

The UK has a strong business and pro-innovation culture; however, it is underperforming in the climate technology sector because of uncertain policy signals support for the sector. Despite leading the world in long-term climate policy, the UK's short-term climate policy is being steadily undermined.

The UK scores very well on certain business-related indices (e.g. second on the Global Innovation Index 2014) but less well on ostensibly similar indices (e.g. 18th on the IMD World Competitiveness Scoreboard 2014). Similarly, the UK is ranked very high on certain environment indices (second on the Climate Change Performance Index 2014), yet much lower on related indices (20th on the Green Economy Performance 2014). There are a number of potential interpretations of this: one is that the way the metrics are constructed is somewhat subjective and that small differences in how the data is weighted and interpreted can result in large differences in country rankings; another is that the UK itself has contradictory policies and forces.

The UK energy sector has faced a number of great challenges in recent years: falling indigenous energy supplies have been coupled with difficulties (technical and public acceptance) in producing unconventional oil and gas, nuclear energy production is being run down and there have been unplanned shut-downs in electricity generation. These have all combined to bring considerable tightness to the UK energy and electricity market. Energy security has been worsening as a result, and carbon budgets and policy implementation are entering a difficult phase at the same time as energy policy is becoming increasingly politicised, leading to significant policy uncertainty (Wyman, 2014).

Overall, while the UK is a world leader in having long-term policy climate legislation (e.g. to reduce GHG emissions by 80% by 2050 compared with 1990), it has encountered great challenges in the implementation of short-term policy, such as the Green Deal (Wyman, 2014), and there is still uncertainty that will hamper progress beyond 2020 (Cleantech Group, 2014). These difficulties are also to be seen in the performance of the green economy, which "suffer[s] from inconsistent and sometimes negative political rhetoric related to green economy, which in turn may send mixed signals to the marketplace about the country's policy commitment to more sustainable growth pathways" (Tamanini *et al.*, 2014).

While the UK scores well for cleantech, it is weakest for commercialised cleantech, despite its legislation to help build a long-term low-carbon economy. It has a high ranking because of its very good general innovation inputs (e.g. ease of credit, research and education). For general innovation, the UK does well with good innovation inputs (R&D, publications, etc.) and good university–industry collaboration (for which it ranks very high). The UK derives many advantages from having a large and highly competitive economy (Schwab, 2014). However, its SME sector has a mixed record of innovation, with a small proportion of product and process innovation (Hollanders and Es-Sadki, 2014).

Overall, the UK has a pro-business culture and economy, but its innovation system for the green economy is hampered by inconsistent and contradictory policy signals.

5.2.5 Switzerland

Switzerland is even more of a leader in comprehensive innovation policy than Denmark. It has an excellent climate technology sector and its general innovation and competiveness metrics score very high.

Of the 10 indices in this analysis, Switzerland is either first or second in five, and it is never outside the top 10 for the other five. Switzerland is the highest-ranked of the five countries in this analysis. Like Finland and Denmark, it has a very stable society and receives a high score for transparent and effective government and institutions; in addition, Switzerland's macro-economic environment is among the most stable in the world and its financial sector is mature and well endowed (Schwab, 2014).

Switzerland balances things well: it has world-leading academic institutions, spends a lot on R&D and scores well for patents (Cornell University *et al*., 2014). It has strong co-operation between academia and business, which enhances productivity, and a business sector that offers excellent on-the-job training opportunities; the labour market balances employee protection with flexibility and the country's business needs; competitiveness is also buttressed by excellent infrastructure and connectivity (Schwab, 2014). In addition, energy prices are low while the environment is protected (Wyman, 2014).

Despite not being in the EU, Switzerland is included in the EU Innovation Scorecard and is, in fact, the top innovating country according to the metrics, scoring well for education, R&D, patents, collaboration and active innovation in the SME sector (which is particularly unusual) (Hollanders and Es-Sadki, 2014).

In terms of its energy system, Switzerland is the highest performer in this index: it has a lot of nuclear and hydroelectric power in its electricity mix, energy is not expensive (so energy equity is excellent) and the environmental criteria are strong. Switzerland has a long-term energy plan ("Energy Strategy 2050") that includes phasing out nuclear energy, increasing energy efficiency and using more renewable energy. According to the report authors, "in the short term Switzerland is likely to become more dependent on gas-fired electricity generation" with additional challenges for Switzerland being "(1) construction of new electricity grids; (2) completing the liberalisation of the electricity market; and (3) come to a bilateral agreement with the European Union regarding electricity and renewable energy" (Wyman, 2014).

Switzerland has very good environmental and climate change credentials, implying a consistent approach across both metrics, which, although not the same, have co-benefits that reinforce each other. As a comparison, Switzerland scores better than Ireland for management of its water resources (for access to sanitation and level of wastewater treatment), biodiversity and habitat (Hsu *et al*., 2014).

In cleantech, Switzerland achieves almost identical scores in both evaluations. This is a function of an overall well-functioning innovation system, unlike Israel and Denmark's relative specialisation in cleantech. Switzerland's score is above average on all factors except commercialised innovation drivers. Switzerland has strong environmental patent output but, despite government policies and relatively abundant cleantech investors, it remains below average in commercialised cleantech because of its low IPO count and renewable energy consumption.

In terms of the green economy, the gap between Switzerland's performance and perception shows that many do not give Switzerland quite the recognition it deserves. On both the efficiency sectors dimension and the markets and investment dimension, Switzerland's performance exceeds generally held perceptions. Further efforts by the Swiss leadership to embed green market opportunities in its sophisticated global communications platforms should improve this perception ranking in future.

Overall, Switzerland's innovation system is well resourced and well balanced. It combines high investment, excellent institutions and governance, and a long-term energy and climate plan.

5.2.6 Ireland

In the 10 indices, Ireland generally ranks between 11th and 20th. While occasionally scoring just inside the top 10, Ireland is just as likely to score between 20th and 30th; however, it rarely ranks lower than this.

In general business and innovation parameters, Ireland scores well, in large part thanks to its vibrant multi-national sector, but also because of factors such as the ease of setting up business and ease of paying tax (Cornell University *et al*., 2014), although Denmark, for example, scores better for business sophistication (local supplier quantity and quality; state of cluster development; nature of competitive advantage; value chain breadth; control of international distribution; production process sophistication). For quality of institutions, Ireland ranks below such countries as Denmark, Finland and Switzerland in terms of stability, regulation quality, strength of auditing and reporting services, government effectiveness and transparency, and rule of law (Schwab, 2014). The broad economic context, such as the recent macro-economic imbalances, has had a negative impact, and the corresponding impact on access to finance, levels of investment and risk capital continues to be one of the main barriers to innovation-led economic growth (Schwab, 2014).

Ireland's education system scores well (about 20th). While numbers in education (up to tertiary) score highly, Ireland is still behind the top-ranked countries for quality and level of education expenditure (Cornell University *et al.*, 2014). For numbers in post-graduate education, number of non-EU postgraduates and number of researchers, Ireland is in the front rank of the EU (Hollanders and Es-Sadki, 2014) (although because the population has a relatively high proportion of young people we might appear to be doing better than we actually are). However, compared with the highest-ranking countries, Ireland is weak for both government expenditure on R&D as a percentage of GDP and business expenditure/performance on R&D as a percentage of GDP, and this trend precedes the recent macro-economic imbalances.

Despite the sizeable presence of multinationals, Ireland consistently scores much worse on university–industry collaborations (research and publications) than our better innovating competitor countries (Cornell University *et al.*, 2014; Schwab, 2014). Collaboration between public and private entities (e.g. as measured by joint publications) is also weak (Hollanders and Es-Sadki, 2014). Possibly related to this, government procurement of advanced tech products is weaker than in other countries (Schwab, 2014).

In terms of entrepreneurship, Ireland scores low on "opportunity perception" but above average (world and EU) for all other metrics. Its scores for innovation capacity, process innovation and product innovation are all considerably weaker than those of the highest scoring countries; patent and trademark counts (private, public and for communities) are also lower. Ireland scores highest on human capital, internationalisation and technology absorption (Ács *et al.*, 2015).

Environmentally, Ireland scores high for air quality and forestry, lower for biodiversity and habitat and for fisheries, and dramatically lower than EU peers for access to water for drinking and sanitation (Hsu *et al.*, 2014). Energy security is the weakest of the three dimensions of energy sustainability, with energy equity and environmental sustainability scoring better; this is despite gradually rising petrol and household energy bills weakening energy equity. The environmental sustainability score is positive thanks to high air quality, relatively high water quality and relatively low energy intensity (kilotonnes of oil equivalent per euro of GDP) (Wyman, 2014).

Ireland's performance on cleantech and green economic indicators reflects its more general performance on innovation and competitiveness: overall, it has good (or high) scores, with many of the high-scoring parameters linked to the multinational sector, while many parameters more associated with SMEs, indigenous companies and institutions score lower than in our small-country competitors (Cleantech Group, 2014; Tamanini *et al.*, 2014). For example, "Ireland scores especially well on general innovation drivers, and is below average but improving for cleantech-specific innovation drivers" (Cleantech Group, 2014). In addition, according to the outputs of the Green Economy report, "Ireland is a case where better communications are clearly needed to advance global understanding of its green economy and associated market opportunities"; to express this more fully, the report notes that "Ireland ranks near the top in terms of being a vital market for cleantech innovation but our survey places Ireland near the bottom of EU nations on this topic in terms of how the country is perceived" (Tamanini *et al.*, 2014).

Overall, the analysis indicates that Ireland is strongly pro-business and has good governance that positively reinforces innovation activity. The environment, cleantech economy and green economy are not being fully valued/appreciated as a resource and opportunity. Investment is lower than in the top countries and it is unlikely that, without a concomitant increase in R&D as a percentage of GDP, Ireland will become an innovation leader. Finally, more and better collaboration is key.

5.2.7 *Caveats of analysis*

As a small country, Ireland is vulnerable to having its indices swayed by the presence of a single dominant factor in any one category. For example, the presence of a large foreign direct investment (FDI) and multinational sector can boost Ireland's score under certain parameters, but can conceal weaknesses in many parts of Ireland's economy or innovation system. The usefulness of this analysis lies not in the precise ranking but in the distribution of scoring, especially relative to other small countries that Ireland tends to be compared with and to compete with. Similar scoring on similar parameters across different indices also provides an insight into where Ireland's innovation system is comparatively weak and thus where improvement efforts could be directed.

Other caveats include the fact that some indices rely on the judgement of individual experts; while they are informed, they are more likely to be subjective judgements than quantitative metrics. Individual scores and values can vary according to larger macro-factors; for example, the constrained macro-economic circumstances Ireland faced in 2008 and 2012 have influenced many non-economic parameters. The scores are also relative to other countries and not relative to targets or goals Ireland has set for itself. In other words, while we may be doing poorly on the former, we could be doing well on the latter.

A caveat of international benchmarking is that Ireland's large FDI sector can overly strengthen our ranking; such benchmarking tends to use GDP and, while the difference between GDP and gross national product (GNP) is not important for most countries, it is important for Ireland, and this also tends to skew the results. Thus, while benchmarking can provide useful insights, it must be supplemented with more in-depth national analysis as enabled by national data.

5.2.8 Additional analysis

Because of the above caveats, this section presents additional data sets and analysis of the conclusions from the indices analysis.

In the last four decades, Ireland's economy transitioned from an "investment driven" economy to an "innovation driven" economy (O'Leary, 2015). Much of the initial driving force for innovation in Ireland's economy came from the international nature of investment in Ireland, 70% of which is based on FDI (DJEI, 2015). It has been called "innovation by invitation" (O'Leary, 2015). These large volumes of FDI investment generated economic growth, which subsequently led to the creation of clusters that helped domestic economic growth, which in turn helped Ireland move up the value chain.

Large levels of FDI investment mean that Ireland continues to be one of the most globalised countries in the world (Dreher, 2006; KOF, 2015). In line with the international nature of investment in Ireland, measures of innovation in Ireland tend to show higher levels of activity and output among foreign-owned businesses than indigenous companies. The difference between firms of Irish and non-Irish ownership holds through nearly all the data describing Irish innovation that were found (CSO, 2012).

This is important to note, since, when comparing metrics (e.g. actively innovating firms among EU28 countries; Eurostat, 2015b), Ireland scores well and is above average; however, this conceals the marked difference in performance between multinational firms and indigenous firms. There is less innovation activity in indigenous than multinational firms, in part because of the cost of innovating (Forfás, 2011b). However, the limited statistics suggest that it is difficult to draw firm conclusions (O'Leary, 2015).

Non-Irish firms are significantly more likely to record an environmental benefit from an innovation, such as reduced CO_2 emissions, reduced energy use per unit of output or less material used per unit of output. Non-Irish firms also appear to be significantly more likely to have a reason for environmental innovation such as "current or expected market demand from customers", future potential environmental regulations or taxes, existing environmental regulations or taxes on pollution (CSO, 2010).

In terms of knowledge transfer, there are higher levels of interaction between foreign-owned companies and higher education institutes. The latter are the source of most of Ireland's government-funded R&D. Foreign-owned companies have also been shown to have higher levels of innovation output from R&D-based activities (CSO, 2012).

Rates of co-operation between Irish-owned firms and other entities are significantly lower than for non-Irish firms across nearly all categories; exceptions are that (1) Irish-owned firms are more likely to co-operate with competitors or other enterprises in the same sector and (2) Irish-owned companies are more likely to co-operate with government or public research institutes (CSO, 2012).

5.3 Summary

Countries that are successfully building vibrant climate technology (cleantech, green tech, etc.) sectors are well governed; have clear policy signals, long-term plans or targets and high levels of collaboration; are well financed; and treat the environment as a vital resource. In general, the countries that have vibrant and pro-innovation economies (Finland, Denmark, Switzerland) are more successful in niches such as climate technology than countries that specialise but have less consistent innovation policies (Israel).

Ireland has a strong innovation system, but remains an innovation follower and not yet an innovation leader. The benchmarking analysis has highlighted areas where Ireland can improve, notably in collaboration, entrepreneurship opportunity evaluation, green public procurement and cleantech deployment. Additional data sources have highlighted the difference between the more innovative MNC sector and the less innovative SME sector. It must be noted that all of these additional data sources were for Irish companies in general and were not focused on the climate technology sector.

Government policy had a clear role in setting the agenda, articulating visions and creating an enabling environment. In 2015, the Irish government launched a new report on innovation strategy that sought a modest increase in R&D as a percentage of GDP, from 1.6% in 2014 to 2% in 2020. The report's initiatives included increasing international collaboration through European funding (i.e. Horizon 2020), increasing the number of postgraduate researchers and stronger linkages between industry and academia (DJEI, 2015). Many of the recommendations and planned action in that report, if implemented, would boost Ireland's climate technology sector.

6 Conclusions

This chapter reviews and summarises the conclusions and recommendations from throughout this report. Additional recommendations are based on outcomes of the Climate Technology Conference and Stakeholder Event[18] held in Dublin in November 2014.

6.1 Climate Technology

Climate technology opportunities exist where climate change challenges align with research strengths and/or commercial capability. These opportunities can be quantified in terms of environmental benefits (GHG emissions, and energy-use, air-quality and land use co-benefits) and economic benefits (cost savings, energy use and value chain potential). Owing to the broad definition of climate technology, the range of co-benefits can be readily demonstrated. By addressing climate challenges with climate technology, many other challenges are addressed (air quality, resilience to extreme weather, indigenous economic development, employment).

Climate technology research being carried out in Ireland, and climate technology companies founded or based in Ireland, create opportunities to address climate change and contribute to economic growth.

Agriculture and land use technologies and projects are being developed in many laboratories in Ireland. Advanced technologies are available for reducing GHG emissions, which can improve efficiency and have a strong business case. While some of these technologies have been deployed by climate technology agriculture companies (particularly the efficiency technology), there is not a significant climate technology agriculture sector because the emphasis of the agriculture sector is mostly on production. There have been a number of successful sector-wide management and accreditation schemes (Origin Green, the Carbon Navigator), which could be readily adapted to new business models that emphasise sequestration. There is a great deal of potential for biofuels resource generation as part of the agriculture sector, and this has been highlighted by many opportunity reports in the past. That opportunity remains, and sufficient government incentives (e.g. for renewable heat) could make a positive contribution.

Both research agencies and companies are active in climate services, but at the moment there is not much overlap. Significant innovative technology research is taking place, and some of the most innovative research is highly collaborative across many types of organisations (universities, research agencies and private companies). Some of the research is also finding users (and a market) outside Ireland. While there are some climate services technology companies, many of them are software companies or describe themselves as consultants. Many climate services applications will require either innovative business models or new types of markets (e.g. local emission-trading markets). Many climate services technology applications are more likely to be used by national or local government entities, owing to their climate adaptation uses. Given the current emphasis on cost in public procurement and the weakness of "green directed" government procurement, there may be potential for government policy to support the young climate services sector more carefully.

Smart buildings is an enormous opportunity area owing to the number of buildings and the increasingly urgent need to decarbonise the buildings (and heat) sector. Ireland has a thriving ICT sector and many researchers and companies are developing technologies that will optimise the use of energy in buildings. There is good collaboration in this sector between researchers and private companies. Unlike other sectors, it is questionable whether more advanced technologies will make a major breakthrough or not. Established building technologies have not been deployed at expected rates, even when the technology is economically viable. Despite many demonstration buildings, building users have been slow to adopt the optimising technology. Technology researchers need to address this challenge in collaboration with industry partners.

There is a diversity of climate technology – both mitigation and adaptation – for the marine sector. Through research centres (such as Marine Renewable Energy Ireland), collaboration between research and industry is taking place and research capacity is growing. A

18 The event report is available online at: http://www.ucc.ie/en/climatetechnology/event/report

research centre approach particularly helps international collaboration, which, in a sector such as marine renewable energy, is particularly important for scaling up technology development.

The water sector in Ireland is applying technology solutions to many adaptation climate challenges. Again, many of the most innovative solutions are emerging from collaborative projects by teams from different types of organisations. Innovative climate technology has been deployed in the agri-food sector, where large volumes of water are used; these are largely efficiency solutions. Other potential users of water technology are utilities and local authorities responsible for water management. Again, as they are the main expected users of climate technology, the role for green public procurement to support technology diffusion is important. In the wastewater sector, research is focused on efficiency gains and remains small in scale.

Most transport climate technology companies are focused on energy efficiency; few are developing or deploying new technology. Ireland needs more innovative transport companies and developers of technology. Developers of air-quality and transport technologies can potentially align their interests.

6.2 Benchmarking Ireland

Benchmarking Ireland using indices (Chapter 5) produces recommendations, mostly from broad-based findings, that a number of common features unite the highest-scoring countries: a long-term plan with which medium- and short-term policy is consistent; good governance; a strong education system; clear support; and a well-integrated and interconnected innovation system of firms and research institutes. One specific suggestion is that government procurement be restructured so that innovative products and services are favoured even if marginally more expensive. In this way, the government uses its large footprint as a customer to lead policy and help stimulate the market.

A data metric that is not yet available for country comparison is the TRL. Through its ability to measure, track, map, plot and be evaluated, it can be an excellent policy lever. A national strategy that makes use of innovative forms of collaboration between different organisation types (especially research and industry) in order to advance these TRLs would be an excellent facility for progress. A TRL map of a technology sector would be an excellent way to evaluate the sector. It could also inform national policy design; for example, it could be considered shortsighted to fund research that does not have a clear funding line across all TRLs. A short-term solution could be to bring in suitable supports from outside. There is further discussion of TRLs in Appendix 4.

6.3 SMEs

Climate change will have local impacts. The potential for regional development has been shown by the heat map showing the distribution of climate technology companies in Figure 3.1. Smart specialisation is a strategic approach to regional development that encompasses climate change challenges. For Ireland, with a large FDI and MNC sector, climate technology is an opportunity to further nurture and grow the indigenous SME sector.

6.4 Collaboration

Many indicators show poorer than expected levels of collaboration (1) between industry and university (for indigenous firms, i.e. 99% of firms in Ireland) and (2) between universities and government bodies, as measured by joint publications and joint patents. A diversity of organisations is involved in climate technology; improving collaboration nationally and building coalitions around climate change challenges could provide a forum and a mechanism for enabling engagement.

A Climate Technology Conference and Stakeholder Event was held in November 2014. It included participants from academia, industry and government agencies on the topic of climate technology and its opportunities. A theme that emerged strongly from this event was the importance of collaboration between different entities and types of organisation involved in climate technology, that is tertiary education institutes, industry, government bodies and the general public. For a home-grown innovation effort, this points to a need for more focused support for indigenous firms to collaborate with Irish research entities. The theory behind the importance of collaboration is the well-known cluster effect (Delgado *et al.*, 2014), and co-operation is essential for clustering. Many measures in the Innovation 2020 strategy launched in 2015 specifically target collaboration.

This report has encountered a number of different models of collaboration: the Electricity Supply Board has a vice-president for external collaboration, who is actively engaged in open innovation, and the I2E2 (Innovation for Ireland's Energy Efficiency) Centre is an excellent example of an innovative model for how industry and academia can collaborate. Nevertheless, more collaboration and models of collaboration are needed. The government and its agencies (e.g. Enterprise Ireland and the Industrial Development Agency) can have a lead role, particularly in facilitating such innovative models.

To foster EU-wide climate innovation, an organisation called Climate-KIC was originally set up by the European Institute for Innovation and Technology (EIT) as Europe's climate innovation laboratory. Climate-KIC currently has permanent bases (co-location centres or regional innovation centres) in 13 EU countries (not including Ireland). There are opportunities to engage with Climate-KIC – more details will be available soon. Through its emphasis on collaborative consortia, Horizon 2020 is changing the research agenda, which will lead to more international collaboration opportunities for Irish researchers.

There are opportunities for international activity through participation in the UNFCCC technology activities, which arise from some of the activities mentioned at the start of this report. The main UNFCCC technology transfer mechanism is the Climate Technology Centre & Network (CTCN). The CTCN is currently fielding requests for assistance from developing countries and the number of requests is expected to grow over time. There are opportunities for Irish companies, universities, non-governmental organisations and firms to participate by becoming members of the network. More details about the CTCN and how to participate are available online (http://ctc-n.org/). On 8 February 2016 the Environmental Research Institute in UCC became the first Irish member of the CTCN.

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Abbreviations

CIT	Cork Institute of Technology
Climate-KIC	Climate Knowledge and Innovation Community
CNG	Compressed natural gas
COP	Conference of the Parties
CTCN	Climate Technology Centre and Network
DCU	Dublin City University
DIT	Dublin Institute of Technology
FDI	Foreign direct investment
GCF	Green Climate Fund
GDP	Gross domestic product
GHG	Greenhouse gas
ICHEC	Irish Centre for High-End Computing
ICT	Information and communications technology
IMD	International Institute for Management Development
IPCC	Intergovernmental Panel on Climate Change
IPO	Initial public offering
MCA	Multi-criteria assessment
MNC	Multinational company
NUIG	National University of Ireland Galway
OECD	Organisation for Economic Co-operation and Development
$PM_{2.5}$	Particulate matter of 2.5 μm or smaller
PM_{10}	Particulate matter of 10 μm or smaller
PV	Photovoltaic
QUB	Queen's University Belfast
R&D	Research and development
RD&D	Research, development and deployment
RIS3	Research and Innovation Strategies for Smart Specialisation
SFI	Science Foundation Ireland
SMEs	Small and medium-sized enterprises
TCD	Trinity College Dublin
TOPSIS	Technique for Order Preference by Similarity to Ideal Situation
TRL	Technology readiness level
UCC	University College Cork
UCD	University College Dublin
UL	University of Limerick
UNFCCC	United Nations Framework Convention on Climate Change
WWF	World Wide Fund for Nature

Appendix 1 Opportunity Space Reports

The following is a list of all the reports represented in the Wordle diagram in Figure 1.1.

- Coakley, T., Cunningham, D., Creedon, M. *et al*., 2007. *Investigation Into Why Existing Environmental Technologies Are Underused*. EPA, Johnstown Castle, Ireland.
- Curtin, J., 2014. *Unlocking Opportunity: The Business Case For Taking Climate Action In Ireland*. Irish Corporate Leaders on Climate Change, Dublin.
- DETE (Department of Enterprise, Trade and Employment), 2009. Developing the Green Economy in Ireland. DETE, Dublin.
- Ernst & Young, 2012. *Cleantech Ireland – an Assessment of the Sector and the Impact on the National Economy*. Cleantech Ireland, Dublin.
- Forfás, 2010. *Adaptation to Climate Change: Issues for Business*. Forfás, Dublin.
- Forfás, 2011a. Report of Research Prioritisation Steering Group. Forfás, Dublin.
- Government of Ireland, 2012. *Delivering Our Green Potential*. Government of Ireland, Dublin.
- ICSTI (Irish Council for Science, Technology and Innovation), 1999. *Technology Foresight Ireland – an ICSTI Overview*. Forfás, Dublin.
- InterTradeIreland and Forfás, 2008. *Environmental Goods and Services Sector on the Island of Ireland*. Forfás and InterTradeIreland, Dublin.
- SEAI (Sustainable Energy Authority of Ireland), IDA Ireland and Enterprise Ireland, 2014. *Ireland's Sustainable Energy Supply Chain Opportunity*. SEAI, Dublin.
- The Green Way, 2014. *Cleantech in Ireland 2014*. The Green Way, Dublin.

Appendix 2 Multi-criteria Headings Full Description

Some of the following principles for criteria selection were adopted: they should be *complete*, that is all relevant criteria have been included; *operational*, that is each option can be judged against each criterion; *mutually independent*, that is options are independent of each other from one criterion to the next; with *no double counting*; and *consistent with effects occurring over time* (de Bruin *et al*., 2009).

Other criteria included were that they should be *guided by their relevance to this objective*; *non-redundant*, in the sense that performance on each criterion must vary significantly between at least some of the adaptation options; *directional*, that is defined in such a way that higher or lower levels of performance can be interpreted as better or worse; *measurable*, that is it should be possible to estimate relative levels of performance for each adaptation alternative on each criterion; and *manageable*, as too many criteria make the process unwieldy and difficult to interpret, and invite duplication (Dolan *et al*., 2001).

The criteria lists for mitigation and adaption projects are as follows:

Mitigation

1. *GHG reduction:* by how much the technology will reduce GHG emissions compared with the baseline and the scale at which can the technology be implemented.
2. *€/CO_2 avoided:* the cost of the project in euros per tonne of CO_2 avoided.
3. *Energy savings:* a measure of the potential energy savings of the technology.
4. *Resource sustainability (raw materials, waste):* a measure of the materialisation requirements, which take account of both input of materials and output of waste.
5. *Co-benefits (air quality, land use, water use):* a measure of any co-benefits of the technology (Smith, 2013).
6. *TRLs:* the technology readiness levels as used by Horizon 2020.
7. *Business case:* the net present value of the technology.
8. *Risk:* the level of risk of the project.
9. *Public acceptability (safety):* a measure of the safety and social acceptability of the technology.
10. *Value chain (commercialisation, market formation, manufacturing, deployment and services, supply chain, job creation):* depending on the value chain for the technology and the potential contribution at each stage.

Adaptation

In addition to criteria 5, 6, 8, 9 and 10 above, the following criteria are chosen for adaptation projects:

1. *Importance:* number of people affected by impact; urgency of the option.
2. *Resilience:* how well measure mitigates risk; likelihood of impact.
3. *No regrets:* good to implement, irrespective of climate change.
4. *Cost:* reduces cost now, but likely to grow over time?

Appendix 3 Climate Technology Company Sectors and Tags

Tag	Company sector						
	Climate services	Energy efficiency	Energy storage, supply, generation	Renewable energy	Transport	Waste management	Water and wastewater
Agrifood	5	17	3	14	–	3	5
Bioenergy	1	37	–	25	1	–	2
Building and materials	6	40	5	11	–	5	3
CHP	1	13	–	9	–	–	–
Climate services	4	–	–	2	2	–	–
Electrical power conversion	8	30	5	24	3	2	–
Energy management and services	18	5	–	1	2	–	–
Energy storage	–	2	2	3	1	–	–
Heat boilers	–	17	1	4	–	–	–
Hydro	–	4	–	5	–	–	–
ICT/Smart grids/Smart cities	1	12	–	3	4	–	–
Marine	8	4	1	–	–	–	–
Marine renewable energy	1	1	–	6	–	18	–
Smart buildings	1	23	1	1	–	1	20
Solar	1	–	1	7	–	–	4
Technology transfer	–	2	–	8	–	–	–
Transport	27	118	8	6	5	24	33
Waste management	2	3	–	–	–	1	–
Wastewater	3	–	–	3	–	1	24
Water	2	–	–	–	–	–	4
Wind energy	11	17	2	23	1	1	23

CHP, combined heat and power.

Appendix 4 Technology Readiness Levels

Technology readiness levels (TRLs) are increasingly used as a policy tool for governments and associated bodies to track technology development over time. For example, TRLs are a central part of Horizon 2020 funding proposals, were prominent in the recent Innovation 2020 report from the Irish government (DJEI, 2015) and are being increasingly used by SFI in tracking the progress of the research they fund. The TRLs are a powerful data analysis tool and policy lever, which can be measured, tracked, mapped, plotted and evaluated over time.

However the use of TRLs in Ireland is in the early stages and (to the best of the authors' knowledge) no *ex post* data are available on TRL distributions according to agency responsibility. The authors held a number of interviews with various persons in various agencies with the intention of building a map of TRL responsibility by agency; however, the diversity of responses implied a lack of coherence regarding TRLs, which may be due to the relative newness of the concept as an evaluation metric in Ireland.

While on a study visit to the West Midlands, UK, organised by the Climate-KIC outreach programme in Ireland, one of the authors of this report was introduced to the Warwick Manufacturing Group, which specifically positions itself to bridge the gap between TRL 4 and TRL 8, which is known as the "Valley of Death". This reflected the strength of the University of Warwick's close ties to industry. Testimonials from successful collaborations between universities and SMEs have pointed to the mutually beneficial nature of the collaboration: both participants had their external credibility boosted by having a clear collaboration with an entity on the other side of the research–private divide. This showed the benefits of building a research organisation specifically around a TRL gap that had been previously identified.

The data shown in Figure A4.1 are for a sample of climate technology research as described in Chapter 2. The distribution of this graph is clearly weighted towards lower TRLs; in part, that is because of the nature of the sample, and it is to be expected that universities and colleges would have a larger share of lower TRLs. A national strategy that makes use of innovative forms of collaboration between different organisation types (especially research and industry) to advance these TRLs would be an excellent facility for progress.

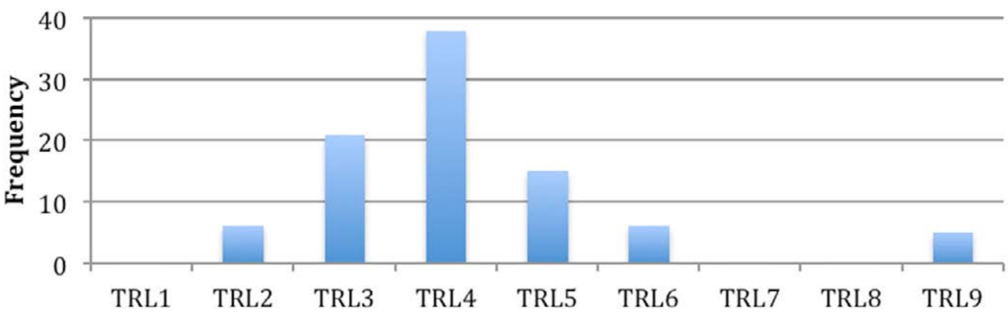

Figure A4.1. TRLs of climate technologies.

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- An Oifig um Cosaint Raideolaíoch
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Climate Technology - Realising the Potential

Authors: Fionn Rogan, Paul Bolger and Brian Ó Gallachóir.

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Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Climate change mitigation and adaptation challenges are faced across all facets of activity; government, business, energy, transport, agriculture and domestic life. Deployment of new technologies, including observation systems, smart systems in electricity distribution, in buildings and in cities, is required. Innovative processes and materials as well as uptake of low emissions energy sources will be crucial to meet long term mitigation goals. Adapting to climate change impacts will also benefit from technological solutions such as sensors, information technologies and observation systems e.g. for early warning systems, to increase resilience of infrastructure and improve response to extreme weather events. These approaches require focussed solutions building on cross disciplinary understanding of technological capacities and climate solution requirements.

Identifying Pressures

Analysis was based on a broad survey of current and recent climate technology research in Irish third-level organizations and institutes, and of climate innovation and technology use activities in the private sector. A technology innovation system framework was employed to explore strengths and weaknesses in climate innovation across sectors.

Informing Policy

Government has a key role to play in supporting climate technology innovation, enterprise and deployment. For many climate technologies, national or local governments and even state-owned companies are key customers, therefore government procurement policy can have great impact. Given the current emphasis on cost in public procurement and the weakness of "green directed" government procurement, there may be potential for government policy to more carefully support the young climate technology sector.

Developing Solutions

There is a very broad range of companies in Ireland developing technology or working with technology that has a direct relationship to climate change. While certain companies and sectors are more directly engaged with climate change than others - e.g. power generation companies compared to pharmaceutical companies - more and more types of companies are bringing climate change into their business models. To capture and describe the diversity of these companies, a climate technology company catalogue was prepared that categorised 261 companies into seven sectors and described each with one or more tags. These climate technology companies are actively involved with different parts of the value chain and for products and services.

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