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Fossil Fuel Lock-in in Ireland: How Much Value is at Risk?

Authors: Celine McInerney, Conor Hickey, Paul Deane, Joseph Curtin and Brian Ó Gallachóir

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Rialtas na hÉireann
Government of Ireland

ENVIRONMENTAL PROTECTION AGENCY
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- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

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EPA RESEARCH PROGRAMME 2014–2020

Fossil Fuel Lock-in in Ireland: How Much Value Is at Risk?

(2015-CCRP-MS.27)

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Prepared for the Environmental Protection Agency

by

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The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders 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.

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Executive Summary

- At the 21st Conference of the Parties (COP21) in Paris in December 2015, 195 countries adopted a global climate deal agreeing to a long-term goal of maintaining temperature increases well below 2°C above pre-industrial levels. Article 2.1c of the Paris Agreement includes an objective to strengthen the global response to the threat of climate change by "making finance flows consistent with pathways towards low greenhouse gas emissions and climate resilient development". The European emissions reduction policy is clear and calls for the energy sectors, particularly the electricity sector, to be carbon neutral before 2050. Ireland has ambitious targets for emissions reductions by 2050, yet these can be achieved only if significant changes are made to reduce emissions in the electricity, heat and transport sectors.
- Focusing on the electricity sector, the objective of this study is to examine how the decarbonisation of the power system will impact the investment case for both electricity generation and infrastructure assets.
- Natural gas has been promoted as the "transition" fuel in decarbonisation pathway scenarios. However, there is widespread acceptance that increasing penetration of low-carbon generation (mainly wind and solar), whose fuel cost is zero with priority dispatch, in many liberalised electricity markets has led to significant reductions in running hours and profits earned for owners of coal, oil and gas electricity generation assets. The share of gas in the European energy mix has declined from 23% of gross electricity production in 2010 to 16% in 2015. Consequently, gas-fired generation assets have become stranded and impaired. Stranded assets are defined as "assets that have suffered from unanticipated or premature write-down, devaluations or conversion to liabilities". Impaired assets are those whose value has been written off because the market value exceeds the current carrying value on the company balance sheet.
- Stakeholders in the finance and banking industries, including central banks, regulators and credit rating agencies, have warned of the financial risk associated with being locked into fossil energy systems and have called for collective action to facilitate the role of the financial sector in achieving the objectives for the Paris Agreement. Ten of Europe's largest utilities have experienced a deterioration in credit ratings by three to four notches from the Aa/high single A rating level. It has been suggested that decarbonisation and the continued transition to renewable energy in Europe poses long-term risks to the region's regulated electricity and gas network operators, as changing business models, developing technology and evolving regulation could potentially undermine their credit quality over time. It has been estimated that €143 billion has already been written off European power sector asset values under accounting impairment rules between 2010 and 2016, as gas is replaced by less expensive renewable technologies in the "merit order" of lowest cost generators. The Bank of England[1] recently warned that climate change poses a major risk to the financial system and warned of a climate "Minsky moment" in which financial risk relating to climate change and fossil fuel lock could lead to a major collapse of asset values.
- Energy system pathways for Ireland and Europe suggest that power generation will have to be carbon neutral by 2040, which means that fossil fuel generators may have to be shut down prematurely, creating stranded asset risks. This means that owners of these assets will suffer financial losses. This may have implications for security of supply in the short term as fossil fuel generators provide back-up and balancing services for intermittent renewable generation. The investment case for fossil infrastructure assets is also likely to be undermined. The gas network is remunerated under a regulatory asset

1 https://www.bankofengland.co.uk/-/media/boe/files/speech/2019/avoiding-the-storm-climate-change-and-the-financial-system-speech-by-sarah-breeden.pdf (accessed September 2019).

base (RAB) regime and is therefore dependent on the size of the customer base to pay fees. In a low gas consumption world, the RAB will come under pressure as a lower customer base will result in higher fees.

- Our assessment suggests that gas generation assets and gas transmission networks could incur risks by 2030, whereas the gas distribution network may incur similar risks between 2030 and 2050. Low-carbon opportunities through the integration of renewable gas and carbon capture and storage to reduce the emissions of gas network customers could prolong the life of the network. However, renewable gas is significantly more expensive than conventional gas and carbon capture and storage technology is yet to prove itself at scale deployment.
- Under the electricity generation projection results to 2030 from the European Commission's Reference Scenario, in which the carbon intensity of power generation from thermal plants decreases by 17% in 2020 relative to 2005 and by 32% in 2030, operators of gas generation assets in Ireland may need out-of-market payments of up to 33% of revenues to incentivise investment in 2030. This is up from the current rate of 22%. Under this scenario we also estimate that gas transmission tariffs could increase by 24% on average for Ireland by 2030 relative to 2015.
- Using a committed emissions approach, which examines the amount of emissions to be produced over the remaining life of an asset, we find that there may be debt maturity management and debt rollover risk for Irish utilities if 2050 low-carbon goals are pursued. The ability of utilities to manage their debt is a function of their credit rating. The credit rating is derived based on cash flows from operations, and the compatibility of these cash flows with low-carbon scenarios is an indicator of future credit quality and the ability to raise debt in the capital markets. Our results indicate that under both the 1.5°C and the 2°C emissions reduction targets there may be challenges refinancing debt for Irish fossil generators.
- The outcome of our investor survey suggests that the understanding of, and ability to accurately quantify, stranding risk may be less developed for financial sector investors than for power sector investors. When we looked at responses by sector, power sector respondents considered Irish, European Union (EU) and international policy development as the most significant sources of stranding risk, in that order, followed by technological change. If storage technologies improve in scale and cost-efficiency, they will be used to help balance the intermittent renewables management issues, a role that gas has traditionally played.
- Our report identifies a significant potential stranded asset risk for both generation and infrastructure assets in Ireland. Under deep decarbonisation scenarios (80% reduction in emissions by 2030 relative to 1990 levels), returns to owners of generation and transmission and distribution assets will no longer be sufficient to attract capital. In order for security of supply to be maintained and for continued investment to be made in infrastructure assets, new approaches to incentivising long-term investment and "out-of-market payments" for capacity will be required.
- Achieving the goals of the Paris Agreement requires a shift in capital allocation to low-carbon assets. This will adversely impact the valuation of fossil fuel assets. Stakeholders in the financial sector are becoming much more focused on stranded asset risk and fossil fuel assets have seen significant diminution in asset values. If European and national policies for emissions reduction are deemed to be credible by investors, the valuation of fossil fuel assets will probably fall further.

1 Project Background and Introduction

1.1 Introduction

If "dangerous" climate change is to be avoided, immediate and rapid decarbonisation must be achieved over the coming decades. Parties to the Paris Agreement of December 2015 agreed to maintain global temperatures "well below 2°C above pre-industrial levels" and to "pursue efforts" to limit temperature increases to below 1.5°C (UNFCCC, 2015). Staying within the 2°C temperature target would require an estimated US$3.5 trillion in investment each year until 2050 across the energy generation, industry, transport and buildings sectors (Covington, 2017; IEA, 2018), which is about double the current level of investment. There is a significant body of literature around the idea of "unburnable carbon" (CTI, 2013; Knight *et al*., 2015; McGlade and Ekins, 2015), with the carbon content of the reserves of quoted oil and gas companies approximately three times that which could be burned to maintain the global 2°C scenario by 2050. McGlade and Ekins (2015) show that, globally, one-third of oil reserves, half of gas reserves and over 80% of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2°C.

Unruh (2000) suggests that industrial economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution, driven by path-dependent increasing returns to scale that inhibit the diffusion of low-carbon technologies, despite their apparent environmental and economic advantages. However, once these technological and institutional lock-in issues are overcome, the risk of stranded assets will increase significantly. Policy initiatives to decarbonise electricity generation to reduce emissions of harmful greenhouse gases (GHGs) have had unexpected consequences for risk and return for power sector investors. There is now widespread acceptance that increasing penetration of low-carbon generation, with no operating costs as the fuel is free and with priority dispatch in most liberalised electricity markets, has led to significant changes in price volatility and operational regimes for thermal generators (Sàenz de Miera *et al*., 2008; Sensfuß *et al*., 2008; Green and Vasilakos, 2010; Hirth, 2012; Muñoz and Bunn, 2013).

Recent commentary from equity research analysts and rating agencies highlights the investment risk of fossil fuel stranded assets. Decarbonisation has resulted not only in reduced annual profits but also in a more fundamental devaluation of carbon-intense generation, with significant asset write-downs as a result of impairment charges under accounting regulations that reflect the lower running hours of fossil generators in deep decarbonisation scenarios. The asset write-offs are largely attributed to the development of renewable energy sources, which tends to push thermal power plants out of the merit order, lowers electricity prices on wholesale markets and has led to mothballing and plant closure.

1.2 Stranded Assets

Much of the literature cited above has focused on how investor perception may unjustly disadvantage low-carbon technologies (Masini and Menichetti, 2013), the ways in which high-carbon investments are therefore "locked in" (Unruh, 2000) or the manner in which past investments in fossil fuels may influence the risk–return perception of decision-makers (Pinkse and van den Buuse, 2012). However, the ways in which climate change could affect risk perception for investors in fossil fuel assets have also been the subject of growing interest from regulators, banks and rating agencies. Krause *et al*. (1989) first applied the concept of "stranded assets" to the climate policy arena by identifying the potential for "early obsolescence" of infrastructures built up around fossil fuels under low-carbon transition, which could pose risks for the value of stocks and financial markets (Simshauser, 2017).

Ten of Europe's largest utilities have experienced a deterioration in credit ratings by three to four notches from the Aa/high single A rating level. Moody's (2014, 2017a) suggests that decarbonisation and the continued transition to renewable energy in Europe poses long-term risks to the region's regulated electricity and gas network operators, as changing business models, developing technology and evolving regulation could potentially undermine their credit quality over time. To date, Irish utilities have been insulated from gas being "out of merit" by capacity payment and constraint payments. However, this risk is increasing in Ireland as growth in zero marginal cost generation puts further pressure on the old market mechanisms.

1.3 Irish Policy Context

The energy policy White Paper (DCCAE, 2014) sets out a vision for transforming Ireland's fossil fuel-based energy sector into a clean, low-carbon system by 2050. The Climate Action and Low Carbon Development Act 2015 (Government of Ireland, 2015) provides a statutory basis for the national objective of transition to a low-carbon, climate-resilient and environmentally sustainable economy by the year 2050 and gives a solid statutory foundation to the institutional arrangements necessary to enable the State to pursue GHG emission mitigation and climate change adaptation measures. The recently launched National Development Plan 2018–2027 (DPER, 2018) includes a commitment of €21.8 billion investment (€7.6 billion Exchequer/€14.2 billion non-Exchequer) towards achieving the 2050 goal (National Sustainable Outcome 8). There is an indicative allocation of €8.6 billion for environmentally sustainable public transport (National Sustainable Outcome 4). This project provides insight for Irish policymakers to understand where capital is best allocated to avoid stranded asset risk. The government's *Climate Action Plan to Tackle Climate Breakdown*,[2] released in June 2019, charts an ambitious course towards decarbonisation targets and commits the government to carbon-proofing policies and future investments. This is important as many fossil fuel generation assets are in state-owned companies that pay dividends to the State. Under deep decarbonisation scenarios the use, and hence profitability, of both generation assets and network transmission assets vary. This will have implications for how these assets are financed and how asset owners are compensated for investment risk. This is particularly relevant in the context of returns on regulated assets.

1.4 Project Objectives and Methodologies

This research assesses Ireland's exposure to carbon lock-in and stranded asset risk. A literature review quantifies and documents existing fossil fuel assets, infrastructure and support systems in Ireland. These results are compared with global and European Union (EU) studies to benchmark Ireland's position. The Irish integrated energy systems model, TIMES (The Integrated MARKAL-EFOM System), which allows for detailed techno-economic scenario analysis, is used to assess how the value of these assets evolve under a series of decarbonisation scenarios for Ireland up to 2050. The output from the Irish TIMES energy model is then used to value these assets using a number of different valuation techniques, including discounted cash flows and banking models, to assess financial viability under the decarbonisation scenarios. We examine the published literature to determine the financial impact of stranded asset risk. Various financial models are developed and a survey of Irish investors is also conducted to assess how stranded asset risk impacts investor capital allocation decisions.

1.5 Report Layout

This report presents the output from each of the project objectives. Chapter 2 reports on a systematic literature review examining stranded asset risk. In Chapter 3, the Irish fossil fuel generation and infrastructure assets are catalogued and the financial viability of Ireland's generation and infrastructure assets is examined under deep decarbonisation scenarios. In Chapter 4, Ireland's position is benchmarked with those of other European countries. Chapter 5 presents the results of a survey conducted with Irish investors in power generation assets to assess their understanding of stranded asset risk. In Chapter 6, we draw conclusions and make policy recommendations based on our research findings.

2 https://www.dccae.gov.ie/en-ie/climate-action/topics/climate-action-plan/Pages/climate-action.aspx (accessed September 2019).

2 Literature Review

2.1 Introduction

Over the last decade, investor perceptions of risk and return have become an important stream of research in the energy finance, energy policy and energy economics literature. The importance of the risk and profitability characteristics of investments is generally accepted to be highly influential over investor behaviour (Dinica, 2006). It is widely accepted that investors – whether in electric utilities, insurance companies, pension funds or even retail – compare opportunities according to perceived risk-adjusted returns (Wüstenhagen and Menichetti, 2012). Lower risk perception for renewable energy projects or higher risk perception for fossil fuel projects could therefore affect investors' cost of capital, which in turn is important for determining the rate of technology diffusion and the pace of low-carbon transition.

Much of this literature has focused on how investor perception may unjustly disadvantage low-carbon technologies (Masini and Menichetti, 2013), the ways in which high-carbon investments are therefore "locked in" (Unruh, 2000) or the manner in which past investments in fossil fuels may influence the risk–return perception of decision-makers (Pinkse and van den Buuse, 2012). However, the ways in which climate change could affect risk perception for investors in fossil fuel assets have also been the subject of growing interest. Krause *et al*. (1989) first applied the concept of "stranded assets" to the climate policy arena by identifying the potential for "early obsolescence" of infrastructures built up around fossil fuels under low-carbon transition, which could pose risks for the value of stocks and financial markets (Simshauser, 2017).

This is a theme that has garnered greater analytical attention as the international political movement to address climate change has gathered pace over the past decade. Most notably, 193 nations at the Cancun Climate Conference in 2010 agreed to "hold the increase in global average temperatures below two degrees". This objective was subsequently incorporated into the Paris Agreement of December 2015, which committed parties to avoid "dangerous" climate change and to maintain global temperatures "well below 2°C above pre-industrial levels", and to "pursue efforts" to limit temperature increases to below 1.5°C (UNFCCC, 2015).

A parallel scientific development was the increasing prominence given to carbon budgets, that is, the amount of cumulative GHG emissions in the atmosphere consistent with meeting a particular climate objective. The UK's Committee on Climate Change has been a world leader in this regard, setting climate budgets supported by legislation and outlining future pathways for delivering on those budgets. Carbon budgets refer to CO_2 emissions and imply that stabilisation of the global temperature at any level will require net zero emissions at some point. The first global carbon budget estimates were provided by Meinshausen *et al*. (2009) and Allen *et al*. (2009). Further estimates have subsequently been provided under different assumptions in a wide number of studies (Rogelj *et al*., 2010, 2016). The concept was mainstreamed into climate policy analysis by the Intergovernmental Panel on Climate Change synthesis report (IPCC, 2014), which provided estimates for budgets consistent with 1.5°C, 2°C or 3°C warming. Recent budget estimates have focused on achieving the 1.5°C target (Millar *et al*., 2017; Goodwin *et al.*, 2018). These carbon budget estimates gave rise to the concept of "unburnable carbon", which refers to the fossil fuel reserves that cannot be burned and which are consistent with staying within a particular carbon budget (CTI, 2011), an idea that has attracted considerable analytical and public attention (Vergragt *et al*., 2011; *Economist*, 2013; Leaton *et al*., 2013; Griffin *et al*., 2015; Caldecott, 2017) and that has clear implications for investor risk perceptions.

If these assets are effectively "unburnable", their worth could be vastly reduced and they could therefore fail to produce the return hoped for (Caldecott *et al*., 2014). In other words, these assets may become "stranded". Although there are a number of possible definitions of stranded assets, we adopt the definition proposed by Caldecott (2014: 7), that "stranded assets are assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities". Central to the question of stranding risk, therefore, is the extent to which risks arising from climate change are correctly integrated into the risk-adjusted returns by actors in the financial system, and therefore the extent to which these risks are integrated into market prices. The premise of the stranding literature is that stranding risks may be mispriced for a number of reasons (Harnett, 2017; Silver, 2017; Thomä and Chenet, 2017), although some have argued that stranding risk has been adequately integrated into market prices (Byrd and Cooperman, 2018).

This concept of stranding risk has moved from the fringes to the mainstream of debates in the climate change financial community. In September 2015, for example, the Governor of the Bank of England, Mark Carney, warned that there was a danger that assets of fossil fuel companies could be left stranded by tougher rules to curb climate change and that investors faced "potentially huge" losses because this action could make vast reserves of oil, coal and gas "literally unburnable". The Financial Stability Board, which reports to G20 governments and is chaired by Governor Carney, subsequently launched a Task Force on Climate-related Financial Disclosures (2017), which recommended that climate-related financial disclosures should be incorporated into mainstream public annual financial statements.

Within this context, the objective of this study is, first, to develop a novel analytical framework to codify both the academic and grey literature studies that evaluate stranding risk for fossil fuel assets and how this affects investors' risk–return preferences. Second, we use this analytical framework to undertake the first comprehensive and systematic review of this literature, covering the first decade of research, assessing both the methods used and the results of the literature.

2.2 Systematic Literature Review Approach

To identify studies of interest, we employed a systematic literature review approach. Systematic literature reviews offer an established methodology for presenting summaries of empirical evidence from across a range of disciplines (Kitchenham and Charters, 2007; Petticrew and Roberts, 2008; Hansen and Rieper, 2009).

In order to ensure the scientific validity of a systematic literature review it is important to determine the types of primary studies that the review is trying to locate by identifying inclusion and exclusion criteria. In this case, we included both *ex post* and *ex ante* studies employing both quantitative and qualitative methodologies that seek to explore stranded assets posed to fossil fuel assets from the transition to a low-carbon economy. We focused on studies related to financial assets and fossil fuel infrastructure (see section 2.3) and therefore excluded studies focusing on natural assets. We also excluded studies related to the physical impacts of climate change (HSBC, 2013) and instead focused on the risks posed by transition to a low-carbon economy (see section 2.4).

In order to identify academic studies of interest that met these inclusion criteria, we carried out searches using the search engines Science Direct, Google Scholar, Scopus and Web of Science and combinations of the terms "climate", "carbon" and "stranded asset" (Table 2.1). The titles and abstracts of these papers were read and irrelevant papers were discarded. Following Curtin *et al.* (2016), it became clear that, after the first hundred titles (in Science Direct and Google Scholar), the remaining results were irrelevant.

In addition, we searched for grey literature following Siddaway (2010), using the Stranded Assets Research Network's bibliography, curated by the Smith School of Enterprise and the Environment at Oxford

Table 2.1. Results of database searches using four different search engines

Search engine	"Carbon" + "stranded asset"	"Climate" + "stranded asset"
Science Direct	716	714
Google Scholar	11,400	18,100
Scopus	40	42
Web of Science	31	40

University, as a starting point. Furthermore, a number of key organisations, including the Carbon Tracker Initiative (CTI), the 2 Degrees Investing Initiative, the United Nations Environment Programme (UNEP), HSBC and Mercer, have undertaken much of the research into stranded assets. Reports by these groups were therefore reviewed as a starting point and bibliographies were used to identify further grey literature studies that met our inclusion criteria.

2.3 Types of Assets

Following Chenet *et al*. (2015), we first categorised relevant studies according to the type of assets considered, looking across the entire investment chain. Stranding risk first affects physical assets, including both the underlying fossil fuel reserves and the "downstream" infrastructures that rely on fossil fuels (power stations, transport assets, real estate, etc.). However, asset impairment can also affect the companies or countries that own these assets and could therefore impact on the share price or creditworthiness of these actors. This, in turn, could feed through to financial portfolios owned by institutional investors or, indeed, the balance sheets of financial institutions. Finally, the value of portfolios and the creditworthiness of financial institutions have the potential to feed into systems risk and to undermine the stability of the financial system (Carney, 2015) (Figure 2.1).

2.4 Risks

The focus of this study is on risk arising from climate change, excluding risks associated with the physical impacts of climate change. These have been described as "carbon risks" or "transition risks" (Chenet *et al*., 2015). Initially, transition risk was understood to arise from full implementation of a scientifically derived carbon budget agreed at international level (Caldecott, 2017). More recent work, however, has focused on a wider range of inter-related risks, including regulatory and policy risks (including carbon pricing), technological change and associated changes to the competitiveness of technologies, social norms and legal considerations. Following Caldecott *et al*. (2014), studies are categorised according to the types of carbon or transition risks they consider (Figure 2.2). Each pillar represents a source of potential risk to investors across a spectrum of relevant risks.

2.5 Methods Used

A wide variety of methods have been used to quantify the value of assets at risk of stranding (Chenet *et al*., 2015). In the case of physical assets, stranding risk to fossil fuel reserves is often measured by estimating the impact of a particular carbon budget constraint, in some cases integrating consideration of fossil fuel supply curves against emissions associated with each CO_2 budget scenario. Energy and economic systems modelling approaches have also been used. For downstream fossil fuel-dependent assets, exposure of power generation plants, transport infrastructure and real estate to risks arising from climate change has been determined through the development of qualitative and quantitative risk assessments.

In the case of companies and their stock, a variety of overlapping methods have been employed. Some studies explore fossil fuel supply curves under a particular constraint to determine risks for a particular

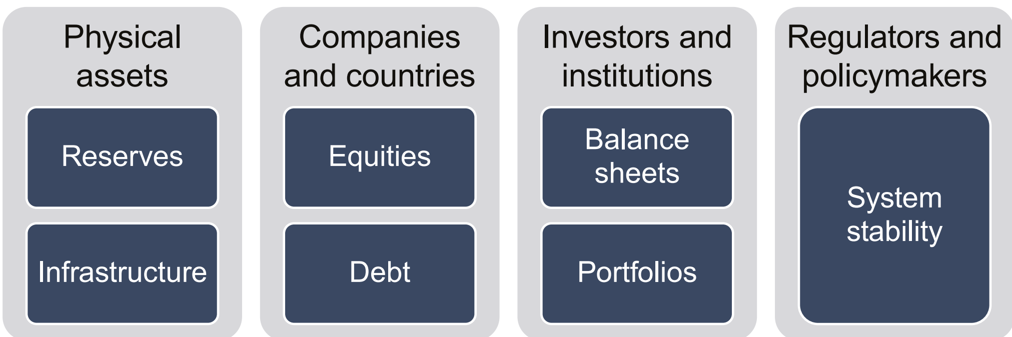


Figure 2.1. Investment chain for stranded assets. Source: adapted from Chenet *et al.* (2015) and WRI/UNEP (2012).

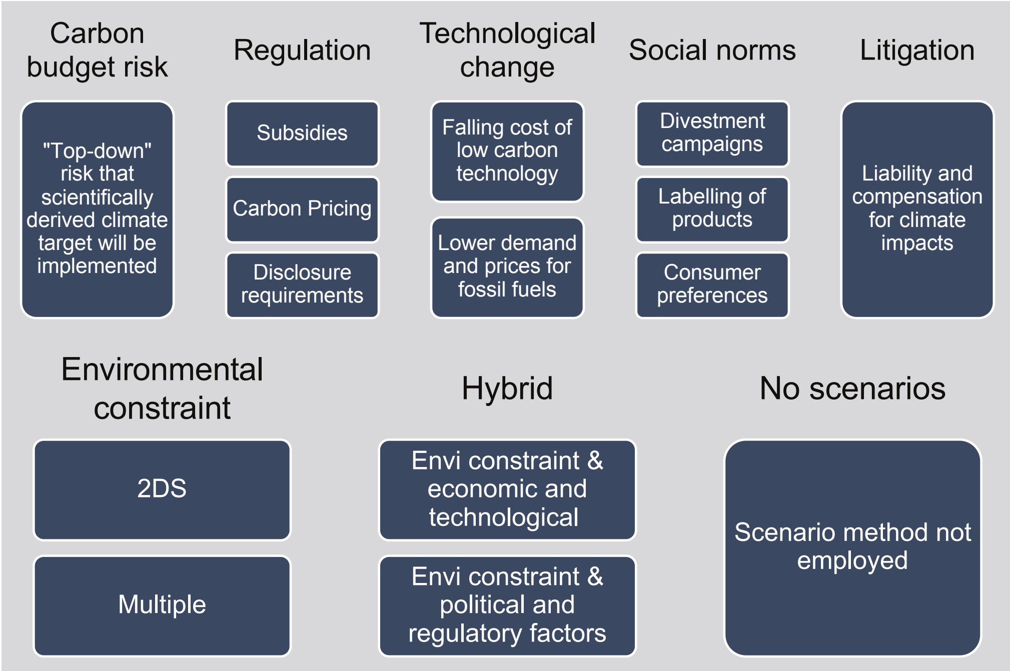


Figure 2.2. Analytical framework for carbon or transition risks. Source: adapted from Caldecott *et al.* (2013b).

company or sector. In other cases, a variety of financial/accounting tests are employed to determine value at risk and/or the potential implications for market capitalisation, share price, creditworthiness, etc. Other approaches include using a shadow price for carbon, qualitative risk assessments or measuring emissions intensity. Finally, *ex post* studies have quantified historical asset stranding using historical case studies and events studies. In the case of debt, stranding risk to sovereigns (or national governments) has been evaluated using carbon intensity of national income measured by gross domestic product (GDP). Company- and country-specific credit ratings and risk assessments have been used to determine the creditworthiness of a country or company under low-carbon transition.

When it comes to portfolios, economic/energy systems models have been used to assess the magnitude of risks for a variety of asset classes. The carbon intensity of portfolios and traditional stress tests have also been used to assess stranding risk. Finally, macro-prudential stress tests can be used to determine the implications of stranding risk for the financial system. The typology of methods used to value stranding risk, divided according to asset type, is provided in Figure 2.3.

2.6 Results and Discussion

2.6.1 Physical assets

Fossil fuel reserves

Many studies have explored stranding risk for total known fossil fuel reserves. The majority of this literature is forward looking, aimed at measuring potential future stranding risk under a 2°C scenario by comparing carbon budgets with known reserves. A strong consensus emerging from this literature is that, in a tightly carbon-constrained future, a large quantity of known reserves could face a stranding risk, especially carbon-intensive resources that are costly to exploit. The Carbon Tracker Initiative (CTI, 2011, 2013), for example, estimated that up to 80% of declared reserves could become stranded, whereas McGlade and Ekins (2015) estimated that one-third of oil reserves, half of gas reserves and over 80% of current coal reserves should remain unused from 2010 to 2050. Other studies have monetised this value at risk. For example, the value of the global fossil fuel reserves in a business-as-usual case (US$295 trillion) could decrease by 63% (Linquiti and Cogswell, 2016), whereas Kepler Cheuvreux (2014) estimated that the fossil fuel industry could lose up to US$28 trillion by

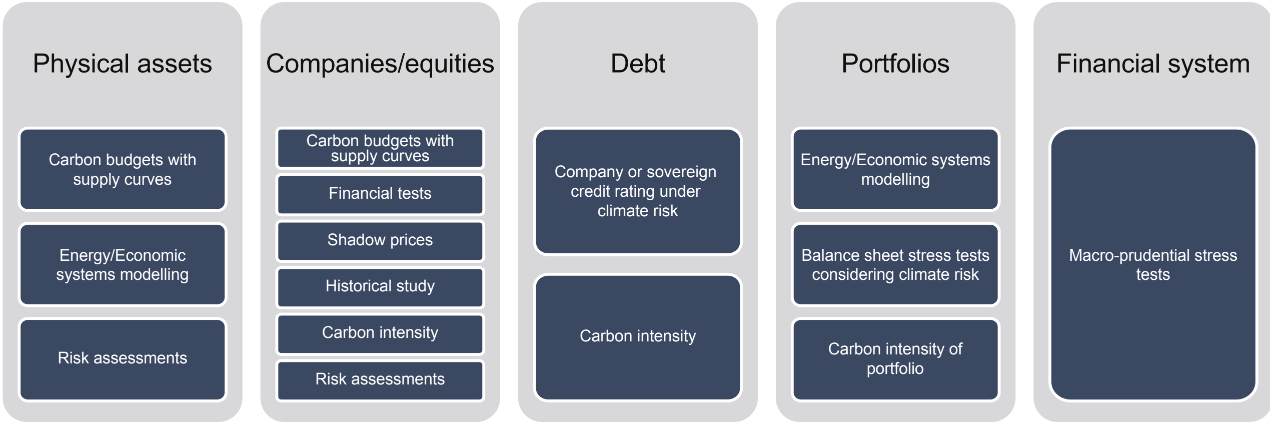


Figure 2.3. Methods used to value stranding risk. Source: adapted from Chenet *et al.* (2015) and WRI/UNEP (2012).

2035 and found that high-cost producers tended to be the most carbon-intensive ones and that the oil sector had the greatest level of exposure. CTI (2015a) concluded that US$2 trillion of capital expenditure (CAPEX) may not be profitable under a 2°C scenario, that no new coal mines could be developed, that liquefied natural gas (LNG) production would be curtailed slightly and that US shale oil, Canadian oil sands, Russian conventional oil and Arctic oil could also be stranded.

Not all studies, however, agree with projections of stranding risk for fossil fuel reserves. For example, Newell *et al*. (2016) did not impose a particular carbon constraint, but instead used harmonisation techniques to compile energy forecasts from the International Energy Agency (IEA), Exxon, Shell and the Organization of the Petroleum Exporting Countries (OPEC) and estimated that fossil fuels will remain from 60% to 80% of total primary energy sources in 2040. Aside from the uncertainty associated with whether or not a particular constraint will be implemented in practice, other studies have sought to assess the potential implications of negative emissions technologies for stranding risk. For example, Caldecott *et al*. (2015a) estimated that negative emissions technologies [including afforestation, soil carbon sequestration, biochar, bioenergy with carbon capture and storage (CCS)] could extend the 2050 carbon budget by a modest 11–13% and that they were subject to considerable uncertainty (Caldecott *et al*., 2015a). A weakness of this literature, therefore, is that the results are, to some extent, determined by assumptions about the carbon constraint.

Other studies have focused more forensically on establishing stranding risk for a particular type of fossil fuel reserve in scenarios with a tight carbon constraint. In the case of oil, McGlade and Ekins (2015) estimated that 45% of available oil could not be produced before 2035 without CCS, rising only moderately with CCS, and that Arctic, unconventional and "tight" oil were largely "unburnable". CTI (2014) found that oil projects above US$75/barrel were likely to be incompatible with a 2°C scenario rise and that CAPEX of US$1.1 trillion earmarked for projects requiring an oil price of US$95/barrel were highly exposed. Knight *et al*. (2015) compared project break-even points for Russian Arctic oil, Canadian oil sands, US shale oil, North Sea oil, Venezuelan heavy oil and Saudi Arabian conventional crude, concluding that only the last two were profitable at low oil prices. In the case of gas, CTI (2015b) found that there were US$283 billion of high-cost, energy-intensive LNG projects in the USA, Canada and Australia that could be stranded in low demand and price scenarios.

A strong message from this literature is therefore that, in future scenarios with a tight top-down carbon constraint, difficult-to-reach projects with high capital costs, along with carbon-intensive reserves, face a high stranding risk. However, a weakness is that the results are highly dependent on input assumptions and the methods used. The absence of *ex post* studies assessing stranding risk of fossil fuel reserves is also notable. There would appear to be opportunities for future *ex post* research focusing on stranding risk of coal and shale oil assets, particularly in geographical locations where low-carbon transition has begun.

Assets and infrastructure reliant on fossil fuels

Stranding risk for fossil fuel reserves inevitably feeds into impairment risk for downstream assets that are dependent on the exploitation of known fossil fuel reserves. The majority of studies that explore stranding risk for downstream assets are also forward-looking; however, in this case there is an emerging *ex post* literature.

Several *ex ante* studies that have explored stranding risk for downstream assets have focused on assessing overall stranding risk for the power generation sector. For example, Green and Newman (2017) explored the potential impact of disruptive change in power generation from new technologies, concluding that, in the most optimistic future scenarios, 100% of power could be generated by renewables by 2046, posing a stranding risk for fossil fuel-based power-generating assets. Pfeiffer *et al*. (2016) estimated that the 2°C scenario capital stock for power generation would be reached by 2017 based on current trends and concluded that all new emitting electricity infrastructure therefore faced a stranding risk. Although gas is viewed as necessary in the medium term, it is not clear how gas will be eliminated in the long term.

A strong message emerging from this literature is that stranding risk may be particularly acute for coal-powered generation compared with gas. Farfan and Breyer (2017a), for example, concluded that about 300 GW of installed coal power plants may end up as stranded assets, most of it in China (59%) and India (22%). Future coal investment was also likely to be stranded but the risk for gas generation capacity was likely to be lower (Farfan and Breyer, 2017b). Farfan and Breyer (2017a) estimated that 17 GW of coal capacities installed in Europe from 2010 onwards faced a shorter than expected operational lifetime and that gas- and oil-fired capacities commissioned from 2016 onwards may be required to shift to carbon-neutral fuels to avoid future stranding. Caldecott *et al*. (2015b) identified a particular exposure for subcritical coal generation technologies, finding that Indian, former Soviet and Chinese companies' portfolios were particularly exposed, owing to high reliance on older technologies. Caldecott *et al*. (2016a) explored the stranding risk to Japanese and Chinese coal-fired power generation respectively, finding considerable stranding risk in both cases, depending on the speed at which the risks identified materialised. In terms of mitigating stranded asset risk for coal-fired power generation, Johnson *et al*. (2015) found that strengthening near-term climate policy (i.e. lowering the global GHG emission target in 2030) generally reduced the risk of stranding and that an effective strategy for reducing risk capacity was to minimise new construction of coal capacity without CCS.

A clear finding from the *ex ante* literature, therefore, is that coal-fired generation may face a stranding risk in a carbon-constrained world and that this risk may be particularly prevalent in emerging economies. This conclusion is supported by an emerging *ex post* literature focusing on developed markets where low-carbon transition has begun. Ernst & Young, for example, have published a number of assessments of asset write-downs to EU utilities over the past 5 years. Most recently, Ernst & Young (2017) estimated that €143 billion has been written off against assets that had lost value between 2010 and 2016, which they largely attributed to rapidly growing volumes of zero marginal cost renewables, carbon pricing, and growing policy and regulatory pressure against coal-fired assets (in addition to poor overall economic conditions). Similarly, Caldecott *et al*. (2017b) explored the investment plans of the EU's 14 largest utilities in coal generation, finding that more than a sixfold increase in write-downs had occurred since 2008. They concluded that, in jurisdictions where coal expansions are being considered, stranding risk can be enhanced when a sector is experiencing significant technology, policy and market innovation. The weakness of the *ex post* literature is that it has focused exclusively on the EU context; there is therefore an opportunity for further *ex post* research exploring write-downs to coal generation assets in other markets.

Fewer studies have focused on stranding risk for generation technologies other than coal. One exception is the study by McGlade *et al*. (2018), who found that, without CCS, a "second dash for gas" was unlikely to be the most cost-effective way to reduce emissions in the UK. With significant CCS deployment, however, they found that natural gas could remain at 50–60% of the 2010 level by 2050, reducing stranding risk. Muñoz and Bunn (2013) concluded that decarbonisation of a wholesale power market, such as that of the UK, was associated with a progressive deterioration in the financial risk–return profile of all new *and* existing assets, irrespective of whether they were high or low carbon. The stranding risk to gas generation is underlined by one *ex post* study. Caldecott and McDaniels (2014b) assessed the impact of market contractions, fuel price changes and climate and energy policies on gas-fired power assets in the EU, finding that stranding risk had significant and immediate consequences for company value, utility strategy and policy (see the following section).

The majority of studies exploring stranding risk for fossil fuel assets therefore focus on the power generation sector. However, Lloyds (2017) suggested that stranding risk could additionally affect property and transport assets and Dericks *et al*. (2018) found that the progressive tightening of environmental standards could limit the future exploitation of coal and steel reserves in Chinese "resource-based cities", thereby undermining real estate markets in these locations.

2.6.2 Securities

Equities/companies

There is an extensive literature that explores how stranding risk posed to physical assets (see the previous section) can feed into risks for companies. In many cases, the intention is to establish if the financial risk of asset stranding is fully reflected in company valuations and the extent to which a "carbon bubble" could be said to exist (Caldecott, 2017).

This literature is again dominated by *ex ante* evaluations, many of which explore the implications of carbon constraint for coal, oil and gas companies. For example, CTI (2011) evaluated the link between reserves and share prices of listed fossil fuels, estimating that the reserves of 100 of the largest listed coal, oil and gas companies were greater than the total carbon budget for the 2°C scenario. CTI (2017) ranked companies according to exposure to "carbon risk", finding that the majority of highly exposed companies were North American. Moody's (2017a) found that implementation of Paris Agreement pledges could bring price volatility and rising pressure on margins and cash flows, potentially leading to stranded assets, especially for companies with high-cost projects with long lead times. In the case of oil companies, CTI (2014) found that oil majors such as Petrobras, Exxon Mobil, Rosneft, Shell, Total, Chevron and BP had high capital expenditure on projects with a break-even point of US$80 per barrel (see the previous section); HSBC (2008) found that Eni and Statoil faced the lowest carbon risk, whereas Repsol, OMV and Royal Dutch Shell faced the highest potential carbon costs; and Bloomberg New Energy Finance (BNEF, 2013) found considerable share price change for oil majors such as Exxon, Total, Chevron and Royal Dutch Shell, but results were dependent on the scenarios considered and assumptions applied. In the case of gas, CTI (2015b) found that Chevron, Shell, BG, Cheniere and Exxon have the highest total capital expenditure exposed and identified considerable stranding risk for capital expenditure on costly projects in the LNG sector.

However, not all studies find that a carbon constraint would necessarily impact company valuations. For example, HSBC (2013) found that "unburnable" carbon would have a limited impact on most companies' value at risk. However, when possible lower oil prices were also considered, the impact was found to be equivalent to 40–60% of the market capitalisation of affected companies, including Shell, BP, Total, Eni and BG. Heede and Oreskes (2016) found that stranding associated with existing reserves was minimal for private entities (of which there were 70), but, for eight state-owned companies, stranding risk associated with existing reserves was apparent, especially those in high-cost environments and for carbon-intensive resources. They also concluded that new reserves would face a stranding risk for both private and state-owned companies. The finding of minimal stranding risk for oil and gas companies is supported by Griffin *et al*. (2015), who used an *ex post* event study to evaluate the impact on stock prices of 72 oil and gas firms of media coverage of a possible carbon bubble during 2012–2013. They concluded that there was little evidence of a "carbon pricing bubble" for these stocks. Suggestions of stranding risk have also been contested by industry studies, such as that by ExxonMobil (2018), which estimated that there was little risk to its current reserves from a 2°C scenario target.

In the case of coal mining companies, results of *ex ante* studies indicate exposure of some assets, but that these risks can be minimised through diversification strategies. An assessment of stranding risk posed to Australian coal mines concluded that the coal price required for many of these projects to be economic was unlikely to be sustained, given China's changing demand for coal, posing a stranding risk for investors (Caldecott *et al*., 2013a). found that mining companies in Australia and South Africa (Xstrata, Anglo American and BHP Billiton) were exposed to the implementation of a carbon price. However, HSBC (2013), which explored the risk to four major UK-listed coal companies (Rio Tinto, BHP Billiton, Anglo American and Xstrata), found that impacts would be relatively minimal for these companies because they were highly diversified, and BHP Billiton (2015) concluded that low-carbon transition posed a minimal stranding risk to the company's diversified portfolio of assets. A weakness in this literature is that there is little *ex post* evidence to draw on. For example, little analytical attention has been paid to examining the role of low-carbon transition in unanticipated write-down of coal mining company valuations in North America. One exception is the event study of carbon capture and storage news events by Byrd and Cooperman (2018), who concluded that coal investors had priced carbon risk into share prices.

In the case of power generation utilities, the impact of possible carbon prices for the largest 72 US utility companies has been estimated (Credit Suisse, 2007). Caldecott *et al*. (2016a) (see the previous section) found that all of the Japanese utilities considered faced a stranding risk; Tokyo Electric Power Company had the highest exposure to asset in absolute value, whereas J-Power had the highest exposure to asset stranding relative to total assets. Caldecott *et al*. (2017a) (see the previous section) found that the five largest coal-fired utilities in China (Huaneng, Datang, Guodian, Huadian and State Power Investment Corporation) all faced a stranding risk in all of the scenarios explored. The stranding risk for these utilities is supported by *ex post* evidence from Europe, which has moved further along the pathway of low-carbon transitioning than China. Caldecott *et al*. (2014) found that, between 2012 and 2013, 10 major EU utilities (E.ON, RWE, Statkraft, Vattenfall, EnBW, GDF Suez, Centrica, SSE, Verbund and CEZ) announced, and implemented, planned mothballing and closure actions of over 20 GW of combined cycle gas turbine capacity, concluding that asset stranding had significant and rapid consequences for company value, utility strategy and policy (Caldecott and McDaniels, 2014a).

When it comes to company valuations, therefore, many *ex ante* studies, in particular those employing a carbon constraint, find a stranding risk for companies that rely on costly and carbon-intensive resources, and for utilities dependent on these resources. This finding, however, is heavily caveated in other studies; for example, companies that are highly diversified appear to be less exposed to carbon risks. Several *ex post* studies find that carbon risk may already have been integrated into share prices in the case of some exploration companies, but *ex post* studies support findings of a stranding risk for energy utilities.

Debt in countries and companies

The quality of the debt issued by companies and countries is also exposed to stranding risk, giving rise to a greater risk of defaults and ratings downgrades (Comerford and Spiganti, 2015). Nevertheless, there are fewer studies focusing on the implications of carbon risk for sovereign debt, even though bonds make up a significant percentage of diversified investment portfolios, especially among institutional investors. The Global Footprint Network (2016) assessed the risk to sovereign debt of transition, using the carbon intensity per unit of GDP for countries as a starting point. It concluded that China could face a higher risk given its high carbon intensity, but that the findings were sensitive to the choice of metric (e.g. production- or consumption-based emissions). Malova and van der Ploeg (2017) found that a carbon constraint could lead to the Russian government's fiscal stance tightening by 5.5% of GDP. In the case of companies, Standard & Poor's (2013) adapted its standard risk assessment of fossil fuel company creditworthiness to include a "stressed scenario", finding that companies with high exposure to Canadian oil sands and other unconventional fossil fuel activities could see ratings pressure build. This adaptation tool, however, is typically intended to have a time horizon of 3–5 years, limiting its effectiveness (Standard & Poor's, 2013). The implications of stranded assets for creditworthiness is therefore an underdeveloped theme; the methods are insufficiently developed and it would therefore be premature to draw conclusions from the preliminary studies that have been undertaken.

2.6.3 Investment portfolios and financial institutions

As one moves along the investment chain, understanding of the financial risk associated with the transition to a low-carbon economy, and how it can be managed, is less developed. This is perhaps because the risk is diversified across portfolios and balance sheets and may appear less acute to investors and other actors at later points in the investment chain. Following a global divestment campaign, however, institutional investors are becoming more aware of stranded asset risk and mangers of some US$6 trillion of financial assets have committed to divest from carbon-intensive sectors and companies (Divestinvest, 2018).

There are, first of all, a number of general studies that attest to the potential materiality of climate-related financial risks for asset portfolio managers and financial institutions. For example, Dietz *et al*. (2016) assessed how much the global portfolio of financial assets stands to lose from climate change, estimating a value at risk (without abatement) of 1.8% of total assets, whereas Mercer (2015) found that asset class return impacts could be material, but that a 2°C scenario would not necessarily have negative return implications for long-term diversified investors at a total portfolio level.

The concept of portfolio diversification as a means to manage investor risk is well established (Markowitz, 1952). However, there are relatively few studies that evaluate, quantify and seek to manage climate-related financial risk at an individual balance sheet or portfolio level. In cases in which this has been attempted, the focus is generally on analysis of the emissions intensity of portfolios and balance sheets. For example, Credit Suisse (2015) undertook an analysis of a hypothetical portfolio comprising 30 stocks and used tier 1 and tier 2 reported emissions. They found that the 10 equity positions with the largest footprint accounted for 90% of the total carbon footprint, meaning that portfolios contained carbon “hot spots”. BlackRock (2016) developed a “climate score” as an aide for portfolio managers, which indexed companies based on resource efficiency, exposure to climate-related financial risk and their opportunities to gain from climate opportunities. It found that incorporating climate factors into the investment process could present investment upsides. The Global Footprint Network (2016) proposed a methodology that weights the carbon intensity of bonds as well as each bond holding’s position within the investor’s total portfolio and argued that this intensity approach can be applied to other asset classes. Other approaches have involved focusing on the exposure of portfolios and balance sheets to fossil fuel exploration companies. For example, the Green European Foundation (2014) estimated the exposures of 23 large EU pension funds and the 20 largest EU banks to oil, gas and coal mining firms. The exposures were estimated at approximately 5% of total assets for pension funds, 4% for insurance companies and 1.4% for banks. CTI (2014) (see the previous section) suggested that investors should understand their exposure to companies with the highest level of capital expenditure devoted to high-risk (costly and carbon-intensive) projects and set thresholds for holding of these assets. These approaches are in their infancy, however, and are limited by a number of factors, not least by the absence of reliable reported information on climate-related financial risk.

Stress tests have also been adapted in some studies to evaluate climate-related financial risk under low-carbon transition. The Industrial and Commercial Bank of China (ICBC, 2016) recommended that environmental stress testing should be used to assess the possible impact of environmental risk factors and argued that this would promote the rational arrangement of bank loans and investment portfolios. The Cambridge Institute for Sustainability Leadership stress tested representative investment portfolios, concluding that climate risks could lead to financial tipping points that investors are not prepared for (Reynolds, 2015). It found that diversification strategies could offset approximately half of the negative impacts but that climate risk is, to a certain extent, “unhedgable” against. Other studies have identified challenges associated with hedging against climate-related financial risk. 2DII (2014) warned that strategies that seek to diversify at only the industrial sector level may be suboptimal, whereas Haslam *et al*. (2018) warned that focusing only on carbon emissions embedded in investment portfolios is insufficient for managing climate-related financial risk.

Finally, there has been some analytical focus on exploring the extent to which climate-related financial risk is considered by financial institutions and asset managers. For example, in a survey of the European banking sector, significant differences in the integration of environmental risks were found between banks (Weber *et al*., 2006). The Asset Owners Disclosure Project (2017) indexed the world’s 500 biggest pension funds, insurers, sovereign wealth funds, foundations and endowments on their success at managing climate-related financial risk within their portfolios. Oceania and Europe were found to be the most progressive regions, whereas the USA and China were among the worst performers. Considerable diversity within regions, however, was also noted.

2.6.4 Systemic risk

Some central banks and financial regulators have raised concerns that climate change may pose a "systemic risk" to the financial system. In September 2015, Mark Carney, Governor of the Bank of England, declared that climate change – in particular "transition risk" – could threaten financial stability via a sudden and significant collapse in asset values. Both the Bank of England[3] and the Network for Greening the Financial System[4] have called for action from central banks, regulators, banks and other stakeholders to reduce the impact of financial risk associated with being locked into fossil carbon infrastructure, as well as collective action to facilitate the role of the financial sector in achieving the objectives of the Paris Agreement. Campiglaio *et al*. (2018) and Battison *et al*. (2017) highlight the link between climate risk and the overall stability of the financial system. The Bank of England's Sarah Breeden, in a speech[5] on the risk of climate change to the financial system, warned of a "Minsky moment" where prolonged periods of investment gains encourage a diminished perception of overall risk that can lead to a major collapse of asset values, which generates a credit cycle or business cycle.

The extent to which low-carbon transition could threaten financial stability is an open question and there are few studies seeking to quantify the systemic financial risk posed by climate change. One exception is that by the European Systemic Risk Board (2016), which found that an abrupt and late switch away from fossil fuels could adversely affect systemic risk. Several CTI studies considered the systemic implications of highly fossil fuel reserve-dependent companies listed on global stock exchanges. For example, CTI (2013) found that the Moscow Interbank Currency Exchange (MICEX) Index and the Athens Stock Exchange General Index were the most intense and that some of the smaller exchanges (Brazil, Hong Kong, Johannesburg, India, Greece, Italy, Vienna and Budapest) were also found to have high fossil fuel dependency. However, others have disputed the thesis of systemic risk. Yergin and Pravettoni (2016), for example, argued that an energy transition would unfold over decades and would not therefore pose a "Lehman-style" systemic risk to the global financial system, because 80% of the market capitalisation for large oil companies reflected reserves reaching markets in the next 10–15 years.

In terms of managing systemic risk, ICBC (2016) found that environmental stress testing could reduce systemic risk and the Task Force on Climate-related Financial Disclosures (2017) recommended that comprehensive climate-related financial disclosure reports should be incorporated into mainstream public annual financial reports.

2.7 Conclusions

The topic of "stranded assets" arising from the transition to a low-carbon economy, and how this might affect investor perceptions of risk and return, has risen up the agenda of regulators, researchers and investors over the past decade. In this study, we systematically reviewed the literature on stranded asset risk arising from the transition to a low-carbon economy, focusing in particular on approaches used to value and manage these risks at different points in the investment chain. We have developed an analytical framework that has been employed to categorise studies according to the asset category they focus on, as well as the risks evaluated, the scenarios considered, the methods used and the results (see Appendix 1).

This systematic review suggests that there has been a strong focus in the literature on the earlier points in the investment chain: fossil fuel reserves, the power generation sector and companies that own these assets. This literature on fossil fuel reserves

3 https://www.bankofengland.co.uk/prudential-regulation/publication/2019/enhancing-banks-and-insurers-approaches-to-managing-the-financial-risks-from-climate-change-ss (accessed 30 August 2018).

4 https://www.banque-france.fr/en/communique-de-presse/ngfs-calls-action-central-banks-supervisors-and-all-relevant-stakeholders-greening-financial-system (accessed 30 July 2018).

5 https://www.bankofengland.co.uk/-/media/boe/files/speech/2019/avoiding-the-storm-climate-change-and-the-financial-system-speech-by-sarah-breeden.pdf (accessed 30 September 2019).

suggests that difficult-to-reach and carbon-intensive reserves with high capital costs face a higher risk of stranding from a low-carbon transition, particularly when a robust emissions constraint is assumed. Much of this literature is, however, *ex ante* and there are no *ex post* studies to support these findings. When it comes to power generation assets, a strong message emerging from this literature is that stranding risk may be particularly acute for coal-powered generation compared with gas, particularly for the older, less efficient technologies that are often deployed in emerging economies. In this case, there is *ex post* evidence from markets where a low-carbon transition has begun (most notably in the EU) that coal generation assets are highly exposed to stranding risk under low-carbon transition. However, there is an opportunity for further *ex post* research to explore write-downs to coal generation assets in markets outside the EU. There has been little analytical attention paid to exploring the stranding risk for real estate and transport assets reliant on the exploitation of fossil fuels, and these are other areas perhaps meriting greater analytical attention before conclusions can be drawn.

The final area where there is substantial depth to the literature is exploring if stranding risks are fully reflected in company valuations and the extent to which a "carbon bubble" could be said to exist. Much of the *ex ante* literature suggests that, in a carbon-constrained world, valuations of coal, oil and gas companies could be overstated, especially those with significant capital exposure to costly projects or carbon-intensive resources. However, this finding is contested by industry analysis and some independent studies, and companies that are highly diversified are generally found to be less exposed to carbon risks. The *ex post* literature, on the other hand, suggests that in some cases investors may have factored in stranding risk into company valuations.

The further along the investment chain one moves (towards systemic stability), the increasingly sparse the literature becomes. This perhaps reflects a greater diffusion of risk for financial institutions and portfolio managers, also noted in previous studies (Global Investor Coalition on Climate Change, 2013). For example, there are fewer studies addressing the implications of stranding risk for the creditworthiness of counterparties, asset portfolio managers, financial institutions and the stability of the financial system, and the methods in these areas are also less developed. Stress tests under carbon risk and aids to efficient resource allocation under climate change, for example quantifying the carbon intensity of an investment portfolio or a bank's balance sheet, have been proposed to manage stranding risk. Although carbon intensity is used in many risk assessments to measure the exposure of securities, portfolios or balance sheets to low-carbon transition, this approach is challenging and is limited by a number of factors. Although there is some provisional evidence that stranding risk may affect financial institutions and portfolios, there is also some evidence that these risks can be managed by investors through diversification strategies. However, there are few studies exploring optimal diversification to minimise climate-related financial risk and some studies point to the limitations of these strategies. The understanding and quantification of stranding risk for actors at these points in the investment chain is therefore at an early stage, and these are areas that require greater analytical consideration before definitive conclusions can be drawn.

The stranding assets literature is faced with a number of limitations and difficulties, which are challenging to overcome. A lack of reliable reported data and accepted methodologies for measuring exposure to low-carbon transition makes managing these risks more challenging. The results of studies tend to be largely determined by which risks and scenarios are considered and by the choice of method. Furthermore, risks that are typically considered by financial market actors (such as market, inflation or interest rate) are measured on a short-term basis (1–3 years) using familiar metrics such as volatility or value at risk. Climate-related financial risk generally demands longer-term measurement (> 3 years) and risks come from outside the market (regulation, carbon price developments, physical impacts, etc.). These factors are outside the average investor's experience. Even for *ex post* evaluations, the magnitude of stranding risk attributable to low-carbon transition can be difficult to differentiate from other factors, such as the macroeconomic backdrop or new electricity market rules, for example.

3 Identification, Cataloguing and Assessment of Fossil Assets, Infrastructures and Support Systems in Ireland

3.1 Introduction

In this chapter we identify state-owned fossil fuel infrastructure assets that are susceptible to stranded asset risk in a low-carbon energy system, using an integrated energy systems modelling approach. Our assessment suggests that gas generation assets and gas transmission networks could incur short- to medium-term risks, whereas the gas distribution network may incur similar risks in the long term. The focus of this chapter is on the long-term utilisation of gas in all sectors, future gross electricity production and the financial performance of the distribution network. The next chapter assesses gas infrastructure in the medium term in a European context.

The results of this analysis build on previous research that presented scenarios for low-carbon pathways for the Irish energy sector (Chiodi *et al*., 2013). Scenarios that see a 95% reduction in CO_2 emissions by 2050 see little use for natural gas in all sectors of the economy, including power generation. However, in an 80% reduction scenario, aggregate gas use is higher relative to current levels. In this chapter, we analyse scenarios to understand the likely impacts of CCS and the electrification of heat on network utilisation and, in later chapters, we analyse revenue recovery via tariffs. The analysis begins by briefly presenting a baseline business-as-usual (BAU) scenario, followed by a mitigation scenario of an 80% reduction in emissions. Two further exploratory mitigation scenarios are presented: one in which the imports of bioenergy are constrained, which leads to higher levels of electrification of heat, and another in which the availability of CCS is removed because of its speculative nature.

Gas network operator revenues are generated based on earning an allowed return on the value of the assets, known as the regulatory asset base (RAB). The rate of return is recovered through tariffs. The RAB involves the full recovery of investors' capital through earning a risk-adjusted rate of return on the capital invested. A full recovery of investor capital aims to ensure that there is no stranded asset risk for investors, providing an incentive for further investment in gas network infrastructure (Stern, 2013). With the fixed-cost nature of gas networks and the expected certainty around an adequate return to investors under the RAB, less gas demand could alter the transport cost of gas. This may reduce the competitiveness of gas itself and, therefore, render gas networks stranded.

Future investments such as CCS fall outside the RAB as the technology does not directly alter the transport cost of gas. Low-carbon opportunities, through the integration of renewable gas to reduce the emissions of distribution network customers, could prolong the life of the network, in addition to acting as a signal for further investment. An argument can be made that following this path of continued investment in distribution networks to reduce emissions in the short term will require an increase in investments to the RAB and puts a greater value at risk. Therefore, although biogas is viewed as positive from a renewable energy perspective, it may have the unintended consequence of increasing the gas RAB and ultimately increasing the long-term stranded asset risk and barriers to change. It is unclear how changes in gas demand interact with changes to the regulatory model and regulatory decisions in a low-carbon energy system. One of the main findings of this analysis is that, once an investment is in the RAB, the risk of stranding may not come from gas demand, but from changes in regulation and how tariffs are allocated.

3.2 The Gas Networks Operation and Economic Regulation

Changes in each sector's gas consumption have a direct impact on the utilisation of the networks. For example, gas use in power generation affects the utilisation of the transmission network and gas use in the residential sector affects the utilisation of both the transmission and the distribution networks. This is because gas is transported through both networks to get to the residential customer for final exit. Hence, power generation customers have to pay to use only one network but residential customers need to pay tariffs for both networks. The gas network's viability relies on a sufficient level of gas being transported between the entry and exit points.[6] In order to generate revenue, shippers[7] of gas can book the use of these entry and exit points through contracts called capacity products, which are provided by the network operator (Hunt, 2015). To use entry points shippers book entry capacity and to use exit points shippers book exit capacity through capacity products. Therefore, the utilisation of the gas network is influenced by the characteristics of sectoral demand and individual network demand in a 2050 low-carbon energy system for gas.

3.3 Inputs for Gas Demand and Scenarios Analysed

Published scenarios from the Irish TIMES, an integrated energy systems model, were analysed to understand total and sectoral gas demand by fuel and technology within a low-carbon energy system. The Irish TIMES models the entire Irish energy system through a technology-oriented, dynamic, linear programming optimisation approach. The model creates cost-optimal energy system pathway evolutions under certain constraints. Chiodi *et al.* (2013) provide a more comprehensive analysis of the model and scenarios used in this study in the context of the entire energy system, with more detailed information given about the input assumptions. The scenarios used in this analysis have also informed Ireland's energy research strategy (ERSG, 2016).

The four main published energy system scenarios analysed are as follows: the BAU scenario, which is introduced to provide a starting point against which the three GHG emissions mitigation scenarios can be measured, namely the CCS scenario, the CCS + no bioenergy import scenario and the no CCS scenario. These scenarios reflect different perspectives on the use of bioenergy and on the availability of CCS technology.

- The BAU scenario represents a baseline scenario of the energy system based on current trends and in the absence of emissions reduction targets.
- In the CCS scenario, the energy system meets future energy service demands at least cost and is required to achieve at least an 80% CO_2 emissions reduction below 1990 levels by 2050.
- The CCS + no bioenergy import scenario is similar to the CCS scenario in that the energy system is required to achieve an 80% reduction in CO_2 emissions below 1990 levels. In this scenario, however, an additional constraint is applied, with Ireland not allowed to import bioenergy.
- The no CCS scenario requires the energy system to achieve an 80% reduction in CO_2 emissions below 1990 levels by 2050. In this scenario, a constraint is applied of CCS being unavailable as a technology choice.

3.4 Summary of Gas Demand Scenarios

In the process of decarbonising the energy system, gas (both natural and biogas) acts as a fuel source to fulfil the energy demand in all sectors of the energy system. This section provides a summary of the established gas demand scenarios discussed in section 3.3.

3.4.1 A review of gas consumption by sector and scenario

In the mitigation scenarios (CCS, CCS + no bioenergy import and no CCS), total gas consumption increases between 2015 and 2030 (Figure 3.1). In the CCS scenario, gas consumption increases by 5% between 2015 and 2030, with a further increase of 8.2% between 2030 and 2050. This is related to the (cost-effective) fuel switching between high emission factor fuels (mainly oil based) and lower emission factor fuels, such as natural gas and renewables. At a sectoral level, this reduction in gas consumption in the least-cost mitigation scenario, CCS, initially occurs

6 Entry points represent nodes on the transmission network at which gas can enter the network to be transported, that is, interconnectors or gas terminals from indigenous sources or storage. Exit points are nodes on the transmission network that can directly supply gas to generation plants or heavy industrial customers or from which gas can be shipped to the distribution network for final energy use.

7 Shippers represent firms that pay to transport gas from entry points to exit points on the gas network. For example, Bord Gáis Energy is a shipper in Ireland.

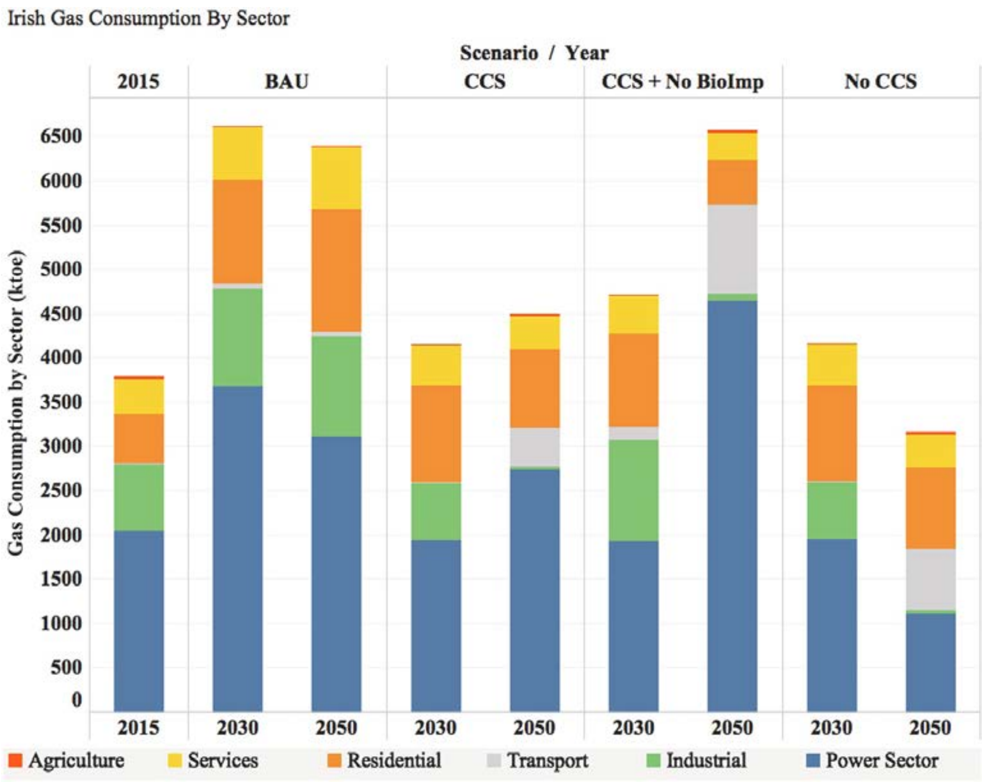


Figure 3.1. The evolution of gas demand to 2050.

in power generation out to 2030, with CCS featuring among the portfolio of least cost-optimal technologies in 2050. This is largely required to integrate the increased capacity of wind and solar energy during this period. In this scenario, gas is displaced by biomass in the industrial sector, which is helped by the economies of scale available to industry for this technology. Gas loses its share in the residential and services sector because of lower cost sources as a result of the installation of more efficient appliances (i.e. heat pumps and high-efficiency lighting systems), investment in energy conservation (i.e. wall and window insulation) and fuel switching (i.e. from oil and gas to electricity in heat). In all scenarios, renewables and electricity (mainly for heating) increase, mostly displacing oil-based heating systems, but also gas.

3.5 Gas Demand Scenarios to Network Throughput

To understand the level of utilisation of each network, it was necessary to disaggregate gas demand in each sector according to both the transmission network and the distribution network. The gas that exits the transmission network for final energy use is associated with power generation and large industrial customers. Gas that exits the distribution network for final energy consumption is consumed by the residential and services sectors and the remaining industrial sector. In this section, a summary of gas demands (see section 3.4) is attributed to each network to better understand network utilisation. Based on historical data sourced from the networks' systems performance report (GNI, 2015a), on average, 46% of industrial gas demand was industrial throughput in the distribution network. This ratio is assumed in all scenarios out to 2050.

In general, even with an 80% reduction in emissions compared with 1990 levels, both gas networks could be utilised to a greater extent than they are today. The demand for final exit at the transmission network in the CCS scenario encounters a slight contraction between 2015 and 2030 but, interestingly, shows an increase between 2030 and 2050 (Figure 3.2). The distribution network in all scenarios experiences a peak in its throughput of gas in 2030 and a decline to 2050. In all scenarios, gas is a prevalent driver in reducing emissions in heat to 2030 but faces competition from the electrification of heat after 2030. The emergence of biogas in the transport sector offsets a large part of this fall in demand from the industrial sector. The distribution network could sustain a higher throughput of gas than today. However, meeting this demand

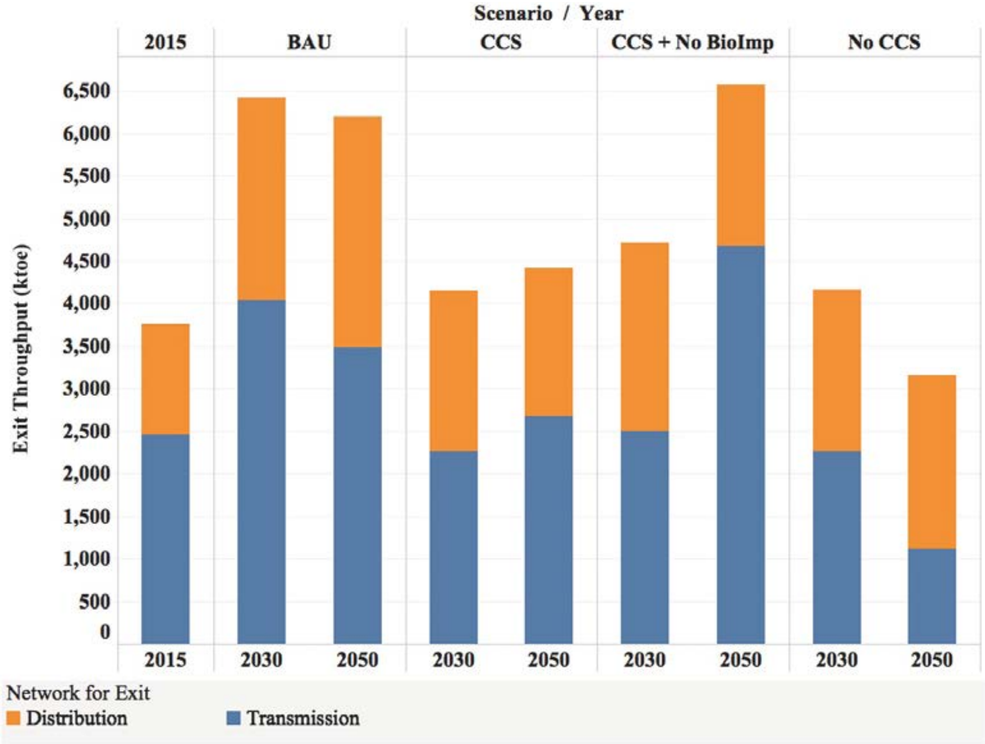


Figure 3.2. Future gas demand to network for exit.

would come at a cost of further network expansion into the future.

3.6. Financial Modelling of the Distribution Network

A high-level gas distribution network is developed based on the level of throughput attributed to each sector, which equates to a certain number of connections. Approximately 33% of a distribution network customer's final gas bill is attributed to the use of the distribution network, with 10% coming from the use of the transmission network.[8] The distribution network is therefore the focus of the financial analysis. In estimating the distribution network's financial performance, the national regulator's price control agreement with the network operator, covering 5-year intervals, was reviewed (CER, 2017). This document is accompanied by a high-level model of how network tariffs are calculated, which, in turn, demonstrates how the network operator generates its income. The current price control formula contains a cost driver based on customer numbers. The revenue is derived from a cost allocation approach to network tariffs.

This cost allocation approach derives tariffs based on a mix of future demand forecasts for the network's utilisation and the network's expected operational expenditure, capital expenditure and costs associated with the depreciation of its asset base over the next 5-year period. This has been replicated to 2050 for this analysis. The capacity demand refers to the quantity of bookings for the capacity products on the network and is based on a projection of the historical annualised profile of capacity demand, scaled up for each year. Suppliers book capacity on the network through products in order to transport gas from one point to another.

3.6.1 Estimating allowed revenue to 2050 for the distribution network

The sum of these allocated costs equates to the distribution network operator's allowed revenue, of which 80% must be recovered from capacity tariffs and 20% from commodity tariffs. The framework outlined in Figure 3.3 represents an interpretation of the methodology for the regulator's "decision on distribution network revenue" (GNI, 2017).

8 www.cru.ie/professional/energy/energy-networks/revenues-tariffs/ (accessed 1 October 2018).

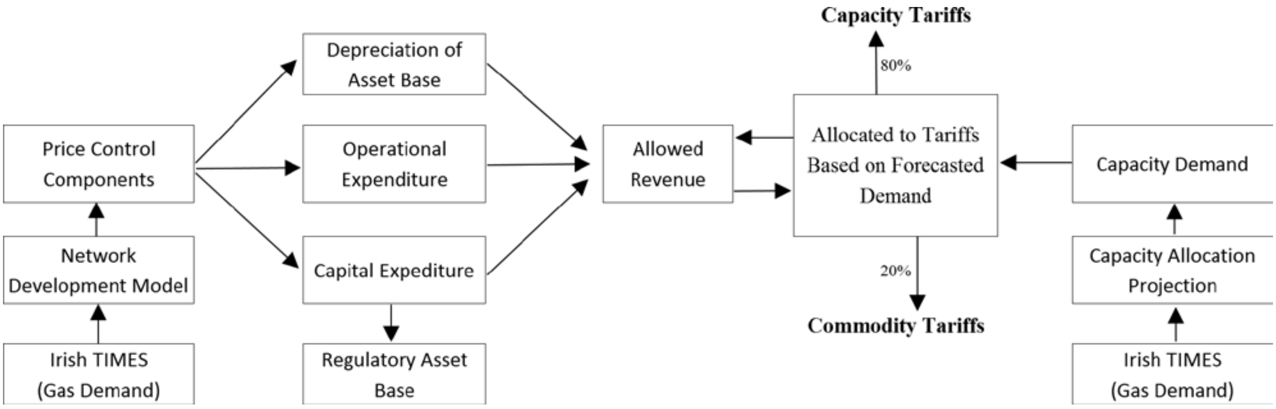


Figure 3.3. Framework for calculating network tariffs.

The RAB is the base to which the rate of return is applied when determining the return on capital for the distribution network. The asset life applied to assets within the RAB feeds through into the level of depreciation that the distribution network receives on those assets within each control period. Pipelines, service lines and above-ground installations are assigned an asset life of 60 years, with meters having a life of 15 years. Because of the nature of the design life of network assets and the system use of network assets, a straight-line method is considered to be a reasonable representation of economic depreciation for network assets. Therefore, in the model, existing assets are depreciated out to 2050 and, as connections increase, so too does the depreciation expense as a result of the acquisition cost approach applied to capital costs. The growth-related capital expenditure is forecast around assumptions such as gas demand and new connection numbers between 2015 and 2050. Initially, this process begins with the consumption per connection in 2015 being calculated. However, each connection becomes more efficient over time in terms of energy consumption. This is accounted for by analysing technological changes within the building stock over time in the TIMES model to reduce emissions. Dwellings may switch to more efficient boilers coupled with retrofitting to reduce gas consumption.

Shippers to commercial and residential non-daily metered (NDM) customers remunerate the gas network operator through purchasing annual “1 in 50” contracts[9] to supply customers. Gas shipped to transport and industrial daily metered (DM) customers for industrial processes or fuel for vehicles remunerates the network operator through the purchase of annual, quarterly, monthly and daily capacity products, the prices of which amount to tariffs paid. Generally, products of shorter time periods are more expensive, which results in shippers having a greater preference for annual capacity rather than daily capacity in the cost-optimal projection. An annual “1 in 50” contract implies that, to supply NDM customers, the shippers must buy a sufficient amount of capacity products to fulfil their demands in a once in 50-year weather event, regardless of actual demand. This remunerates the gas network operator for providing the technical capacity to facilitate a scenario if it ever were to occur. It is an important point to understand when comparing one sector’s investment requirements with another.

Connecting the remaining individual customers will require further network expansion, which will be funded by anchor tenants in the industrial and commercial sectors. These anchor tenants assist in bringing a positive net present value for individual connections, which is further explained in the

9 Gas network operators typically aggregate small industrial, services and residential customers into one sector, known as NDM customers, who are generally connected to the distribution network. NDM exit capacity is required to be reserved in order for a shipper to offtake gas from the transmission system and facilitate the onward delivery to NDM supply point(s) at which the shipper is the registered shipper. The majority of NDM customers rely on gas as a source of heat, which is largely weather dependent. Therefore, under the gas network code of operations, if shippers of gas want to supply these customers, they are required to reserve 1 in 50 scenario levels of capacity to account for the fluctuations in weather patterns (GNI, 2017).

network operator's connections policy (GNI, 2015b). Operational expenditure is calculated from a review of historical operational expenditure in previous price control agreements. The operational expenditure as a function of the RAB is calculated for each year in the existing price control agreements and a mean percentage value is derived. The RAB is valued using an acquisition cost approach, which is historically indexed with inflation. Therefore, the additional growth-related capital costs will increase the asset base and operational costs, which will be reflected in the sustaining of such an asset base.

Biogas injection facilities and compressed natural gas stations, which provide gas for transport, are not included in the investment model as it is assumed that these would be owned and operated by a third party. These assets are currently allocated as operating expenditure under EU funding and are financially written off initially until they become a proven technology (CER, 2016). From a regulatory perspective, the refurbishment and reinforcement of existing network infrastructure are categorised as capital expenditure because of the scale of the costs and are added to the RAB. Although the network may not be expanding, these investments are required to maintain it at an operational level regardless of throughput.

3.7 Results

Building on the results in section 3.4 and applying the investment methodology in section 3.6, gas demand in all sectors and scenarios is generally similar until 2030; therefore, the investments are similar. As a result of the growth-related capital expenditure, the RAB is constantly increasing, which leads to a consistent rise in the operational expenditure required to maintain it. In each scenario, operational expenditure becomes a greater proportion of allowed revenue within this constantly increasing value of the RAB, coupled with a consistent level of reinforcement and refurbishment of capital expenditure to keep the network operational. Because of the straight-line approach to depreciating assets, the costs associated with depreciation also increase. Post 2030 is the point when gas use begins to decline and the composition of sectoral gas consumption begins to change. Network tariffs, illustrated in Figure 3.4, are useful in this instance to understand how changes in sectoral gas consumption might affect the capacity products demanded and tariffs charged to ship gas as a result.

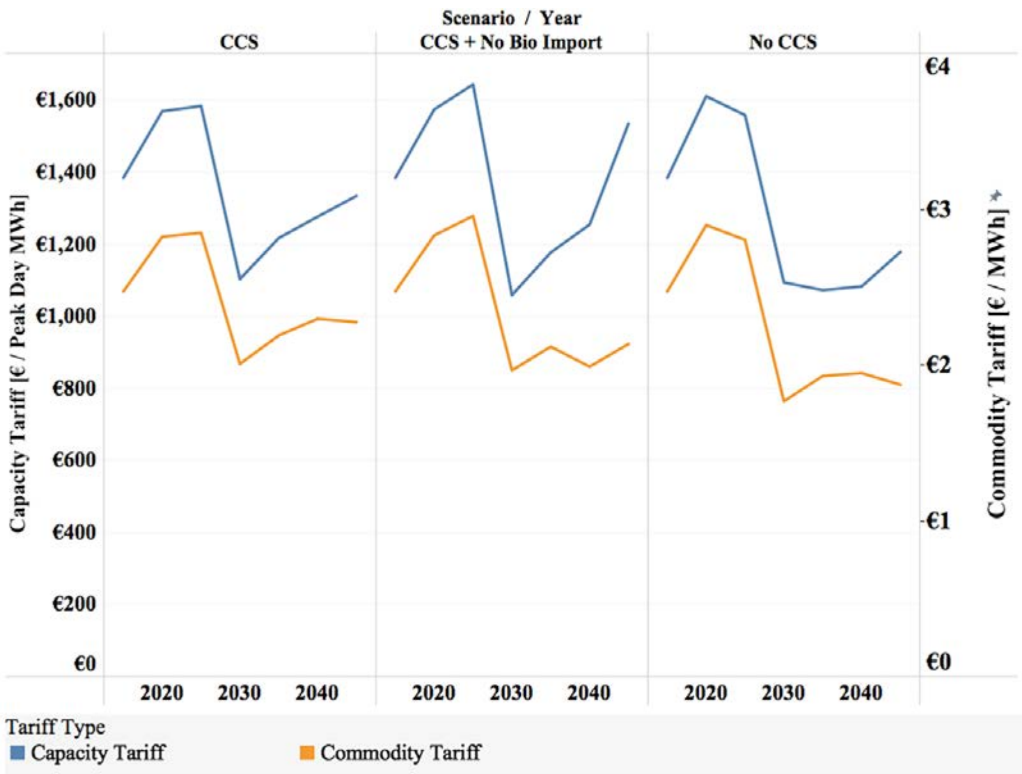


Figure 3.4. The evolution of distribution network tariffs to 2050.

The purpose of the price control agreement described above is that tariffs are charged to cover system costs. Costs are recovered through a split between capacity tariffs (fixed booking cost) and commodity tariffs (volumetric flow cost), with a ratio of 80% of revenue generated by capacity tariffs and 20% by commodity tariffs. Figure 3.4 depicts the changes in the average capacity and commodity tariffs from 2017 to 2050. Tariffs increase by about 17% on average between 2017 and 2030 to facilitate the required increase in capital expenditure caused by network expansion.

As a result of initial higher network tariffs, gas could lose its competitiveness as a fuel relative to other sources, covered in section 3.4, in each sector. The higher network tariffs come from the increasing growth-related capital expenditure from the additional connections required to meet the increasing gas demand. Growth-related capital expenditure increases the allowed revenue on which the tariffs are based. These scenarios have implications for the distribution network revenue model because asset owners are compensated based on an allowed return. The fall in tariffs after 2030 is a result of minimal growth in connections but a consistent level of gas use, followed by a reduction in gas use and an increase in tariffs throughout the period to 2050. With no additional growth in connections, the capital expenditure component of the allowed revenue to be recovered is reduced.

The investment model outlined in section 3.6 indicates disconnections from the network in the CCS, CCS + no bioenergy import and no CCS scenarios of 8%, 44% and 10%, respectively, from 2030 connections by 2050. The number of connections in 2050 still far exceeds today's levels. This fall in connections could have implications of increased costs in the form of large sections of the gas network being decommissioned. Increased disconnections linked to the increase in fixed tariffs may lead to decommissioning of sections of the network, a risk to the network operator. Because of the uncertainty in how this decommissioning would develop over a 20-year period, it is not captured by the investment model. The CCS + no bioenergy import scenario offers valuable insights into the potential impacts of high levels of electrification of heat on the gas networks' competitiveness.

As mentioned in section 3.2, the distribution network is an extension of the transmission network. Distribution customers pay tariffs to use both networks. Hence, the financial viability of the transmission network predicates the viability of the distribution network. This analysis is limited to assessing only distribution tariffs and not transmission tariffs. Uncompetitive transmission tariffs could have a direct impact on the competitiveness of the distribution network.

3.8 Conclusions

Investing in fossil fuel-based infrastructure with such protracted payback periods carries a significant investment risk in terms of "carbon lock-in" (Unruh, 2002). The cost structure of the gas network changes over time, with operating and refurbishment costs required to keep the network operational regardless of throughput. The analysis finds that the risk of stranding may not come from gas demand in aggregate but from how costs are recovered and how tariffs are allocated, potentially creating issues for the regulated return model. Within the three mitigation scenarios reviewed, gas demand in each sector evolves in a similarly upwards fashion for the distribution network until 2035, with equally similar investments to the RAB. However, it is the change in sectoral gas demand that increases tariffs under the modelling framework outlined, more so than aggregate gas demand. A decrease in gas consumption in DM sectors does not have an equal impact to that of a decrease in gas demand in NDM sectors. The effect is most clearly illustrated in the CCS + no bioenergy import scenario, in which the distribution network's throughput of gas is similar to that in other scenarios, but the tariffs applied increase significantly. The results point to a potentially significant level of disconnections from the distribution network from 2030 to 2050, caused by fuel switching and energy efficiency, resulting in less system throughput. The shortfall in demand from the industrial sector is supplemented by the transport sector in most cases. The levels of disconnections could lead to the decommissioning of sections of the network, which presents a risk to the network operator.

3.9 Limitations and Key Sensitivities

The network recovery model is based on current approaches adopted in the gas industry and is not a definitive representation of the future. This is a clear limitation of this analysis and therefore further investigation is required. In addition, there is an assumed secure supply of gas into Ireland whereas indigenous sources of gas are depleting. The modelling does not consider how consumer preferences may change as carbon-free alternatives become available, even if the expected costs are higher. The level of uptake of lower carbon sources such as biomass by industrial customers, displacing gas, may be considered unrealistic because of the reliability and convenience that gas provides. The model assumes that consumers consistently choose the least-cost option over convenience. Anchor tenants are usually industrial customers with high levels of gas consumption who are connected to the network. These connections require higher pressure piping and can be used to justify network expansion. There is also an assumed level of anchor tenants available to support the network's expansion while, simultaneously, industrial demand declines. However, biogas injection facilities and compressed natural gas stations, which represent similar if not greater levels of network utilisation, could fill this void of anchor tenants. Additionally, the tariffs on the transmission network have not been considered. This is a limitation of the study in terms of assessing the overall competitiveness of the network. However, it does offer a valuable insight into, and a framework for, how and when the gas industry could align its strategy for remaining competitive into the future with low-carbon policy objectives. Network charges are a significant proportion of gas customers' final bills. The network cost recovery model may come under serious pressure as remaining customers face significant network charges under decarbonisation scenarios with reduced gas use. There is a danger that increasing prices would create an incentive to get off the network, which may create a snowball effect leading to even higher network charges for remaining customers.

4 Benchmarking Ireland to Other Developed Countries in the European Union

4.1 Introduction

Ambitious European targets for renewable energy call for a vast mobilisation of capital. At the same time, European electricity market reform, reduced electricity demand and decarbonisation of electricity generation have had unexpected consequences for risk and return for power sector investors, with investments in thermal generation assets (primarily gas-fired generation) becoming stranded and mothballed (Caldecott and McDaniels, 2014b). The share of electricity demand from variable renewable power generation is limited by the non-synchronous nature of wind and solar photovoltaics (Ibrahim *et al*., 2011). Sources of flexibility, such as gas-fired generation assets, are required to increase these limits and support a further penetration of variable renewables (Lannoye *et al*., 2012). Achieving generation adequacy has become a challenge for the EU internal electricity market through the energy-only market model operating in some Member States (EPRS, 2017). The electricity energy market has three main revenue categories contributing to annual total revenues available to generators: (1) payments for energy (MWh), (2) capacity to ensure resource adequacy (MW) and (3) flexibility for system stability. Total annual revenues migrate down this list as the volume of zero marginal cost generation meeting demand increases. Capacity payments do not solve carbon problems and potentially only increase stranded asset risk as they prop up older fossil fuel plants over new green entrants. Only by increasing the proportion of annual revenues going towards flexibility will a low-carbon grid be delivered.

A number of Member States have introduced capacity mechanisms that compensate generators for the availability of existing capacity and support an investment case for future generation capacity (Huhta, 2018). For example, in 2018 the European Commission approved six additional forms of capacity mechanisms concerned with more than half of the EU population in Germany, Belgium, Italy, Poland, France and Greece (EC, 2018).

As described in Chapter 3, gas network operator revenues are generated based on earning an allowed return on the value of the assets, known as the RAB.[10] A full recovery of investor capital aims to ensure that there is no stranded asset risk for investors, providing an incentive for further investment in gas network infrastructure (Stern, 2013). The continued viability of the regulatory return model to protect investors and maintain the credit quality of European utilities is an open question in the literature. Although it is clear that gas network operator returns have been driven down by a fall in the weighted average cost of capital because of low interest rates (Moody's, 2017a), the impacts caused by a fall in gas demand are not fully understood.

This chapter evaluates the investment risk for both gas-fired generation and gas network assets in each of the EU Member States using an emissions reduction scenario for 2030. A detailed model-based analysis is developed under the assumptions of the European Commission reference scenario (EC, 2016). This is coupled with a power system simulation and investment appraisal model to assess if returns to owners of gas generation assets in each EU Member State are sufficient to incentivise investment in new gas generation assets in an "energy only" market. The outputs from this analysis are then linked with a high-level gas network investment and tariff allocation model to assess the implications of significant reductions in gas demand from the power generation sector for owners of gas transmission assets. We find the regulated return model for gas networks could fragment across Europe. These results are significant as the credit quality of the debt underpinned by the regulatory model may face refinancing risk, and probably changes in debt structure, if these utilities cannot maintain the desirable traits of investment-grade credit quality.

10 The rate of return is recovered through tariffs; however, the way in which Member States regulate gas networks and apply tariffs to recover revenue varies (Ernst & Young, 2013).

4.2 Methods

Visions for the future, through energy systems modelling, offer useful insights into how market conditions may evolve. In 2016, the European Commission published the *EU Reference Scenario 2016, Energy, Transport and GHG Emissions, Trends to 2050* (EC, 2016), hereafter termed the refence scenario. The refence scenario provides a benchmark for current policy and market trends. It starts from the assumption that the legally binding GHG and renewable energy sources targets for 2020 will be achieved and that the policies agreed at EU and Member State level in December 2014 will be implemented. The market pricing and operational assumptions for gas generation assets and the gas network are derived from a soft-linking approach between an energy system scenario (the EC reference scenario) and a power system model, as described by Deane *et al*. (2012). A discounted cash flow model is used to value generation assets and a tariff allocation model is used to value the gas network. The assumption of the discounted cash flow model is that generators must achieve a minimum internal rate of return (IRR) of 8% (the hurdle rate of return for capital to be forthcoming from investors) to incentivise investment in these assets; this is generally the purpose of capacity remuneration mechanisms (Pototschnig and Godfried, 2014). Payments outside the “energy only” market to achieve this are known as out-of-market payments in this analysis. The required revenue of each Member State’s gas network to remain viable is calculated and tariffs are allocated to all network users, based on their respective demand for gas and the operational cost of the Member State’s network. When gas demand increases, the model allocates capital costs to the RAB as a proportion of the increase in gas use. Cost assumptions for power generation assets and the network are sourced from a variety of industrial sources and surveys (Lochner, 2011; JRC, 2014; ACER, 2015). The cost of debt is calculated using a combination of the Member State-specific bond yields and a European utility corporate debt premium.

4.3 Results

4.3.1 The future for gas generation assets

Figure 4.1 shows the percentage of total generator revenues from out-of-market payments required to achieve an IRR of 8% for owners of gas generation

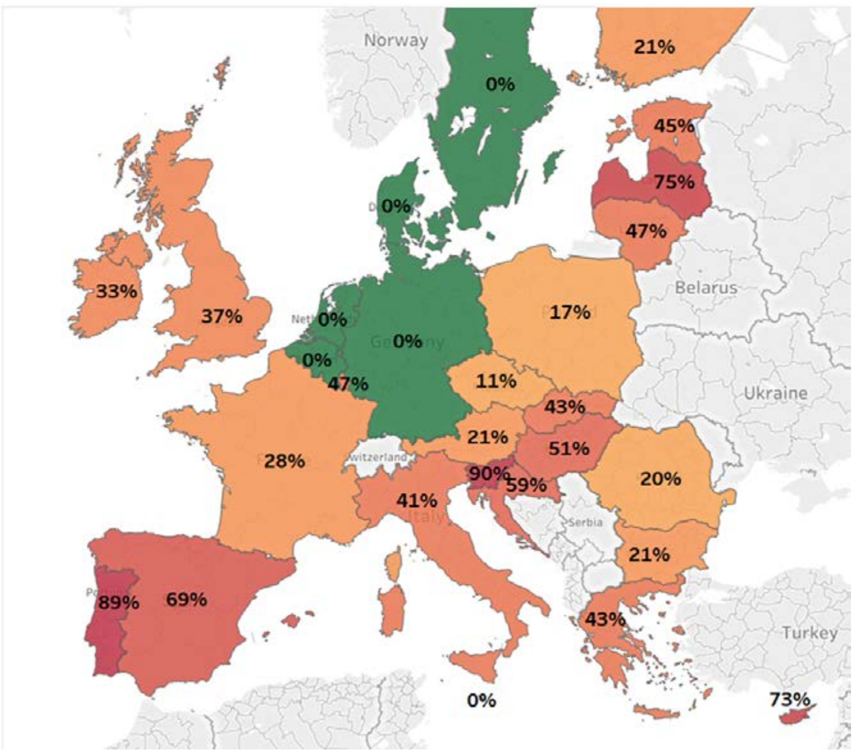


Figure 4.1. The percentage of total generator revenues from out-of-market payments required to achieve an IRR of 8% for owners of gas generation assets in European countries.

assets. Countries that achieve this return in an "energy only" market are represented on the graph as 0%. However, the majority of countries will require either capacity payments or other out-of-market payments to incentivise investment. Member States heavily reliant on out-of-market payments see gas generation assets out of merit and not recovering long-run marginal costs. In an "energy only" market, investment is unlikely to be forthcoming as investors will not receive an adequate return.

The increased installed capacity of renewables across the EU, coupled with their low marginal cost nature, is displacing gas to some degree in all Member States. Gas generation assets in Germany, from energy only, return an attractive IRR of 8% partly because of the decommissioning of nuclear power stations, representing 20% of the generation mix in 2015. In addition to increased capacity factors, for gas generation assets to meet the shortfall in the supply of electricity, coal generation continues as the dominant source of electricity in Germany. In the UK, Spain and Italy there is a noticeable decline in the production of electricity from coal, partially because of the carbon price on the fuel, and gas use increases to meet the decline. France and Sweden show declines in nuclear electricity production, which is counteracted with increased production of electricity from renewables.

The IRR is also influenced by market prices, which are derived from the average hourly system marginal price in each Member State. The growth of electricity produced from variable renewable sources contributes to reducing wholesale prices. Additional influencers of energy market margins in the simulation include operating cost, which was accounted for by enabling uplift in the model to determine pricing, which ensures that generators are recovering both start-up costs and variable operating costs, which did not influence optimal dispatch. Enabling uplift, while also factoring in increases in CO_2 prices and the price of gas, is reflected in higher prices relative to today. Although the IRR is set to 8% in most Member States, the findings from this study indicate that it is considerably more favourable to invest some Member State than others. In Spain, for example, for an investor to achieve an IRR of 8%, out-of-market payments would have to account for 69% of total revenues, indicating that energy-only payment would not be sufficient to attract investment. In contrast, Germany's energy-only payments provide an IRR of 8%, with no additional revenues required from out-of-market payments.

4.3.2 The future for gas networks

In the second part of our analysis, we examine the implications of reduced running hours for gas generators on the flow of gas through the gas network and hence payments and return on investment to the owners of gas network assets. Figure 4.2 illustrates a potential change in tariffs charged to gas transmission network customers for transporting gas that factors in gas demand for power generation but also for other sectors. These changes in tariffs are required to recover network costs, which are largely fixed.

Networks with a greater proportion of gas used in power generation relative to final energy demand are subject to a greater risk of tariff increases in this period. Portugal could see the highest increase in tariffs, largely driven by a decline in gas consumption in sectors outside power generation, such as residential, services and industrial sectors. The same is also true for Spain and Latvia. This shows that the demand for gas in other sectors can have an impact on the viability of gas in power generation. Interestingly, in some Member States, although a fall in gas demand in power generation is increasing tariffs, an increase in gas consumption in other sectors is reducing them. The highest percentage increase in tariffs in Portugal results primarily from a decline in gas consumption in the power generation sector. The same is also true for Austria and Latvia. In Ireland, the UK and France the increases in tariffs for gas network users are rising equally from the power generation sector and from the residential, services and industrial sectors. This shows that the demand for gas in other sectors can have an impact on the viability of gas in power generation. Interestingly, in Bulgaria and the Czech Republic, although a fall in gas demand in sectors outside the power generation sector is increasing tariffs, an increase in gas consumption in the power generation sector is reducing tariffs to a greater extent. Sweden, Finland and Belgium could see significant increases in gas use in power generation, which could reduce tariffs significantly by 2030 because of some higher flows of natural gas. With the fixed-cost nature of gas networks and the expected certainty around an adequate return to investors under the RAB, reduced

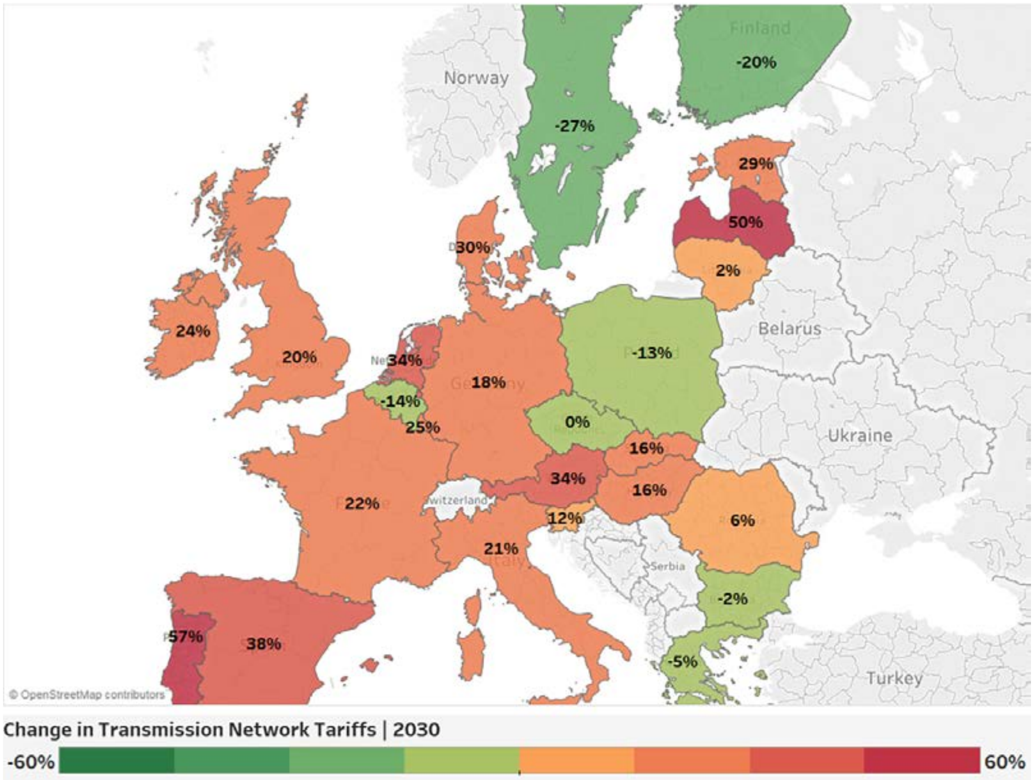


Figure 4.2. The potential change in European gas transmission network tariffs to 2030.

gas demand could alter the transport cost of gas in Europe.

Few of the 23 gas network operators in Europe have material rated debt outstanding with more than 15 years to maturity (Moody's, 2017a). This could raise concerns for the terms of any refinancing under the results of this analysis. The cost of debt forms a significant part of the cost of capital allowance for regulated companies. The issuance of new debt by a regulated entity such as a gas network will tend to affect the average cost of debt paid by a company on all of its debt (Oxera, 2013). As investors earn a risk-adjusted rate of return on the capital invested, with a high degree of refinancing in 2030 across Europe, this could lead to additional higher tariffs. The maturity profile of existing debt and financing policy, and future market rates could therefore potentially impact tariffs, in addition to network utilisation. Increasing indebtedness of regulated network operators could be balanced by higher transmission and distribution tariffs. Direct tariff increases may not hinder the ability of these utilities to recover revenues in the short term but could potentially present as a material risk for the network's competitiveness and debt rollover risk in the longer term.

4.4 Discussion

In this study, system services are rewarded to gas generators through out-of-market payments. However, increases in gas network tariffs, caused by lower fuel consumption in the power sector, are required to recover sufficient revenue to cover network costs and remain viable. Therefore, investments in network assets going forward could bring execution risk and weighs on credit metrics. With few exceptions, gas networks are mature with modest investment needs, but decarbonisation poses questions around their long-term use, particularly for heat. Considerations of remaining useful asset life may influence regulatory remuneration cycles, as well as investment decisions, and network operators with very long-dated debt are exposed to asset stranding risk. The tariff increases are distributed to all network users and would directly lead to higher prices to ship gas for other users, which would lead to, for example, higher costs to the heating sector in some Member States. The change in scope of activities in an environment of significant technological shift may necessitate changes in the way that European networks are remunerated and customers' tariffs are set, if credit quality is to be maintained. A narrow national or regional view may be replaced with an increased focus on long-term planning across borders. An increase in tariffs as a result of a fall in power generation could result in gas becoming uncompetitive in other sectors.

4.5 Conclusions

Stranded asset risk of fossil fuel generation assets and related infrastructure has begun to receive significant attention from investors, rating agencies and regulators. The findings of this analysis point to an uncertain future for gas infrastructure in Europe. The greatest investment case for gas generation assets was focused in central and northern Europe, with low and negative returns on the remaining exterior of the EU, with the exception of Sweden and Denmark. In the remaining Member States, the investment case largely hinged on the availability of out-of-market payments. Although capacity payments are justified by the need for security of supply, capacity payments may also be viewed as propping up assets that are no longer efficient and that may become stranded, and as such may delay a more expeditious transition to a decarbonised system. Member States that attracted poor returns for gas-fired units correlated with higher transmission network costs, potentially leading to a stranded asset risk for networks and an uncertain investment case.

Stranded gas generation assets may represent considerable losses on investments to utilities if plants are not able to recover capital costs. Beyond balance sheet impacts, these stranded assets may affect the ability and willingness of firms to invest in new plants and gas transmission networks. The revenue recovery model for regulated network assets may continue to provide a reliable source of income; regulated transmission and distribution could, on the other hand, become less competitive, partly because of the tariff increases required in some Member States to recover such revenue. The potential evolution of the regulatory environment and energy market design at both European and national levels will be a key theme in the context of future investment strategy. From a policy perspective, it is important that the market model and payments for energy, capacity and flexibility are designed to expedite the transition to zero carbon and are not sunk costs in fossil fuel generation and infrastructure.

4.6 Limitations and Key Sensitivities

There is uncertainty as to how the current European power generation portfolio may evolve, which is not captured in this study. Although scenarios from energy systems modelling can provide useful insights for the future, they aim to solve cost-optimal configurations in the development of the European energy system. A recent report, *Transforming the EU Power Sector: Avoiding a Carbon Lock-in* (EEA, 2016), approaches the term “lock-in” from an excess in the levels of fossil fuel capacity relative to the levels specified in the EU long-term decarbonisation objectives, according to Energy Roadmap 2050 scenarios. Under the assumptions in the report, it suggests that the EU power sector could evolve towards excessive fossil fuel capacity by 2030, compared with the optimal capacity levels in the Energy Roadmap 2050. The prolonged operation of inflexible, carbon-intensive power plants, along with the planned construction of new fossil fuel capacity, could translate into higher costs for decarbonising Europe’s power sector by locking it into a dependence on high-carbon capacity, while simultaneously exposing owners and shareholders to the financial risk of capacity closures (potentially stranded assets). There is also a lack of certainty for fuel prices, which has a significant impact on the dispatch of gas generation owing to its high variable cost nature. Policy to achieve renewable energy sources targets has historically played a pivotal role in displacing gas generation in Europe. The reference scenario cannot capture additional policy developments that may be enacted to reduce emissions in Europe. However, the analysis provides a unique insight into the question of whether or not European gas infrastructure is investable under the assumptions that we can currently make about the future. The results of this analysis are also predicated on an assumed price of natural gas.

5 Assessment of the Consequences of Current Carbon Lock-in, and Investment Issues and Options

5.1 Introduction

A wide range of stakeholders, including financial institutions, governments and financial regulators, are now interested in examining the extent to which investments, loan books and investment portfolios are aligned with the carbon budgets[11] implied by the Paris Agreement to keep global warming "well below 2°C" (Pfeiffer *et al.*, 2018). To date, much of the focus has been on securing public commitments from companies to adopt carbon reduction targets (Bui and de Villiers, 2017), to improve the disclosure of companies' annual CO_2 emissions (Krabbe *et al.*, 2015) and/or to assess what these carbon budgets mean for listed fossil fuel reserves and resources (McGlade and Ekins, 2015). However, comparatively little attention has been paid in the literature to the credit quality implications or rollover risk of corporate debt, which supports and finances these capital- and emissions-intensive processes. Carbon prices and related emissions are a source of this risk and may be the best indicator of how that risk may unfold within the capital structure and debt maturity management of any company.

Ten of Europe's largest utilities have experienced a deterioration in credit ratings by three to four notches from the Aa/high single A rating level (Moody's, 2014) and Moody's (2017a) suggests that decarbonisation and the continued transition to renewable energy in Europe poses long-term risks to the region's regulated electricity and gas network operators as changing business models, developing technology and evolving regulation could potentially undermine their credit quality over time. Previous research demonstrates how credit quality is the primary source of variation driving a firm's optimal debt structure (Diamond, 1991; Bolton and Freixas, 2000; Diamond and Rajan, 2001). Rauh and Sufi (2010) suggest that when firms transition from high-credit quality to low-credit quality they are more likely to have a multi-tiered capital structure consisting of both secured bank debt with tight covenants and subordinated non-bank debt with loose covenants.

Committed emissions[12] analysis coupled with established credit rating models could offer a simple framework to understand the credit quality implications of debt. Committed emissions are based on the current or planned capital stock embedded in company and investor portfolios, or indeed within country development plans. This concept, and its application, is significant as it allows us to estimate if and when the current and planned stock of assets will breach carbon budgets. Recent studies have found that, across all thermal power assets globally, committed emissions breached the 1.5–2°C carbon budget in 2011, and the carbon budget for a 2–3°C warming scenario was breached in 2014 (Pfeiffer *et al.*, 2016). These global findings from periodic studies have not yet been translated to individual company credit quality. When debt is issued for capital projects, operating assumptions and the asset's life are factored in to derive an investment case and cost of debt. We used a published rating agency model to assess the impact of committed carbon emissions on credit quality.

5.2 Committed Emissions Analysis

Committed emissions represent the total CO_2 emissions that are estimated to be emitted over the remaining lifetime of an asset, without substituting

11 A "carbon budget" is the cumulative quantity of CO_2 emissions that are allowed in order to keep global warming below a certain warming threshold (Allen *et al.*, 2009). There is a linear relationship between each marginal tonne of CO_2 released and the resulting warming that occurs. The warming that occurs from CO_2 emissions is also more or less permanent. It is therefore possible to determine the cumulative quantity of emissions or "carbon budget" that will result in various warming scenarios. Each carbon budget typically has an associated probability. For example, for this analysis we use the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) carbon budgets [https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf (accessed 8 October 2019)], which have a greater than 66% probability. These probabilities represent the likelihood of keeping global temperature increases above pre-industrial levels below the given temperature threshold.

12 Committed emissions are the cumulative carbon emissions that an asset is expected to emit over its remaining lifetime (Davis *et al.*, 2010; Davis and Socolow, 2014).

inputs, upgrading assets, retrofitting assets or refurbishments (Davis *et al*., 2010; Davis and Socolow, 2014). Committed emissions occur from both direct and indirect emissions and arise from both existing assets and planned or under construction assets. Carbon lock-in curves (CLICs) are constructed based on the estimated committed emissions for each thermal unit using calculations in line with previous work (Davis *et al*., 2010; Davis and Socolow, 2014; Pfeiffer *et al*., 2016). CLICS have previously been introduced in the literature (Caldecott *et al*., 2018a,b). The CLICS in this analysis have been developed using the Risk Impact and Opportunity Tool (Oxford Sustainable Finance Programme, 2018).

The database of power-generating units that has been used to build each CLIC in this report is the most up-to-date version of the Platts World Electric Power Plants Database[13] (which provides relatively complete information on power-generating assets. This database consists of 90,150 emitting power units spread across 226 countries, of which 82,099 are operating and 8051 are either planned or under construction. The calculation of committed emissions for each emitting asset requires two pieces of information: (1) the estimated future annual emissions and (2) the estimated remaining economic lifetime. The annual CO_2 emissions for each power unit ($kgCO_2$/year) are calculated using the following formula:

$$\text{Annual emissions} = \text{heat rate (Btu/kWh)} \times \text{emissions factor } (kgCO_2/\text{Btu}) \times \text{utilisation rate (kWh/year)} \quad (5.1)$$

The annual emissions are calculated by multiplying the heat rate (in Btu/kWh) with the emissions factor (in $kgCO_2$/Btu) of the specific fuel type and the utilisation rate (in kWh/year). The historical data on heat rates and utilisation rates have been taken from the US Energy Information Administration,[14] whereas the data on fuel type-specific emissions factors have been obtained from the US Environmental Protection Agency.[15] The expected economic lifetime for all power-generating units is assumed to be 40 years. This life expectancy is based on the year that a unit first went online.

Finally, the cumulative committed carbon emissions (CCCEs) for each asset are calculated by multiplying the estimated annual emissions by the expected remaining lifespan. The use of a 40-year expected lifetime is consistent with previous work on committed emissions (Davis *et al*., 2010). However, using a standardised expected lifetime across all global power assets does not take into account differences in lifetimes that are evident across countries and technologies. As such, some of the committed emissions calculations may over- or underestimate what is actually emitted. Similarly, historical heat rates and utilisation rates may not reflect what happens in the future. This could also result in an over- or underestimation of CCCEs. However, these historical estimates are a standard approach to calculating committed emissions in previous work (Pfeiffer *et al*., 2018).

To determine whether specific current or proposed assets are compatible with different climate pathways it is necessary to compare the CCCEs with global and country-level carbon budgets. The global carbon budgets used here represent the cumulative CO_2 emissions required to limit global average warming (with a greater than 66% probability) to below 1.5°C (200 $GtCO_2$), 2°C (800 $GtCO_2$) and 3°C (2200 $GtCO_2$) by 2100. These carbon budgets are taken from the IPCC Sixth Assessment Report (2018).[16] This approach allows us to assess the compatibility of assets relative to a global carbon budget but ignores the presence of countries and therefore the differences between them. Countries have different levels of ambition and some have already announced their own carbon budgets for certain sectors. To assess

13 A detailed description of the database is provided by Platts' Data Base Description and Research Methodology [https://www.spglobal.com/platts/plattscontent/_assets/_files/en/our-methodology/methodology-specifications/platts-assessments-methodology-guide.pdf (accessed 23 October 2019)]. Concerning the coverage of the database, Platts states that "[t]he WEPP Data Base covers electric power plants in every country in the world and includes operating, projected, deactivated, retired, and cancelled facilities. Global coverage is comprehensive for medium and large sized power plants of all types. Thus, we consider the database to be representative for our analysis. With regard to the owner/operator of the power plants, Platts states that "[a]s a general matter, the listed COMPANY is both the operator and sole or majority owner".

14 https://www.eia.gov/electricity/data.php (accessed 1 February 2019).

15 https://www.epa.gov/sites/production/files/2018-03/documents/emission-factors_mar_2018_0.pdf (accessed 1 February 2019).

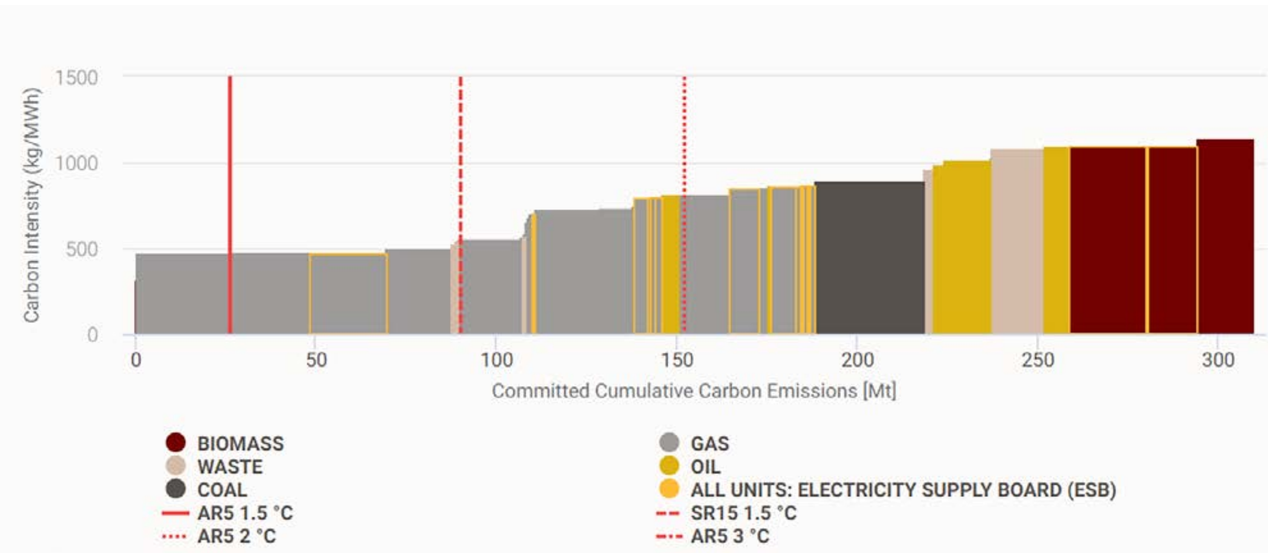
16 See https://www.ipcc.ch/assessment-report/ar6/ (accessed 25 September 2019).

the compatibility of assets within a country context, we need to establish country-specific carbon budgets. A global carbon budget can be allocated to different countries in different ways. There are established climate mitigation burden-sharing approaches in the extant literature (Robiou du Pont *et al*., 2017). The five main approaches for sharing a global carbon budget between countries are as follows: capability, equal per capita, greenhouse development rights, equal cumulative per capita and constant emissions ratio. These approaches were developed to assign mitigation burdens to different countries in the context of the international climate negotiations. In this analysis we have employed the constant emissions ratio approach.

Once the committed emissions of a plant are calculated, each asset is ordered using a particular ranking method, in this case a plant's carbon intensity (Figure 5.1). The width of each bar in Figure 5.1 represents the CCCEs and the ordering variable is plotted on the *y*-axis. The carbon budgets are then plotted as a vertical line. Assets that are on the left of these budget lines are compatible with that carbon budget, given various assumptions, whereas assets that fall to the right of these budget lines are incompatible with the carbon budget for a given warming threshold and are likely to face a higher risk of becoming stranded as a result of climate-related transition risks. We have developed CLICs for initial use in the power sector for thermal assets. However, the methodology is applicable to other sectors with assets generating point source emissions. The construction of global and country-level CLICs requires three sets of assumptions to be made:

1. the future CCCEs for each asset (for power this is each thermal power-generating unit);
2. the carbon budget for each probability threshold for degrees of warming; and
3. the proportion of carbon allocated to each sector globally (and to each sector within each country).

The analysis of a leading Irish utility in Figure 5.1 finds that 71% of the units are incompatible with a (SR15) 1.5°C carbon budget, 84% of the units are incompatible with an Fifth Assessment Report (AR5) 1.5°C carbon budget, 27% of the units are incompatible with an AR5 2°C carbon budget and none of the units exceed the threshold of the 3°C budget. All of the fossil fuel units that are compatible with a 2°C budget are gas-fired units. This could present credit quality and debt maturity management risk from



% of portfolio assets incompatible with each warming threshold			
SR15 1.5°C	*AR5 1.5°C*	*AR5 2°C*	*AR5 3°C*
71	84	27	0

Figure 5.1. Carbon lock-in curve for Ireland and a leading Irish utility. AR5, Fifth Assessment Report; SR, Special Report.

a leading Irish utility in the 1.5°C and 2°C scenarios. The units that are owned by a leading Irish utility are framed in yellow.

5.3 Credit Quality Analysis

Having established the committed emissions for a leading Irish utility, a credit rating model was used to measure the credit quality impact of these carbon liabilities. Moody's (2017b) *Rating Methodology – Regulated Electric and Gas Networks* provides the ratings framework in which the impact of carbon liabilities on a regulated electric company's ability to service debt, on its credit quality and on its cost of debt was evaluated. We held metrics associated with regulated networks constant and focused solely on the generation business. When analysing credit risk in the power sector, Moody's (2017b) focuses on the key rating factors shown in Figure 5.2.

The first three sub-factors in the ratings model are market assessment, cash flow predictability and financial policy, all of which are subjective; we focus on the financial strengths metrics, which are based on actual ratios calculated using historical financial data.

Using the ratings methodology outlined above, the "carbon-constrained" credit rating (based on financial strengths metrics) was calculated for a leading Irish utility, assuming zero contributions to cash flows from fossil fuel units. Normally, Moody's uses 3-year averages of financial statement information with the latest period on a trailing 12-month basis to capture improving or deteriorating trends (Moody's, 2017b). In this analysis, just 1 year of data is used on the basis that decarbonisation of the European power market has made historical data redundant. After mapping the letter ratings to a numeric scale [with higher numbers corresponding to lower ratings, as described on page 5 in Moody's (2017b) Ratings Scale Factor Numerics],

EXHIBIT 1

Regulated Electric and Gas Networks

Broad Grid Factors	Factor Weighting	Sub-Factors	Sub-Factor Weighting
Regulatory Environment and Asset Ownership Model	40%	Stability and Predictability of Regulatory Regime	15%
		Asset Ownership Model	5%
		Cost and Investment Recovery (Ability and Timeliness)	15%
		Revenue Risk	5%
Scale and Complexity of Capital Program	10%	Scale and Complexity of Capital Program	10%
Financial Policy	10%	Financial Policy	10%
Leverage and Coverage	40%	(FFO + Interest Expense - Non-Cash Accretion - Capital Charges) / (Interest Expense - Non-Cash Accretion) OR (FFO + Interest Expense) / Interest Expense	10%
		Net Debt / RAB OR Net Debt / Fixed Assets	12.5%
		FFO / Net Debt	12.5%
		RCF / Net Debt	5%
Total	**100%**		**100%**

Factor 5 – Structural Considerations and Sources of Rating Uplift From Creditor Protection – is a notching adjustment to the preliminary grid-indicated rating that results from Factors 1-4.

Figure 5.2. Rating factor/sub-factor weighting: regulated utilities. Source: Moody's (2017b).

the average credit rating was calculated as a simple average of the corresponding numerical rating. This is not the actual current company rating but the rating implied by putting each company's cash flow and debt metrics through the financial metrics model.

The credit rating for a leading Irish utility could deteriorate from Baa1 to Baa3 if the firm decides to constrain carbon emissions by a certain budget (Figure 5.3). The timing of this decline in credit quality is most likely to occur when the firm reaches a desired emissions reduction target. A decline in credit quality could have implications for the firm's cost of debt and the conditions of any such financing. The debt structure itself is likely to change in this instance; this could create challenges with regard to how a leading Irish utility's debt is matured and the conditions of any debt that is rolled over. The estimated contribution to cash flows is based on the proportion of kWhs to annual output using the true utilisation rates, discussed in the committed emissions analysis (see section 5.2).

5.4 Debt Maturity Management

To understand when a leading Irish utility's corporate debt may incur rollover risk, we present a first principles analysis of when its assets may exceed a carbon budget if current assumptions for the performance of this debt continue. For this leading Irish utility to maintain an investment-grade credit rating, its assets must equally contribute to free cash flows. Therefore, to generate cash flows this debt could be associated with committed emissions of its own.

Figure 5.4 shows when a leading Irish utility's debt could exceed its carbon budget, which may, in turn, create a rollover risk for that debt. If we are to assume that a leading Irish utility's corporate debt must produce and sell a certain number of units (kWhs) each year in order to generate sufficient cash flows for its credit rating, then under 1.5°C and 2°C carbon budgets it is unlikely that the number of kWhs needed to be produced over the lifetime

	Current		Carbon Constrained	
	Measure	**Score**	**Measure**	**Score**
Factor 1 : Regulatory Environment and Asset Ownership Model (40%)				
a) Stability and Predictability of Regulatory Regime	Aa	Aa	Aa	Aa
b) Asset Ownership Model	Aa	Aa	Aa	Aa
c) Cost and Investment Recovery (Ability and Timeliness)	A	A	A	A
d) Revenue Risk	Aa	Aa	Aa	Aa
Factor 2 : Scale and Complexity of Capital Program (10%)				
a) Scale and Complexity of Capital Program	Baa	Baa	Baa	Baa
Factor 3 : Financial Policy (10%)				
a) Financial Policy	Baa	Baa	Baa	Baa
Factor 4 : Leverage and Coverage (40%)				
a) FFO Interest Coverage (3 Year Avg)	5.1	A	2.0	Ba
b) Net Debt / Fixed Assets (3 Year Avg)	51.7%	A	51.7%	A
c) FFO / Net Debt (3 Year Avg)	19.6%	Baa	3.8%	Ba
d) RCF / Net Debt (3 Year Avg)	16.8%	Baa	3.4%	B
Rating:				
Indicated Rating from Grid Factors 1-4		A2		A2
Rating Lift:	0	0		
a) Indicated Rating from Grid		A2		
b) Actual Rating Assigned		**Baa1**		**Baa3**
Government-Related Issuer	Factor			
a) Baseline Credit Assessment baa1	baa1			
b) Government Local Currency Rating A2 Stable	A2 Stable			
c) Default Dependence High	High			
d) Support Moderate	Moderate			
e) Final Rating Outcome	A3			

Figure 5.3. Carbon-constrained credit rating.

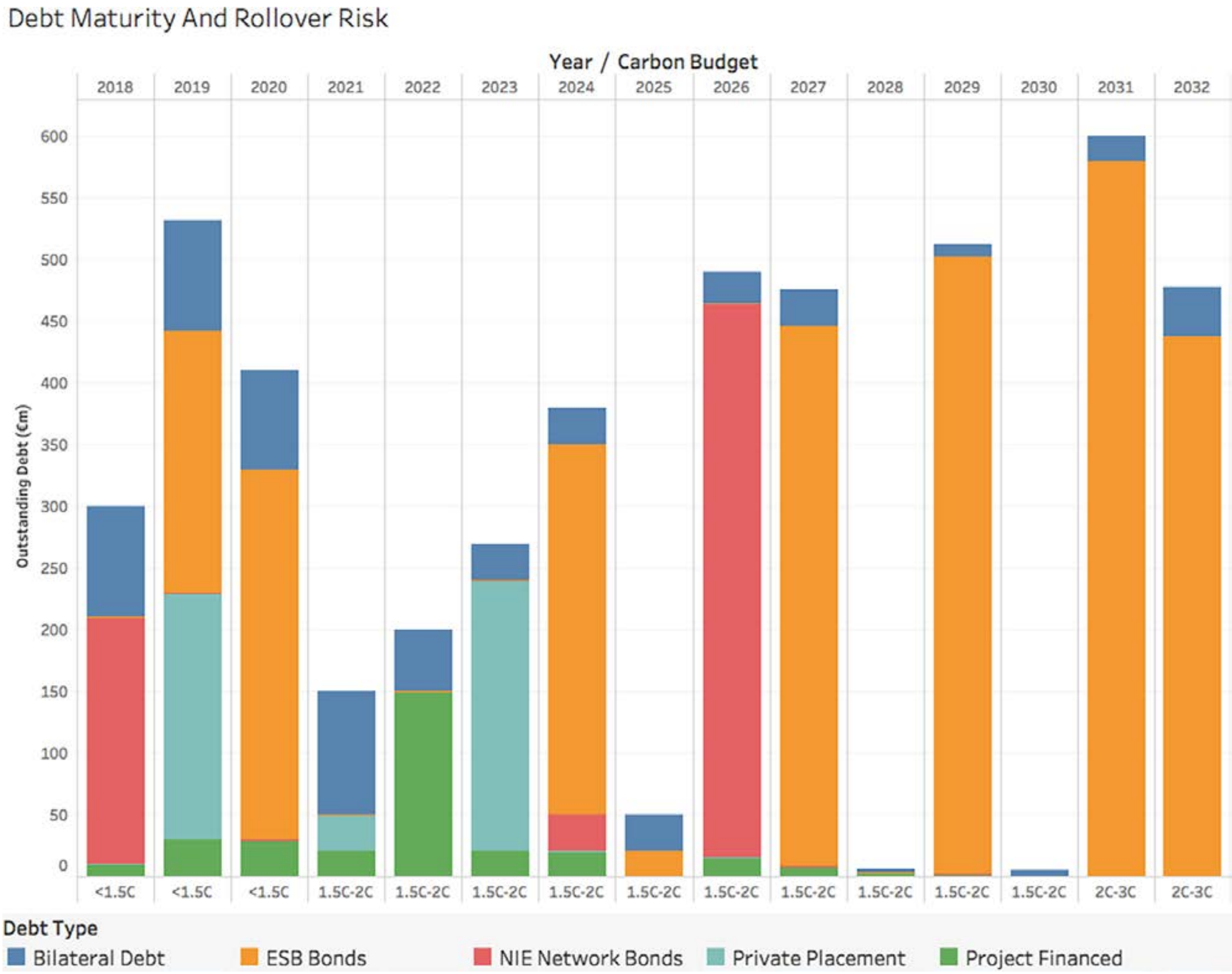


Figure 5.4. A leading Irish utility's total debt, carbon budgets and rollover risk. ESB, Electricity Supply Board; NIE, Northern Ireland Electricity.

of those assets will be sufficient. The analysis assumes that a leading Irish utility's current portfolio of generation assets runs at the true utilisation rates that generate committed emissions and cash flows to maintain its current credit rating. In this case, 68% of potential future cash flows may not be realised in a 1.5°C scenario and 19% may not be realised in a 2°C scenario; this could lead to challenges in settling existing debt. The terms of any refinancing will generally be determined on the ability of current projects to contribute positively towards cash flows. Issues for refinancing could occur in 2021 in a 1.5°C scenario and in 2031 in a 2°C scenario. It should be noted that these results are based on forecasts for the future using particular scenarios and assumptions and as such should be interpreted as being illustrative rather than prescriptive.

5.5 Conclusions

The concept of committed emissions, the cumulative carbon emissions that an asset is expected to emit over its remaining lifetime without substituting inputs or upgrading, retrofitting, refurbishing or replacing the asset, provides the ability to compare assets against carbon budgets. This analysis of a leading Irish utility's units finds that 71% of units are incompatible with an SR15 1.5°C carbon budget, 84% of units are incompatible with an AR5 1.5°C carbon budget, 27% of units are incompatible with an AR5 2°C carbon budget and none of the units exceed the threshold of the 3°C budget. We found that, if assets are to be decommissioned or stranded to align a leading Irish utility with a carbon budget, there are probably consequences for the credit quality of the firm. Those credit quality risks could emerge in 2021 in a 1.5°C scenario and in 2031 in a 2°C scenario. Potentially, 68% of future cash flows may be at risk in a 1.5°C scenario and 19% may be at risk in a 2°C scenario. As the corporate debt for a leading Irish utility is rolled over, that debt could be separated from the regulated electricity networks and the wholesale and generation business. This could counteract a deterioration of credit quality in the utility's debt resulting in a lower cost of debt for the regulated electricity transmission and distribution networks, helping to maintain their overall competitiveness.

6 Survey

6.1 Introduction

Staying within the 2°C temperature target would require an estimated US$3.5 trillion in energy-sector investments each year until 2050 across the energy generation, industry, transport and building sectors (Covington, 2017; IEA, 2018), about double the current level of investment. Approaches to mobilising greater levels of capital investment in green assets have therefore garnered considerable analytical attention (OECD, 2017; Hall *et al*., 2018). This imperative has, in turn, given rise to an inter-related complex of emergent themes within the finance literature, including green investing, climate finance, risk management and portfolio diversification strategies, the impacts of low-carbon transition on asset prices, climate insurance, climate bonds and broader financial stability risks (Okoli and Pawlowski, 2004; CTI, 2014; Credit Suisse, 2015; Griffin *et al*., 2015; BlackRock, 2016; Dietz *et al*., 2016; Diaz-Rainey *et al*., 2017; OECD, 2017).

Among these, the "asset pricing" branch takes the perspective of traders and explores, inter alia, the extent to which investors are correctly pricing risk into asset values. For example, in the capital asset pricing model, investors hold well-diversified portfolios consisting of the market portfolio and risk-free investments (Barber and Odean, 2013). Within the energy sector, it is also widely held that investors – whether electric utilities, insurance companies, pension funds or even retail investors – compare opportunities, and choose to buy and sell assets, according to perceived risk-adjusted returns (Wüstenhagen and Menichetti, 2012). Although other studies indicate that individual investment behaviour may not be either entirely rational or homogeneous (Barber and Odean, 2013), it remains true that cost of capital is a central determinant of the pace at which relevant technologies are deployed in the marketplace, and that this is influenced by both the risk and the profitability characteristics of investment options (Dinica, 2006; Barber *et al*., 2016).

For this reason, the ways in which climate change mitigation and the energy transition could affect risk perception for asset owners and investors have been the subject of growing interest. A particularly important risk is that fossil fuel reserves and associated assets could face "stranding" in a carbon-constrained world. Stranded assets have been defined as "assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities" from climate change (Caldecott *et al*., 2014: 7). Numerous studies have found that transitioning to a low-carbon economy at a pace consistent with meeting globally agreed temperature targets (1.5°C or 2°C) would render a portion of known fossil fuel "unburnable" (Vergragt *et al*., 2011; *Economist*, 2013; Leaton *et al*., 2013; McGlade, 2013; Griffin *et al*., 2015). Central to the question of stranding risk is the extent to which climate-related financial risk from low-carbon transition is fully appreciated by investors and asset owners, and the extent to which these risks are fully integrated into market prices.

6.2 Literature Review

Although the majority of studies on stranding risk tend to focus on one point in the "investment chain", there has been some analysis of the implications of asset stranding for actors across the investment chain. The investment chain includes owners of physical fossil fuel assets, countries and companies responsible for issuing equities and debt, institutional investors, and financial institutions and regulators (Figure 6.1) (Chenet *et al*., 2015).

Evaluating the risk of stranding to physical assets has been the primary research focus. First of all, physical assets include known reserves of coal, oil and gas (CTI, 2011, 2013, 2015a; McGlade and Ekins, 2015; Linquiti and Cogswell, 2016; Newell *et al*., 2016). However, this category also encompasses power generation assets that are dependent on fossil fuels (Pfeiffer *et al*., 2016; Green and Newman, 2017) and it is estimated that €143 billion has already been written off European power sector asset values under accounting impairment rules between 2010 and 2016 (Ernst & Young, 2017). There has been a particular focus on coal generation within this subset of the literature (Caldecott and Mitchell, 2015; Caldecott *et al*., 2015b, 2016a, 2017b,c; Farfan and Breyer,

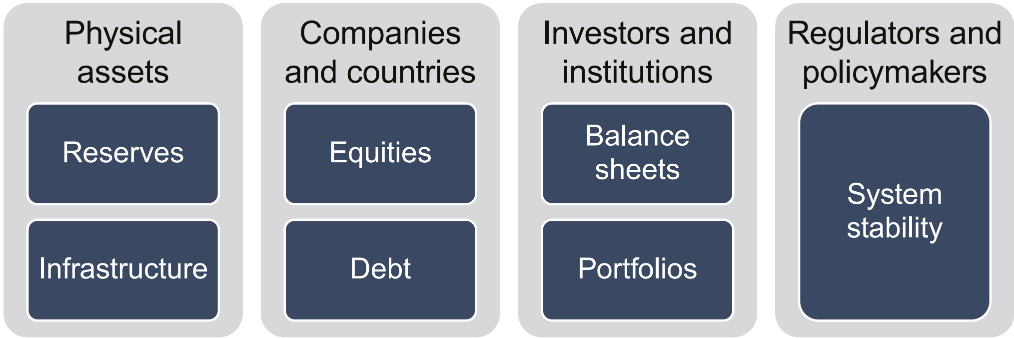


Figure 6.1. Stranded assets across the investment chain. Source: adapted from Chenet *et al.* (2015) and WRI/UNEP (2012).

2017a,b). Transport (Lloyds, 2017) and real estate (Dericks *et al*., 2018) assets that are dependent on the continued exploitation of these reserves, by contrast, have received less attention.

There has also been some analytical focus on the risk to financial assets posed by low-carbon transition. This category encompasses the shares of fossil fuel companies (HSBC, 2013; CTI, 2014, 2015b, 2017; Heede and Oreskes, 2016; Byrd and Cooperman, 2018), but also considers the quality of the debt issued by companies and countries exposed to stranding risk (Comerford and Spiganti, 2015; Mercer, 2015; Global Footprint Network, 2016; Malova and van der Ploeg, 2017). Finally, this category also includes investment portfolios (Credit Suisse, 2015; Mercer, 2015; BlackRock, 2016; Haslam *et al*., 2018) and even the balance sheet of financial institutions (Weber *et al*., 2006; Asset Owners Disclosure Project, 2017). Although the starting premise of this thread of the literature is that stranding risks may be mispriced for a number of reasons (Harnett, 2017; Silver, 2017; Thomä and Chenet, 2017), some studies have concluded that asset stranding may have a limited impact on financial assets such as equities (Griffin *et al*., 2015; Heede and Oreskes, 2016; ExxonMobil, 2018). Overall, the risk of stranding of financial assets has received comparatively less analytical focus than physical assets.

There has been some analytical focus on assessing the extent to which various actors across the investment chain in the financial and energy communities are aware of stranding risk from low-carbon transition (Asset Owners Disclosure Project, 2017; Harnett, 2017; Silver, 2017; Thomä and Chenet, 2017; Divestinvest, 2018). Preliminary research has indicated that there may be information asymmetries that affect perceptions of stranding risk for owners of physical assets compared with owners of financial assets (Global Investor Coalition on Climate Change, 2013). The concern is therefore that financial sector investors may have less information on climate risks because of an absence of reported information (Task Force on Climate-related Financial Disclosures, 2017; EC, 2018). Finally, there has also been some focus on determining the weight given to stranding risk in investment decisions for different actors, and the methods used to value and manage stranding risk across the investment chain (CTI, 2011; Caldecott *et al*., 2013a; ICBC, 2016; Task Force on Climate-related Financial Disclosures, 2017), although understanding of these issues is incomplete.

6.3 Objectives

Grounded in the necessity to study different country frameworks individually, as well as the lack of research comparing attitudes and perspectives on asset stranding risk across the investment chain in any jurisdiction, the objective of this study is to measure, compare and contrast perspectives on stranding risk from climate change across the Irish investment chain.

Ireland is an interesting case for two reasons. First, low-carbon transition has proceeded rapidly in the power sector, which has been transformed over the past decade. Renewable electricity generation has expanded rapidly: only 7% of electricity was generated from renewables in 2005 but by 2017 this had increased to 30% (SEAI, 2018a). Second, Ireland also has a well-developed financial services sector, which is one of the leading hedge fund service centres in Europe, focusing, in particular, on administration, insurance, aircraft leasing and payments. A thriving green finance cluster has emerged within this sector in recent years and a considerable number of professional services providers are focused on supporting green asset management (Sustainable Nation, 2018).

Given the prominence of low-carbon transition in the power and green financial sectors, we focus in this study on comparing perspectives on stranding risk for investors across these two cohorts. The key research questions addressed in this study are therefore as follows: first, we seek to assess if awareness of and attitudes to the risk of asset stranding differ for actors across the Irish investment chain, focusing in particular on evaluating differences between investors in the power and financial sectors; second, we seek to assess if methods used to value and manage stranding risk, and key barriers to integrating stranding risk into decision-making, are different for these key investors.

Section 6.4 introduces the research framework and the methodology used in the study and section 6.5 presents an overview of the data. Section 6.6 discusses the results and, in section 6.7, the implications of these results are assessed within the context of the research questions. Finally, section 6.7 also sets out conclusions and policy recommendations and identifies areas for future research.

6.4 Materials and Methods

In order to achieve the research objectives outlined above, we undertook interviews and an online survey of key figures in the Irish power and financial sectors. We therefore employed a convenience sampling approach instead of more systematic techniques, which is common within qualitative business studies research (Eriksson and Kovalainen, 2008).

The first step was to undertake a literature review to uncover the key aspects of stranding risk that may be relevant for key actors across the Irish investment chain. In addition, the Global Investor Survey on Climate Change (2013) and Inter-American Development Bank (IADB, 2016) were drawn on to identify relevant questions. On this basis, a draft survey was designed that identified the main aspects of stranding risk relevant to Irish stakeholders and experts.

We followed the literature review with semi-structured interviews with key “gatekeepers”, following the approach employed by Harnett (2017) and Eleftheriadis and Anagnostopoulou (2015), and akin to the iterative approach suggested by the Delphi method (Okoli and Pawlowski, 2004). Two specific “gatekeeper” organisations were chosen because of the concentration of their members at particular points in the investment chain:

1. the Electricity Association of Ireland (EAI), the representative body for the Irish power sector, which was used to identify key power sector actors;
2. Sustainable Nation Ireland (SNI), a platform for capital market participants, corporates, innovators and public sector organisations focused on green finance, which was used to target key financial sector actors.

Within these gatekeeper organisations a number of key people were interviewed.[17] Interviewing these key “gatekeeper” organisations served two purposes. We used responses and feedback to refine the draft questionnaire, thereby ensuring that it was targeted to issues relevant to the skills and expertise of prospective respondents. The semi-structured interviews therefore ensured a degree of flexibility and responsiveness in our research design, which has been identified as important when interviewing elite figures from business and finance (Okoli and Pawlowski, 2004; Harvey, 2010). Issues raised in initial interviews provided questions for subsequent interviews (Ziebland and McPherson, 2006) and allowed us to design and refine an online survey so that we could reach a wider cohort of respondents.

Second, these “gatekeeper” organisations were used to identify key relevant investors in the power and green finance sectors who were owners and managers of assets and who were centrally involved in making investment decisions. These organisations recommended that we contact other key figures to interview and survey and we therefore employed a “snowballing” technique, which has been found to

17 Dara Lynott and Stephen Douglas (EAI) and Laura Heuston and Stephen Nolan (SNI).

ameliorate the subjective choices of researchers (Atkinson and Flint, 2001).

The "convenience sampling" approach allowed us to overcome the typical challenges associated with gaining access to a representative sample of key "elite" figures in the business and finance world (McDowell,1998; Okoli and Pawlowski, 2004; Eriksson and Kovalainen, 2008; Harvey, 2011; Harnett, 2017).

6.5 Data

Interviews with key individuals in the gatekeeper organisations were undertaken between 26 March and 5 April 2018. A survey was subsequently circulated by email to approximately 203 key experts, divided evenly between the energy sector and the financial sector. Overall, 54 responses were collected, which is in line with the numbers recommended for expert consultation exercises (Okoli and Pawlowski, 2004). Of these, however, seven respondents failed to provide sufficient data for analysis. There were 47 completed responses.

There were 24 completed responses from the power sector; respondents were primarily generation asset owners, but also included a smaller number of owners and operators of the transmission and distribution systems. There were 23 respondents from the financial sector, including institutional and private investors, financial asset managers, lenders, investment consultancies and accounting firms (Table 6.1).

Respondents were generally at a high level within their organisation. Of the 47 respondents, 23 were in a senior management position and a further 17 were in a middle management position. Of the 24 respondents from the power sector, 14 were involved in "policy, regulation and public affairs", eight were involved in "business development" and two were involved in "investment"; in the financial sector, 11 respondents were focused on "investment" and only six were focused on "policy, regulation and public affairs" (Table 6.2).

Nearly all respondents from the power sector were involved with power generation and transmission assets and about half of the financial sector

Table 6.1. Overview of respondents

Sector	Stakeholders identified	Responses received	Completed responses
Power sector	103	28	24
Finance sector	100	26	23
Total	203	54	47

Table 6.2. Summary of respondent characteristics

		Power sector	Financial sector	Total
Role in organisation	Senior manager	13	10	23
	Middle manager	8	9	17
	Other	3	4	7
Key focus	Policy/regulation/public affairs	14	6	20
	Investment	2	11	13
	Business development	8	3	11
	Project finance	0	2	2
	Other	0	1	1
Relevance of asset class to business activities	Stocks	3	14	17
	Fixed income or bonds	7	14	21
	Money market or cash equivalents	5	14	19
	Commodities	14	9	23
	Real estate and infrastructure	13	14	27
	Power generation assets	21	14	35
	Energy transmission/distribution assets	22	12	34
Total number of respondents		24	23	47

respondents also had some focus on these assets. More power sector respondents were focused on "commodities", but fewer were involved with bonds, money markets and stocks than financial sector respondents (see Table 6.2).

6.6 Results

In interviews conducted with the EAI, stranding risk "from low-carbon transition" was identified as "the most important topic" on the minds of its members at the time. By contrast, SNI observed that stranding risk was only an issue for a subset of members focused on green finance and that, even within this cohort, knowledge and awareness of the issue was mixed. These observations were borne out by the survey results.

A large majority of survey respondents were "very familiar" or "somewhat familiar" with the concept of stranded assets, which was defined in the survey as "assets that have suffered from premature write-downs, devaluations or conversion into liabilities because of the transition to a low carbon economy". However, looking at familiarity by sector, we found a higher overall level of awareness of the issue among power sector respondents, with 15 of 24 respondents indicating that they were "very familiar" with the concept, compared with only 9 of 23 financial sector respondents.

When it came to the methods used to assess stranding risk, scenario analysis and risk analysis were the most popular, whereas stress testing, assessment of emissions testing of assets and asset impairment tests were less popular for both cohorts. No discernible differences were noted between power and financial sector professionals in this case.

Finally, we asked power and financial sector respondents to briefly describe actions that they or their organisation had taken to "manage stranding risk from climate change". Many power sector professionals indicated that stranding risk had already affected investment decisions. For example, several respondents commented that they had "delayed investment decisions", "reassessed investment strategy", "re-evaluated asset management investment case decisions" or "reassessed investment decisions to manage stranding risk". Several other respondents said that they had focused on investing in low-carbon technologies to manage stranding risk. For example, one had "invested in renewable and emerging technologies", another had invested in "a broad range of renewable and innovative low-carbon technologies to future proof" their asset portfolio and another was "focused on new technology". Two respondents added that they had already written down asset values in response to asset stranding.

By contrast, the financial sector respondents were far less likely to have taken specific actions to address stranding risk. In response to this item, several survey respondents responded "no action taken to date", "nil" or "none" or "I have no idea". Others responded that stranding risk was "not very important in a diversified portfolio" or that they did not have "any real exposure to stranding risk as a lender" or that they only managed "a very small part of any portfolio, so not sure how relevant it is for us". One respondent stated that their organisation was "not specifically focused on stranded assets as a key driver of climate risk" but that they took a "broader view of risks and opportunities" from the transition to a low-carbon economy.

For those in the financial sector who had taken specific actions to manage stranding risk, "diversification" or "diversification of portfolio", or "invest heavily in alternative energy companies, minimise our investments in fossil fuel companies", was mentioned by a number of respondents. "Ethical screening" and "examination of information available in accessible published sources" were also cited by respondents, with "risk analysis" cited by two respondents and "constant monitoring of assets" cited by another respondent. Another added that their organisation had undertaken "extensive research on the topic and have made investors aware of the risks". One respondent stated that they had undertaken an "environmental, social and governance assessment of all asset managers including asset class specific risks from stranding", whereas another added that they had "integrated carbon emission-related data into our investment processes".

Interviewees suggested that awareness of stranding risk would be more acute in the power sector than in the financial sector, and this observation was borne out by survey responses. We found considerable differences in the level of awareness of stranding risk, with a lower proportion of financial sector respondents "very familiar" and "somewhat familiar" with the concept of asset stranding. Furthermore, power sector respondents were far more likely to consider asset stranding as "very important" for their business, whereas, in the comments provided, several financial sector respondents said that they did not know if stranding risk was an issue for their business or investments, hinting at an information deficit. Furthermore, all respondents, whether from the power sector or from the green financial sector, ascribed the greatest risk of stranding for power generation and other energy sector assets, with financial assets judged to be less exposed. However, it should be noted that financial sector actors also emphasised the importance of stranding risk for financial assets, in particular for stocks and commodities and somewhat less so in the case of real estate and fixed income bonds, whereas power sector respondents were less familiar with the exposure of these assets.

Nevertheless, power sector assets were considered to be the most exposed by both cohorts. This may be because of the diffusion of risk for financial institutions and investment managers across their investment portfolio compared with the owners and managers of fossil fuel assets. Indeed, several financial sector actors emphasised their ability to diversify their portfolio of investments as an effective approach to managing stranding risk, and others pointed out that they already managed a diversified portfolio and that fossil fuel assets formed only a small part of this portfolio. It is inevitable that stranding risk would be more apparent to those managing or owning fossil fuel generation assets under these circumstances. Another possible explanation for the lower risk assessment by financial asset owners is because of the higher liquidity of financial compared with physical assets. It is notable that the most liquid asset class, "money markets and cash equivalents", was rated by respondents as the least exposed to stranding risk, whereas the least liquid assets (power transmission and generation) were considered the most exposed.

As anticipated by power sector interviewees, policy changes were perceived as the most important factor underpinning stranding risk overall, with Irish policy changes ranked as the most important issue. The importance of changes to subsidy regimes, including capacity auctions and feed-in tariffs, was underlined by interviewees and this view was reinforced by the survey results. EU and international policies were also rated as important for power sector respondents. For financial sector actors, however, "technological change" was identified as the most important source of stranding, with "Irish policy" considerably less significant. This perhaps reflects the greater international reach and global perspective of the Irish financial sector, with the power sector being more domestic in nature; therefore, power sector actors would tend to be more specifically focused on the domestic context and national policy developments. Overall, power sector respondents therefore had more awareness of, and exposure to, stranding risk than financial sector actors, and the sources of stranding risks were also perceived somewhat differently.

Second, we sought to assess if methods used to value and manage stranding risk, and key barriers to integrating stranding risk into decision-making, were different for actors across the two sectors. Although power sector respondents were somewhat more likely to have "comprehensibly" measured their exposure to stranding than financial sector respondents, the differences were not stark between the two sectors in this respect. In addition, there were no differences in the measures employed to measure stranding risk across sectors, with scenario analysis and risk analysis the most popular methods for both cohorts. On the other hand, many power sector respondents indicated that they had decisively acted to manage stranding risk, including asset write-downs, re-evaluating their investment strategies and ensuring a greater focus on renewable technologies in their generation and investment portfolios. Financial sector respondents were less likely to have taken specific actions and, when actions had been taken, they were generally somewhat milder. For example, several respondents mentioned methods that had been employed to promote awareness or to screen investment decisions, although it should be noted that some also mentioned diversification of investment portfolios.

Power sector respondents had considerably more confidence in their ability to measure stranding risk and they were also considerably more likely to have formally reported on these risks. However, even in the power sector, less than half of respondents had formally reported to management or externally on their potential exposure. When it came to managing stranding risk, policy uncertainty was identified as the most important barrier by respondents in both sectors. However, "inadequate company disclosures" and "inadequate data on the emissions intensity of debt/bonds" received a considerably higher ranking from the financial sector cohort than from power sector professionals. This indicates that the availability of accurate data is more of an issue in the financial sector than for power sector asset owners and managers, who are more concerned by factors outside their control such as sudden policy changes. Information asymmetries therefore emerge as an important consideration underpinning investor perception.

Power sector actors have therefore been more proactive in taking decisive actions to managing stranding risk and are more confident in their ability to manage these risks. They were more likely to see risks arising from sudden changes in policy that were outside their control than from an absence of data and information.

6.7 Conclusion

In order to meet climate targets, it will be necessary to mobilise a much greater level of investment in low-carbon assets in the period to 2050. How different actors perceive investment risks can be highly influential over the cost of capital and investment decisions and has therefore been a subject of growing analytical interest. The risk of asset stranding posed by the transition to a low-carbon economy is a particular issue of concern for owners and managers of physical and financial assets.

The objective of this study was to measure, compare and contrast perspectives on stranding risk from climate change for two groups in the Irish investment chain: investors in the power and financial sectors. We sought to assess if awareness of and attitudes to the risk of asset stranding differed for these two groups and if the methods used to value and manage stranding risk, and perceptions of key barriers to integrating stranding risk into decision-making, were different.

The study is limited by a number of factors. First, we used a convenience sampling approach and "snowballing", rather than a more systematic technique. This method was chosen because of the challenge of identifying a representative sample of investors from the power and green financial sectors, which were the primary cohorts of interest. Second, we restricted our focus to investors in Ireland, a country with a highly developed financial sector and a power sector that is relatively well advanced in transitioning to sustainability. Third, the number of respondents, although sufficient for the needs of a largely qualitative assessment of this kind, was relatively modest. On this basis, we cannot assume that our results are indicative of the views of the wider international market, and we therefore present our results as indicative and exploratory in nature.

Notwithstanding these limitations, our survey is the first of its kind that looks at how perceptions of stranding risk differ between investors in financial assets and investors physical fossil fuel assets. It therefore makes a unique contribution to an emerging literature. Our findings support the view that stranding risk is perceived to be a more prominent issue for investors in power sector assets than for investors in financial assets, and that stranding risk is perceived to arise from different factors by these actors. The power sector investors were, for example, primarily concerned with the policy context, whereas the financial sector actors were more concerned with technological change. Power sector actors were also more confident in their ability to assess and manage stranding risk and had taken more decisive steps to manage it. Financial market actors, by contrast, pointed to a lack of information or accepted methodologies for making these assessments. These findings therefore support the view that information asymmetries may be a key issue and provide evidence that ongoing efforts to improve reporting of climate-related financial risks (Task Force on Climate-related Financial Disclosures, 2017; EC, 2018) are required.

These findings may reflect a greater diffusion of risk for financial institutions and portfolio managers, noted in previous studies (Global Investor Coalition on Climate Change, 2013), but also perhaps the greater liquidity of financial compared with physical assets.

Overall, our findings suggest that the understanding and ability to accurately quantify stranding risk may be less developed for financial sector than the power sector cohort. The former may not have yet developed a comprehensive appreciation of stranding risk compared with the latter and may therefore not be in a position to fully factor this risk into investment decisions.

7 Fossil Fuel Subsidies

7.1 Introduction

Fossil fuels accounted for 90% of all energy used in Ireland in 2017 (SEAI, 2018b). As an additional work package to this project, the researchers were asked to do a desk review of the impact of fiscal instruments on fossil fuel lock-in. A detailed review of the implications of taxation for the agriculture sector was undertaken in 2018 (Government of Ireland, 2018).

7.2 Methodology

The Department of Communications, Climate Action and Environment (DCCAE) provided a list of relevant taxes, subsidies and levies. This, as well as a report from the Economic and Social Research Institute (ESRI, 2018), were used to identify relevant information. The Taxes Consolidation Act 1997 (Government of Ireland, 1997) were also used to identify taxes and incentives that are directly related to the fossil fuel and renewable industries. Government grants and indirect methods of support available to both the fossil fuel sector and renewable energy sector were also examined. A literature review was also conducted to identify relevant issues. Taxation is a highly specialised area and the findings are limited by the team not being experts in taxation. However, we highlight the following areas. Energy taxes accounted for over €3 billion in 2016 (Table 7.1). This is a significant source of revenue for the Exchequer. Under deep decarbonisation scenarios these revenues would need to be replaced with other sources of funding, particularly given the commitment in the all of government plan to tackle climate disruption[18] that commits to "reviewing the role of the accelerated capital allowances regime in promoting low carbon investments in all relevant sectors".

7.3 Carbon Tax

Carbon tax applies to CO_2 emissions from sectors such as transport fuel, gas, oil, kerosene and solid fuel. The cost of the tax is €20 per tonne, which is levied on fossil fuel consumers. The rationale for this tax is that the emitter pays. In 2016, the carbon tax raised over €434 million for the Irish government (CSO, 2017). An additional increase of €10 per tonne would see an extra €200 million raised; this could potentially be used to pay any penalties that Ireland may incur for missing the 2020 emissions targets (Ó Gallachóir, 2016).[19] A recent report of the Joint Committee on Climate Change[20] recommends increasing the carbon tax to €80 per tonne by 2030 and that the revenues be ringfenced to support climate actions.

7.4 Public Service Obligation Levy

Electricity generation from peat is still being incentivised through the Public Service Obligation (PSO) levy, although this is due to be phased out in 2019. Capacity payments are also available to fossil fuel generators for security of supply.

Table 7.1. Energy taxes generated in Ireland in 2016

2016 energy taxes	€ million
Duty on light hydrocarbon oil products	725
Duty on other hydrocarbon oil products	1454
Electricity tax	5
National Oil Reserves Agency levy	130
Carbon tax	434
Public Service Obligation levy	328
Total	3076

Source: CSO (2017).

18 https://www.dccae.gov.ie/en-ie/climate-action/topics/climate-action-plan/Pages/climate-action.aspx (accessed 1 June 2018).

19 This is based on a straight-line basis assuming no behavioural reaction to the tax increase on the part of consumers or producers, and is sourced from 2018 Tax Strategy Group estimates, compared with more dynamic estimates produced using the ESRI's environment, energy and economy (I3E) model in its recently published paper (De Bruin and Yakut, 2019).

20 https://data.oireachtas.ie/ie/oireachtas/committee/dail/32/joint_committee_on_climate_action/reports/2019/2019-03-28_report-climate-change-a-cross-party-consensus-for-action_en.pdf (accessed 1 June 2018).

7.5 Commercial Rates

Another significant source of revenue is the charges levied on commercial properties in the form of rates. The estimation of commercial rates is a highly complex technical area. However, the research suggests that the rates applicable to fossil fuel energy companies are lower per MW of generation than those applicable to renewable energy companies. This is because the total equipment cost in Irish windfarms falls under the rateable category whereas only the generation technologies are rateable for fossil generators. The recommendation of the Wood Committee's 1993 review in the UK resulted in all turbines and alternators on windfarms being marked as non-rateable, thus resulting in much lower rates figures (Wood, 1993). Furthermore, under the receipts and expenditure method of rates estimation, fossil fuel companies are allowed to deduct fuel expenses arriving at the rateable value whereas renewable companies cannot do this because they do not have any fuel expenses. The current rates system for generation technologies in Ireland is not in line with the aims of the Royal Institute of Chartered Engineers or the Society of Chartered Engineers in Ireland, whose objectives are to harmonise cross-border valuation and global standards (see Farrell, 2017, for further details. The rates system in Ireland should be reviewed to address the bias favouring the fossil fuel industry.

It is worth noting the impact of commercial rates on the cost of debt for independent power producers and state-owned utilities. ESB, Ireland's largest owner of electricity distribution and transmission networks, is 95% owned by the Irish government. The company's credit rating was upgraded to A3 in 2017, with Moody's (2018) citing "potential support given government ownership, should it become necessary" as a reason for the rating, proving that government affiliation positively impacts a company's cost of debt. This could be viewed as an indirect subsidy in which the cost of debt is lower because of an implicit understanding that the Irish government is underwriting the company's debts. It should be noted, however, that ESB has outlined a corporate strategy in which the company seeks to achieve 40% of its generation from renewable sources by 2030 and is seeking to co-fire biomass and peat at its Moneypoint coal-fired power station.

Other supports for the fossil fuel industry include the National Fuel Scheme (€214 million), the Household Benefits Package (€154 million), the PSO levy (€115 million) and the national oil reserves levy (€130 million). Many of these supports are included in a list from the Central Statistics Office (CSO) on Potentially Environmentally Damaging Subsidies (see Appendix 1).

7.6 Conclusion and Policy Recommendations

In previous chapters we presented the findings from the work packages of the project. These covered an overview of the project and project background, a literature review, the identification and assessment of fossil fuel-reliant assets, infrastructures and support systems in Ireland, benchmarking Irish fossil fuel infrastructure against other EU Member States, a value-at-risk assessment of fossil fuel infrastructure and a survey of investor perceptions of stranded asset risk. These chapters provide evidence of the future for stranded assets and investment issues and options in a low-carbon Irish energy system.

The topic of "stranded assets" arising from the transition to a low-carbon economy, and how this might affect investor perceptions of risk and return, has risen up the agenda of regulators, researchers and investors over the past decade. Policies geared towards decarbonising the economy are likely to create significant investment challenges to fossil fuel infrastructure. Ireland's current policy landscape centres on ambitions of an 80–95% reduction target in CO_2-related emissions by 2050 relative to 1990 levels, with interim targets in between. Additionally, Ireland is also a signatory to the Paris Agreement, which aims to keep global emissions well below 2°C.

Wholesale market reforms, introduced under the Integrated Single Electricity Market (I-SEM) project in 2018, aim to ensure a reliable income stream for dispatchable generators in the context of probable reduced energy-only revenues. Non-energy revenues include a guaranteed capacity payment for plants successful in a new competitive capacity auction, and remuneration for ancillary services relating to the Delivering a Secure, Sustainable Electricity System (DS3) programme.[21] These schemes are designed

21 See http://www.eirgridgroup.com/how-the-grid-works/ds3-programme/ (accessed 21 July 2018).

by the transmission system operator (TSO) and National Regulatory Authority to ensure that revenue streams promote sufficient investment in dispatchable generation and to ensure continued security of supply during the decarbonisation of Ireland's power generation sector. Notwithstanding these policy interventions, our assessment of an 80% reduction pathway suggests that gas generation assets and gas transmission networks could incur short- to medium-term risks, whereas the gas distribution network may incur similar risks in the long term. Low-carbon opportunities, through the integration of renewable gas and CCS to reduce the emissions of gas network customers, could prolong the life of the network, in addition to acting as a signal for further investment. However, renewable gas is significantly more expensive than conventional gas and CCS technology is yet to prove itself at scale deployment. It is worth noting that the all of government plan to tackle climate disruption (DCCAE, June 2019) is committed (under Action 7.5) to establishing a steering group to examine and oversee the feasibility of the utilisation of CCS in Ireland.

A continued path of investment in gas networks to reduce emissions in the short term will require an increase in investments to the gas network asset base and puts a greater value at risk in the long term.

We find that once an investment is made in the RAB, the risk of stranding is less likely to come from gas demand and more likely to come from changes in regulation and how tariffs are allocated.

Under the assumptions of this analysis, distribution network tariffs could increase by 17% by 2030 and may increase further as the asset owner seeks to recover a return on investment with falling gas demand. We find that increased electrification of heat and increased efficiencies of existing connections are the main risks to the distribution network. The gas distribution network is currently, and will continue to be, a primary source of low-carbon heat and potential fuel for freight transport. The policy implications from this analysis are that investment in the asset base of the gas network should be continued, cognisant of the potential decline in demand post 2030. The financial viability of Ireland's gas network in a fully decarbonised energy system remains an open question.

Our EU-wide study benchmarked Ireland's stranded asset risk against other EU Member States for gas infrastructure, from a financial performance perspective. In this study we found that Ireland's level of risk is moderate relative to other Member States. The analysis draws from the European Commission's reference scenario for the year 2030, assuming that EU states meet their 2020 targets. The results show that out-of-market payments may need to increase from 22% to 33% to compensate generators for losses if security of supply is to be maintained. The analysis points to an uncertain future for gas infrastructure in Europe. The strongest investment case for gas generation assets is found in central and northern Europe. Most of the remainder of the EU experienced low and negative returns under these scenarios. In the remaining Member States the investment case largely hinged on the availability of out-of-market payments. Member States that generated poor returns for gas-fired units also experienced higher transmission network costs, potentially leading to a stranded asset risk for networks and an uncertain investment case for these assets.

Stranded gas generation assets may represent considerable losses on investments to utilities if plants are not able to recover capital costs. Ernst & Young (2017) estimate that €143 billion has already been written off European power sector asset values under accounting impairment rules between 2010 and 2016. Irish utilities with fossil generation are also exposed to this risk. Beyond balance sheet impacts, these stranded assets may affect the ability and willingness of firms to invest in new plants and gas transmission networks. The revenue recovery model for regulated network assets may continue to provide a reliable source of income; regulated transmission and distribution networks could, on the other hand, become less competitive, in part because of the tariff increases required in some Member States to recover such revenue. However, there is a risk that the customer tariff model may break down if disconnections reach a tipping point and the costs become too high for remaining customers to bear. The potential evolution of the regulatory environment and energy market design at both European and national levels will be a key theme in the context of future investment strategy.

Creating a continued investment case for Irish energy infrastructure is of paramount importance. Using a committed emissions approach, we find that there may be debt maturity management and debt rollover risk for Irish utilities if a low-carbon or carbon neutral pathway to 2050 is pursued. The ability of utilities to manage their debt is heavily weighted on key credit rating metrics. It is important that utilities can manage existing and future cash flows and debt throughout the transition period. Investment-grade corporate debt generally consists of a series of positive net present value projects and the compatibility of those projects with low-carbon scenarios is an indicator of future credit quality. We find that 84% of a leading Irish utility's existing fossil fuel-based power generation assets may be incompatible with a 1.5°C budget and 27% with a 2°C budget. If these budgets are to be realized, this utility could move from a Baa1 rating to a Baa3 rating. Additionally, 68% of potential future cash flows may not be realised in a 1.5°C scenario and 19% in a 2°C scenario and this could lead to challenges in settling existing debt. If these generation assets are to comply with low-carbon ambitions, debt rollover risks could emerge as soon as 2021 for a 1.5°C budget and by 2031 for a 2°C budget.

The survey of Irish financial sector and power sector investors supports the view that stranding risk is perceived to be a more prominent issue for investors in power sector assets than investors in financial assets and that stranding risk is perceived to arise by these actors from different factors. The power sector investors were concerned primarily with the policy context, whereas the financial sector actors were more concerned with technological change. Power sector actors were also more confident in their ability to assess and manage stranding risk and had taken more decisive steps to manage it. Financial market actors, by contrast, pointed to a lack of information or accepted methodologies for making these assessments and also to a lack of disclosure of information on which to make these risk assessments. These findings therefore support the view that information asymmetries may be a key issue and provide evidence that ongoing efforts to improve reporting of climate-related financial risks (Task Force on Climate-related Financial Disclosures, 2017; EC, 2018) are required.

In addition, these findings may reflect a greater diffusion of risk for financial institutions and portfolio managers, noted in previous studies (Global Investor Coalition on Climate Change, 2013), and also perhaps the greater liquidity of financial compared with physical assets. It may also be because risks that are typically considered by financial market actors (such as market, inflation, or interest rate) are measured on a short-term basis but risks posed by climate change demand longer time horizons. Power sector actors, by contrast, are familiar with evaluating investment decisions over much longer investment horizons. Overall, our findings suggest that the understanding of and ability to accurately quantify stranding risk may be less developed for financial sector investors than the power sector cohort. The former may not have yet developed a comprehensive appreciation of stranding risk and may therefore not be in a position to fully factor this risk into investment decisions.

The transition to a low-carbon energy system has significantly altered the risk and return to power sector investors. There is now widespread acceptance that increasing penetration of low-carbon generation, with zero operating costs (i.e. the fuel cost for renewables is zero) and priority dispatch in most liberalised electricity markets, has led to significant changes in price volatility and operational regimes for thermal generators, and hence network assets. Our report identifies significant potential stranded asset risk for both generation and infrastructure assets in Ireland. Significant policy intervention and innovation will be required to provide a return to capital providers to maintain security of supply while endeavouring to reduce energy costs. Policymakers, in considering future policy changes, need to review the effect of decarbonisation on power sector investor returns. This will require new approaches to remunerate investors in generation capacity, ancillary services and network assets. A key theme that emerges from our investor survey is the need for policy certainty to attract long-term investment in the energy sector.

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Abbreviations

AR5	Fifth Assessment Report
BAU	Business as usual
CAPEX	Capital expenditure
CCCE	Cumulative committed carbon emissions
CCS	Carbon capture and storage
CER	Commission for Energy Regulation
CLIC	Carbon lock-in curve
CSO	Central Statistics Office
CTI	Carbon Tracker Initiative
DM	Daily metered
EAI	Electricity Association of Ireland
EPA	Environmental Protection Agency
ESB	Electricity Supply Board
ESRI	Economic and Social Research Institute
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal rate of return
LNG	Liquefied natural gas
NDM	Non-daily metered
PEDS	Potential environmentally damaging subsidies
PSO	Public Service Obligation
RAB	Regulatory asset base
SEAI	Sustainable Energy Authority of Ireland
SNI	Sustainable Nation Ireland
TIMES	The Integrated MARKAL-EFOM System
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

Appendix 1 Potentially Environmentally Damaging Subsidies (PEDS)

Programme	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Agricultural product subsidies: cattle	632,700	512,600	675,700	695,000	625,500	438,800	3400	600	32,300	29,900	31,641	30,794	28,524	9350	28,820	43,217	55,900
Agricultural product subsidies: sheep	133,600	82,000	108,300	109,300	106,600	11,500	200	–	–	–	–	–	–	–	–	–	–
Agricultural product subsidies: cereals	99,700	108,400	112,400	116,300	112,200	1800	–	–	–	–	194	241	13	–	–	–	–
Agricultural product subsidies: other	9900	7600	7600	7700	67,700	1400	100	100	100	100	–	–	–	–	–	700	–
PSO levy: electricity generation from peat	–	–	39	38,929	58,428	62,707	65,145	–	–	84,488	78,200	41,597	94,178	94,800	119,000	121,900	115,400
PSO levy: security of electricity supply	–	–	–	–	–	19,987	–	–	–	18,200	14,000	20,739	42,191	61,000	104,700	47,300	–
Fuel allowance	66,450	61,300	80,600	87,017	84,700	82,384	84,969	136,835	151,117	193,624	222,062	261,615	211,394	228,141	217,731	214,222	230,921
Electricity allowance	47,036	51,300	62,100	72,408	87,900	103,874	114,710	130,769	152,085	165,515	171,589	179,251	176,733	161,048	154,551	149,572	150,729
Gas allowance	2182	2640	3211	4708	5613	6430	7956	13,624	15,292	17,700	19,982	20,716	20,615	16,299	21,815	18,752	19,193
Other supplements (including heating and diet)	5323	5100	6250	650	7300	6696	6767	6918	7143	–	6701	6383	5624	–	4062	3690	3347
Smokeless coal allowance	–	–	–	–	–	–	6036	5884	5982	5985	6601	4224	–	–	–	–	–
Fishing Fleet Investment Scheme	8797	3941	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Petroleum Infrastructure Support Group	378	159	349	29	2559	0	32	299	251	723	5227	1105	1105	70	280	4297	191
Funding of Petroleum Scholarships	–	–	8	14	11	–	–	–	2	–	–	–	–	–	–	–	–
Haulier's diesel rebate scheme	–	–	–	–	–	–	–	–	–	–	–	–	–	700	21,100	13,100	1300
Marine diesel tax relief	–	–	–	–	–	–	–	–	–	–	–	–	100	200	100	–	–

Source: CSO (2018).

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
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- 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.

EPA Research Report 302

Fossil Fuel Lock-in in Ireland: How Much Value is at Risk?

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

Authors: Celine McInerney, Conor Hickey, Paul Deane, Joseph Curtin and Brian Ó Gallachóir

Identifying Pressures

European emissions reductions policy points to achievement of carbon neutrality by energy sectors, particularly the electricity sector, by 2050 at the latest. Gas has been promoted as the "transition" fuel in this process; however, the financial viability of gas generation assets is no longer guaranteed. The transition to a low carbon energy system has significantly altered the financial risk and return for energy sector investors. The increasing penetration of low carbon generation, with zero operating costs (i.e. the fuel cost for renewables is zero) and priority dispatch in most liberalised electricity markets, has led to significant changes in price volatility and operational regimes for thermal generators and, hence, network assets.

Stakeholders in the finance and banking industries, including central banks, regulators and credit rating agencies, have warned of the financial risk associated with being locked into fossil energy systems and have called for collective action to facilitate the role of the finance sector in achieving the goal of the Paris Agreement of ensuring that finance flows are consistent with low emissions and climate resilient development.

Informing Policy

Energy system pathways for Ireland and Europe suggest that power generation will have to be carbon neutral by 2040, which means that fossil fuel generators may have to be shut down prematurely, creating stranded asset risks. This means that owners of these assets may suffer financial losses. This may have implications for security of supply in the short term as fossil fuel generators currently provide back-up and balancing services for intermittent renewable generation. The investment case for fossil infrastructure assets is also likely to be undermined. The gas network is remunerated under a regulatory asset base (RAB) regime and is therefore dependent on the size of the customer base to pay fees. In a low gas consumption world, the RAB will come under pressure as a lower customer base will result in higher fees. The financial viability of Ireland's gas network in a fully decarbonised system remains an open question. The concentration of bank debt and insurance in these sectors may also have wider implications for the banking and finance industry.

Developing Solutions

Our report identifies a significant potential stranded asset risk for both generation and infrastructure assets in Ireland. Under deep decarbonisation scenarios (80% reduction in emissions by 2030 relative to 1990 levels), returns to owners of generation and transmission and distribution assets will no longer be sufficient to attract capital. For security of supply to be maintained and for continued investment to be made in infrastructure assets, new approaches to incentivising long-term investment and "out-of-market payments" for generation adequacy and reliability services will be required. Policymakers, in considering future policy changes, need to review the effect of decarbonisation on power sector investor returns. This may require new approaches to remunerate investors in generation capacity, ancillary services and network assets. A key theme that emerges from our investor survey is the need for policy certainty to attract long-term investment in the energy sector. Investment in renewable technologies is typically characterised by higher capital costs and much lower operating costs than those for fossil technologies. A high carbon price would assist in creating greater incentives to invest in low carbon assets. This will be necessary to achieve Ireland's low carbon transition.

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