Energy for generations

Ireland's low carbon future

– Dimensions of a solution

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Executive Summary

The role of electricity in the transition to a low carbon energy future
Climate change is one of the biggest challenges facing humanity and globally there is a critical need to reduce greenhouse gas (GHG) emissions to protect future generations. This is acknowledged in a range of international agreements and national policy documents that set out ambitious targets to restrict global warming and eliminate greenhouse gases.

The energy sector is a major contributor to GHG emissions and has both a responsibility, and an opportunity, to be part of the solution. The Government published the Climate Action and Low-Carbon Development National Policy Position in April 2014, committing Ireland to an 80% aggregate reduction in Carbon Dioxide (CO_2) emissions in the energy sector on 1990 levels - from 38 million tonnes today to to just over 6 million in 2050 (Department of Environment, Community and Local Government, 2014). The Government White Paper on Energy Policy (2015) underlines this target[1] and sets out a commitment to eliminate CO_2emissions from energy by 2100.

The implications of this are wide ranging and significant, not just for the energy sector but for all citizens. By 2050, Ireland's population is expected to grow by almost a quarter[2], resulting in some 500,000 additional homes being built and about one million more cars on the roads. (AECOM & ESRI, 2014).

Given the scale of the challenge, the eventual elimination of GHGs cannot be achieved through the continuation or expansion of current energy efficiency and renewable energy policies alone. It will need radical new thinking and fundamental changes in the way that we consume energy, particularly in those sectors where emissions are highest. With this comes significant investment.

This report sets out a roadmap for change that prioritises investment towards those areas that will have the greatest impact on reduction in emissions from energy. It seeks to minimise the risk of stranded assets by looking at the probable shape of our low carbon energy system in 2050 using technologies that exist today and moving towards this in our plans with a "low regrets" series of options. It particularly looks at the transport, heating and electricity generation sectors, which together account for just over 50 per cent of total GHG emissions in Ireland.

This Executive Summary groups Key

Insights across four specific areas:

i. Ireland's Energy and Climate Challenge to 2050
ii Technology options for full electricity system decarbonisation
ii The challenge of significantly reducing emissions from Agriculture, Heating and Transport
iv The building blocks of a successful Energy Roadmap to 2050

i Ireland's Energy and Climate Challenge to 2050

a. Ireland is now committed to the long term, progressive decarbonisation of the energy system, and plans to reduce emissions by at least 80% by 2050[3] and 100% by 2100. This means that the total allowable energy emissions in Ireland by 2050 will be 6 Megatonnes (Mt) (This is explained in Chapter 6). To put this in context, the Transport sector produced 11.8 Mt of GHG emissions in 2015 and the Electricity Generation sector 11.3 Mt. In the same year, the provision of heating to our homes and businesses with fossil fuels produced 9 Mt of emissions.

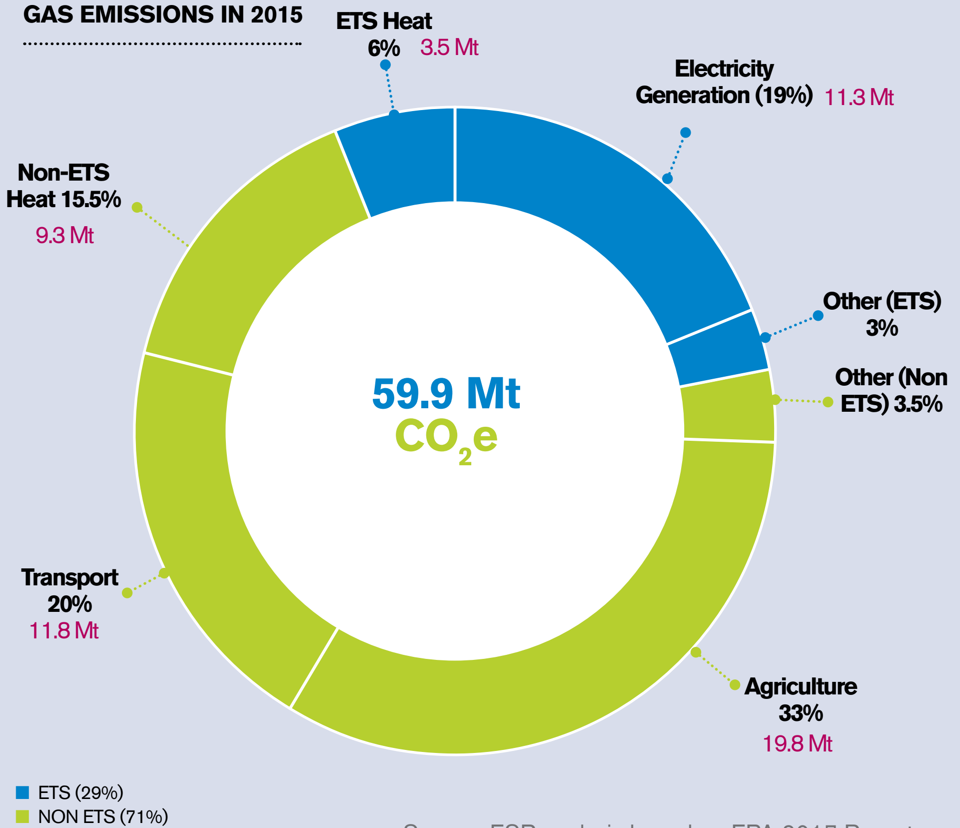
b. In the period to 2050 it is forecast that Ireland's population will grow by 23% (Central Statistics Office, 2013), the number of cars will grow by 54% and housing stock by 34% (Deane, et al., 2013) placing upward pressure on energy demand and "Business as Usual" CO_2 emissions.

c. It is clear that the change required will need to be transformational across all sectors. Put simply, perfecting the current high carbon energy system through delivering more efficient thermal generation stations, more efficient gas and oil boilers and more efficient internal combustion engines will simply not deliver against these targets. The decarbonisation of electricity must continue and, at the same time, low carbon and renewable options will be required in the remaining 80% of the energy system.

d. While these targets represent significant challenges, emerging climate science indicates a likely need to accelerate the pace of transformation even further. This is more fully explored in Chapter 1.

e. This all points to an urgent need to develop a comprehensive roadmap to 2050: a roadmap which is firmly grounded in the present, works back from the 2050 target of around 6Mt of GHG emissions, and selects and deploys technologies to deliver a progressive profile of GHG reductions to minimise the total cost over that period. An outline roadmap is presented in Chapter 6.

IRELAND'S GREENHOUSE GAS EMISSIONS IN 2015



Source: ESB analysis based on EPA 2017 Reports

f. The European Union Emission Trading Scheme (ETS) imposes quotas on the quantity of permissible emissions from specific large installations such as electricity generating stations. These quotas are being progressively lowered each year to drive the technology changes necessary to achieve full decarbonisation by 2050. Each individual installation and not the member state, carries the costs of compliance – including fines in the event of breaches.

g. In considering roadmaps to 2050 and beyond, different policy approaches will be required for sectors such as heating and transport which are not covered by the ETS, than for electricity generation and other installations which are included in the Scheme.

ii. Technology options for full electricity system decarbonisation

a. Significant progress has been made across the globe in decarbonising electricity generation over the last two decades. In Ireland the CO_2 intensity of electricity generation has halved in the period since 1990. This means that oil and some peat and coal burning have been displaced by zero carbon renewables and lower carbon natural gas. This progress is expected to continue to 2020, by which time around 40% of Ireland's electricity will be from zero carbon renewable plant, primarily wind and hydro.

b. Beyond 2020, renewable generation is expected to rise towards 50% as wind and solar continue to grow market share. In moving significantly beyond that level, technical and economic solutions to intermittency will be required, as well as a greater degree of social acceptance than at present. While increased interconnection and incorporation of storage technologies will play a role in this, many barriers to significant further intermittent RES penetration remain to be overcome.

c. The analysis contained in this report indicates that the suite of options to complete the pathway to full electricity system decarbonisation includes:

- Further (beyond 50%), intermittent RES in conjunction with Interconnectors and storage.
- Sustainable Biomass
- Carbon Capture and Storage (CCS)
- Nuclear Power

Each of these technologies present significant strategic and operational issues in terms of technology maturity, costs, security of supply, sustainability and public acceptance. The main body of this document (in Chapter 3) summarises the advantages and challenges of each of these technologies and concludes that, at present, no one technology emerges as the 'clear winner' that will enable Ireland to decarbonise the electricity system and the outcome will most likely involve a combination of these technologies.

d. ESB's coal generation plant at Moneypoint has been a strong focus of the climate debate in Ireland. As the annual quotas of emissions in the ETS progressively ratchet down, Moneypoint and all other coal plants across Europe will become uneconomic and will either close or operate under a different configuration. The issue facing Ireland is not therefore what will happen to Moneypoint, but which combination of the four candidate low carbon technologies can best replace Ireland's coal and gas generation after 2030, in a way that preserves energy affordability and security of supply. As thermal electricity generation plant are large, the process of transition is unlikely to be linear and clear-cut. It is more likely to come in large steps and to be complex.

Carbon capture and storage (CCS), a key candidate technology, is technically proven (The Crown Estate; Carbon Capture and Storage Association; Department of Energy and Climate Change, 2013). Its commercial feasibility is likely to depend on sharing of CO_2 pipeline and storage infrastructure and the creation of a low risk legal and regulatory framework. CCS is likely to be particularly important for Ireland given the limited options available to complement intermittent renewable sources. Steps to maintain the availability of potential storage sites and the preparatory work on a regulatory and legal framework need to start shortly so that investment decisions can be taken soon after 2025 – or earlier, if necessary.

e. Therefore while we can be confident that the Irish electricity system will be half way towards full decarbonisation in the 2020s, the optimal technology choices to achieve the second 50% cannot be predicted now with confidence. All of the current suite of available options face challenges.

iii The challenge of low carbon transitions in Agriculture, Heating and Transport.

a. Those sectors of the Irish economy which emit GHGs but do not fall under the EU's Emission Trading Scheme for large installations are referred to as the Non ETS sector. It comprises three main components, transport, heating and agriculture. Typically these sectors are distributed and comprise numerous installations. Ireland has been subject to annual binding Non ETS GHG emission reduction targets since 2013 under the EU's 2020 framework and is currently projected to fall short of those target reductions from 2017 and by an increasing margin thereafter.

b. It is broadly accepted that emissions in the agriculture sector are among the most difficult to mitigate as technology solutions are limited and emissions therefore rise in proportion to the size of the beef and dairy herds. This is explored further in Chapter 1 of this report. This and the fact that emissions from agriculture are a higher proportion of the total in Ireland than anywhere else in Europe, means that meeting 2030 targets will require significant reductions in the energy sectors within the Non-ETS – largely the heat and transport sectors. The impact of this is that a 20% reduction in heat and transport emissions from 2015 levels is needed to meet the proposed 2030 GHG target assuming full use of flexibilities. Our roadmap is focused on energy and the Government target for an 80% reduction in energy-related emissions by 2050. It assumes a 30% reduction in energy-related emissions for 2030, recognising the need to get on to a trajectory for 2050.

c. There are a number of technology options available and emerging to mitigate emissions in the heat and transport sector. Some of these options are individual in nature, for example the installation of a domestic heat pump, while others have system wide characteristics, for example the provision of a nationwide Electric Vehicle (EV) charging network or a nationwide compressed natural gas network for heavy transport. The system nature of these technologies impacts on the implementation cost and the need for coherent system wide planning. Low carbon technologies for heat and transport are explored in Chapters 4 and 5.

d. Ultimately a roadmap to 2050 will require difficult choices and will involve trade-offs to meet the binding constraint of a maximum 6Mt of emissions by 2050, while minimising the total investment cost. A roadmap is set out in this document (in Chapter 6) which seeks to achieve these objectives. The principles followed are summarised below.

iv. The building blocks of a successful Energy Roadmap to 2050

a. In order to construct the outline road map, a broad cross-section of roadmaps from diverse sources were studied. This revealed a consensus on several elements of a low carbon energy system. These elements were applied to the Irish energy sector to get as close to the Government's 80% reduction target as possible.

b. The international consensus was less transferable in electricity generation due to Ireland's particular constraints as a small system without synchronous interconnection. The results of the UCC model (Deane, et al., 2013), which were similar to analysis by ESB, were used for the power sector.

c. Due to concerns around the overall sustainability of biofuels, most of the road maps – including those of Ireland's energy system - assume a defined limit to the availability of biofuel imports. This approach was adopted in the roadmap. A limit of 10% of total energy was used.

d. It was assumed that the extent of the required transition and the existence of EU targets for 2030 required an early start with lowest cost, established technologies, applied first.

To minimise cost and the risk of stranded investment, the roadmap focused on proven technologies with associated proven migration paths to low carbon. For these reasons, these are seen as 'low regrets' options. The omitted technologies were ones that are technically or commercially unproven or could only be applied on a large scale and from which there was no migration path in the event that zero carbon proved beyond reach. The omitted technologies can later be adopted as part of the transition in the event their viability is proven. For example conversion of gas distribution networks to hydrogen would involve steam reforming plants to extract hydrogen from natural gas* investments in CCS networks to store the CO_2, potentially adjustments to the network and the replacement of customer gas appliances. It is a new system approach with a risk of stranding and no migration path in the event of failure. This option was considered but not included. On the other hand, district heating is a proven system concept and there is a migration path because a variety of alternative future heat sources can be used. District heating was included, although not on a large scale.

e. The roadmap studies all highlight electrification as a major trend with heat pumps in 60% of households by 2050, electric vehicles accounting for 60% of new car sales by 2030 and bioenergy and heat networks playing important roles. The roadmap set out in Chapter 6 takes these common factors into account.

f. A major obstacle to the transition is the current low cost of fossil fuels. Low carbon technologies generally cost more to install, but have lower running costs than their high emission equivalents. Low fossil fuel prices lengthen the payback period and lower the incentive to invest. Policy measures such as regulation of heat sources, fossil fuel taxes, incentives or low cost finance will be needed to effect the transition. Further obstacles lie in regulation: for example the lack of an established district heating utility and framework and the lack of full alignment of the building regulations with our low carbon future.

g. The roadmap proposed includes the following major components:

The Electricity System

i. Continued decarbonisation of electricity generation through renewable generation and through more use of gas plants (and less coal) as prices in the ETS increase.

ii. As the level of variable renewable generation approaches technical or social limits, a share of low carbon, dispatchable energy generation will be needed to complete Ireland's journey to full electricity decarbonisation at least cost. Based on currently feasible alternatives, it seems likely that this will be a combination of gas generation with CCS and biomass. The figures in our report reflect this assumption

Transport

iii. Progressive electrification of the light vehicle fleet through to 2025 and beyond, with compressed natural gas (CNG), biomethane, second generation biofuels and potentially, electrical solutions in the medium term, for heavy goods vehicles.

Decarbonising Heating in Homes and Workplaces

iv. Containment of emissions from homes and workplaces through zero emission building standards for new builds.

v. A national renovation programme for existing buildings with deep retrofit and switching to low carbon heating sources such as heat pumps, biomass and district heating. As this process will be costly and will take time, the initial focus for retrofit should be on pre-2007 buildings with oil-fired heating.

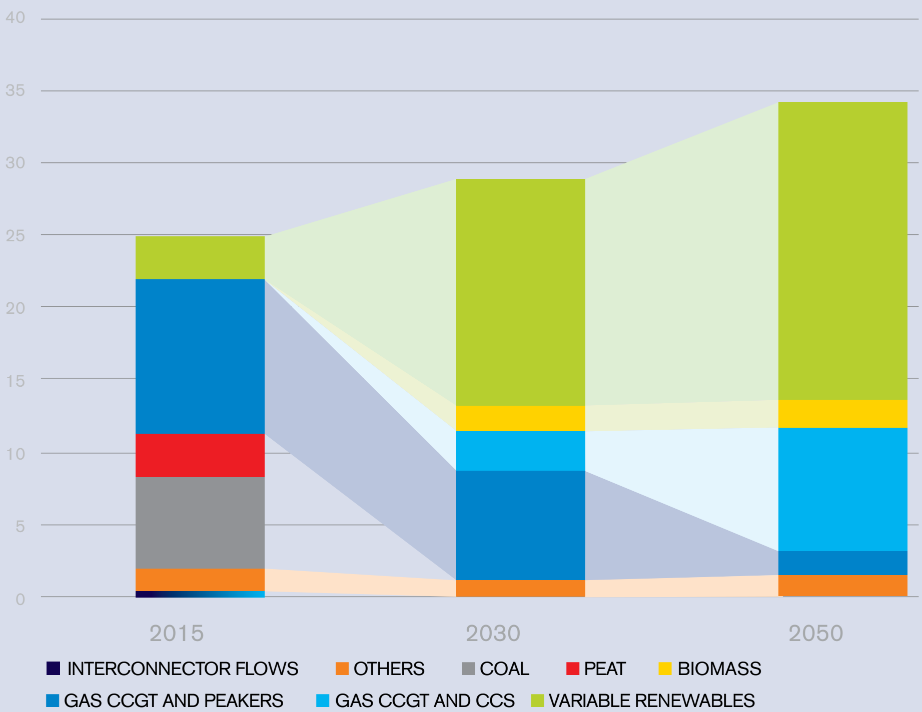
Industrial Heat

vi. Industry is diverse and employs heat in a range of processes. Each type of application requires a specific solution. Industrial processes often make use of high temperature heating above 60°C (or process heat) which is harder to meet with electric heat pumps than is the case with space heating. Heating in industry should be moved to a combination of low carbon fuels - such as biomass - and fossil fuels with carbon capture by 2050. In addition, research is starting on methods to extensively electrify industrial processes. These may mature to supplant a portion of the fossil fuels with CCS component by 2050.

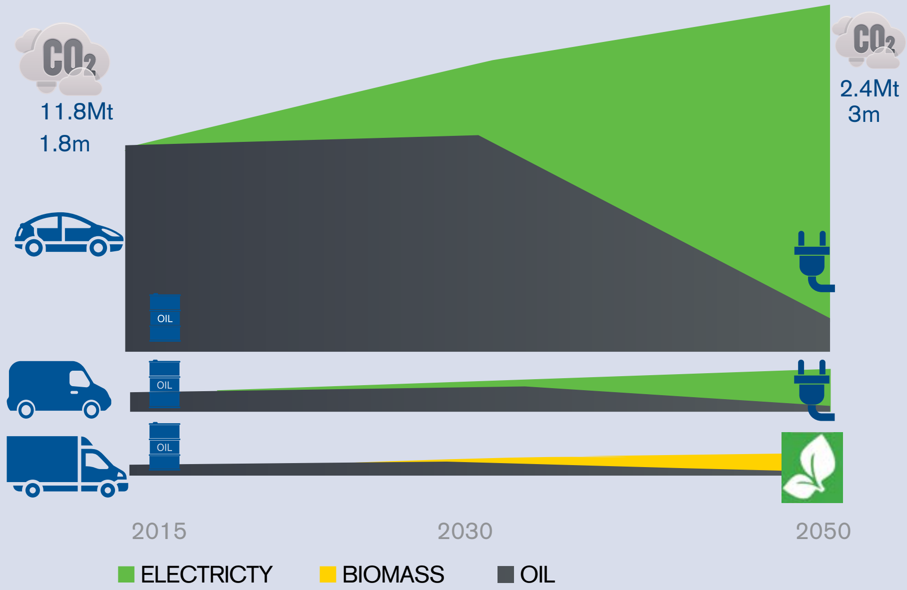
Conclusion

Feasible, low regret technologies exist to make significant inroads into the transition to a low carbon

ELECTRICITY TRANSITION - GENERATION (TWh)



TRANSPORT ROADMAP BY FUEL



energy future. These options coincide with the energy choices that also lead to the best health and social outcomes for society. For example fewer respiratory issues due to better indoor and outdoor air quality.

These may well be required to meet air quality regulations regardless of the climate agenda. Early action is cheaper in the long run. The challenge will be to scale the investment to meet the need, especially in heating, and courage to adopt creative approaches to drive the transition.

This document offers an illustrative roadmap to this future. Ireland needs to embrace the challenge now if we are to meet the extremely onerous challenge that faces our society in delivering on a low carbon future for all.

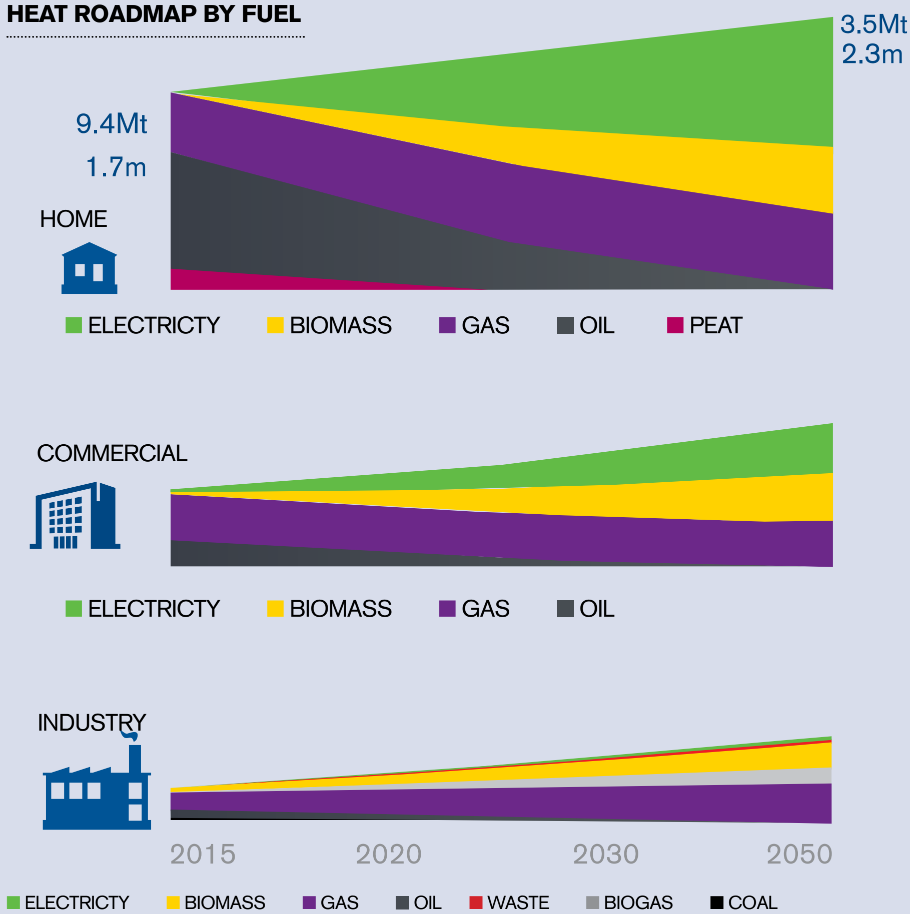
Structure of this report

The remainder of this report is structured as follows.

- Section 1 sets out the EU and national policy context for Ireland's climate and energy targets and describes the structure of Ireland's energy sector and its emissions pattern.
- Section 2 explains the sources of Ireland's emissions and analyses the breakdown within each sector.
- Section 3 describes each of the alternative technological options for low carbon electricity generation in Ireland and describes the most probable mix for 2050.
- Section 4 compares the alternative technologies for decarbonising transport, briefly explaining their relative impacts, costs and constraining factors.
- Section 5 compares the alternative technologies for decarbonising heat, briefly explaining their relative impacts, costs and constraining factors.
- Section 6 briefly surveys a range of recent low carbon roadmaps, drawing out key insights for Ireland and uses these to outline a likely decarbonisation pathway to 2050 for Ireland.
- Section 7 provides an overview of the role of the customer and the 'smart home' as well as of customer decision-making in the transition to a low carbon energy system.
- Section 8 provides an overview of the implications of decarbonisation of transport and heat for electricity networks, including smart network management.
- Section 9 proposes least regret options for policymakers.

- Annex A lists the references drawn on in this report.
- Annex B gives further information on some of the roadmaps references in Section 6.
- Annex C sets out additional and supporting information in infographic form.
- Annex D summarises the workshops upon which this report is based.

HEAT ROADMAP BY FUEL



[1] The Energy White Paper sets out a vision of a low carbon energy system envisaging greenhouse gas emissions from the energy sector reduced by 'between 80 and 95%, compared to 1990 levels, by 2050, and will fall to zero or below by 2100.'.

[2] The CSO projections range from 5m to 6.73m by 2045

[3] The Energy White Paper sets out a vision of a low carbon energy system envisaging greenhouse gas emissions from the energy sector 'reduced by between 80 and 95%, compared to 1990 levels, by 2050, and will fall to zero or below by 2100.' This report has assumed the 80% figure

*Note: Electrolysis is also a possibility but efficiency is currently too low for it to be economic as a large scale option

1

The Energy Policy Framework

- Through its climate action policy statement, its ratification of the Paris Agreement, and the low carbon goal in its energy white paper, the Irish government is committed to a long-term decarbonisation pathway for the Irish energy system leading to a reduction in greenhouse gas emissions from the energy sector of between 80% and 95% on 1990 levels by 2050.

- With constraints on capital, it is important that investment is selected for its efficiency over the full course of the transition. Rather than focus on short term goals and risk stranding of investment, it will be necessary to establish a carbon scenario for 2050 that is likely to be least cost and to start adopting technologies now that are compatible with that future.

- Within the EU policy framework, Ireland's energy commitment translates to two distinct imperatives:
  - the setting of the long term strategic direction for the fuel mix of new electricity generation stations compatible with the national target. Generators and other large emitting sites are responsible for their own day-to-day emissions within the EU Emission Trading System.
  - taking action to reduce emissions in **heat and transport** in Ireland, both in the near term and over the next decades.

- The EU Effort Sharing Regulation gives rise to the second of these imperatives. It requires Ireland to achieve reduction targets for its greenhouse gas emissions outside of electricity and major industry. In addition to Heat and Transport, this 'Non-ETS' sector includes Agriculture and Waste and amounts to 72% of Ireland's greenhouse gas emissions. Since this is such a large proportion of the national economy, any significant reduction target in this sector implies profound transformation

- The EPA currently projects that Ireland will exceed its annual Non-ETS binding targets from 2017. Taking into account over-performance in earlier years, this implies an estimated cumulative cost to 2020 of around €90m – €205m (DPER, 2015) for surplus credits purchased from other member states. Higher costs are estimated beyond 2020. One source has estimated residual compliance costs from 2020 of between €2.2 and €4bn or €50 to €100 per tonne in the hypothetical case of no further policy action being taken (Curtin, 2016)

- Since Agriculture alone represents 33% of all emissions, and emission reductions here are more challenging and likely to come more slowly, a significant GHG reduction target for Ireland's Non-ETS sector implies early and deep transformation in Ireland's heat and transport sectors. If agriculture emissions remain static in the period to 2030, Heat and Transport emissions will have to reduce by between 20% and 30%, depending on flexibilities, to meet Ireland's expected obligations.

- Ireland's proposed 2030 Non-ETS target of a 30% reduction – even allowing for flexibilities[4] - represents a major transformation of Ireland's energy system. This will require time and investment over a long period. For this reason and because the Paris Agreement will need to force an acceleration of action by developed countries beyond current commitments to keep within the GHG budget identified by the IPCC for the 2°C temperature limit, it is crucial that the current and imminent policy initiatives be redirected to this priority.

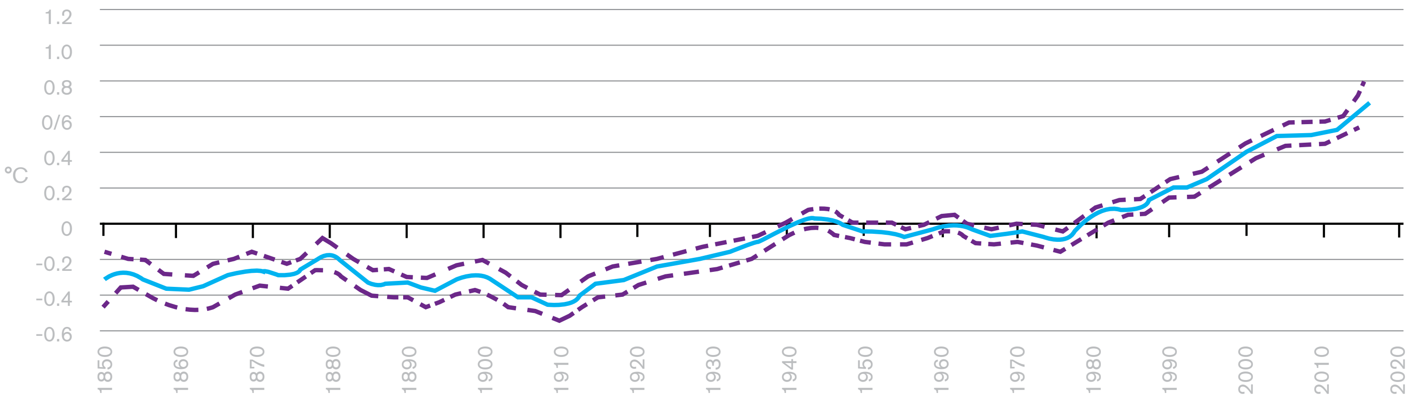
4 If fully availed of, these would leave a residual Non-ETS reduction requirement of 20.4%

1.1
THE GLOBAL POLICY CONTEXT

The scientific principles behind climate change caused by greenhouse gases have been understood since the late 19th century. The earth's atmosphere is transparent to sunlight that warms the earth but much less transparent to the infrared radiation that the earth emits in response, leading to a net gain in heat or warming. John Tyndall established as far back as 1864 that carbon dioxide and methane were opaque to infrared radiation. Therefore these gases contribute to the warming or 'greenhouse effect'.

However measurements in the 1800s were not precise and absorption by the oceans of carbon dioxide was not understood so these theories were disputed and largely dismissed. By the mid-20th century this view changed as measurements improved and climate models were developed and so concern gradually increased. During the 1980s, mounting evidence led to the development of a scientific consensus that human-induced climate change was already a reality and an increasing concern for the future.

FIGURE 1 - GLOBAL ANNUAL MEAN TEMPERATURE DEVIATIONS 1850 – 2016[1]



Notes:[1]degrees C compared with 1961 to 1990 average

Source: European Environmental Agency, The European Environment State and Outlook 2015

THE ROLE OF THE UN

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 within the UN to compile and report on evidence to enable the risk of human-induced climate change to be understood. The IPCC reports chart the emission reduction scenarios that would lead to various levels of global warming within degrees of probability.

In June 1992, the UN Framework Convention on Climate Change (UNFCCC) was agreed at the Earth Summit in Rio de Janeiro, entering into force in March 1994. The framework has as its objective the stabilisation of greenhouse gas concentrations at a level that would prevent dangerous human-induced interference with the climate system.
The parties to the convention, including the EU member states and the EU Commission, meet each year at the conference of the parties (COP) to progress this goal. Their efforts over the intervening years to secure a comprehensive climate agreement between all nations, culminated in the Paris Agreement at COP21 in December 2015. The treaty came in to force on 4th November 2016 a month after ratification by EU countries brought the treaty over the necessary thresholds in early October 2016.

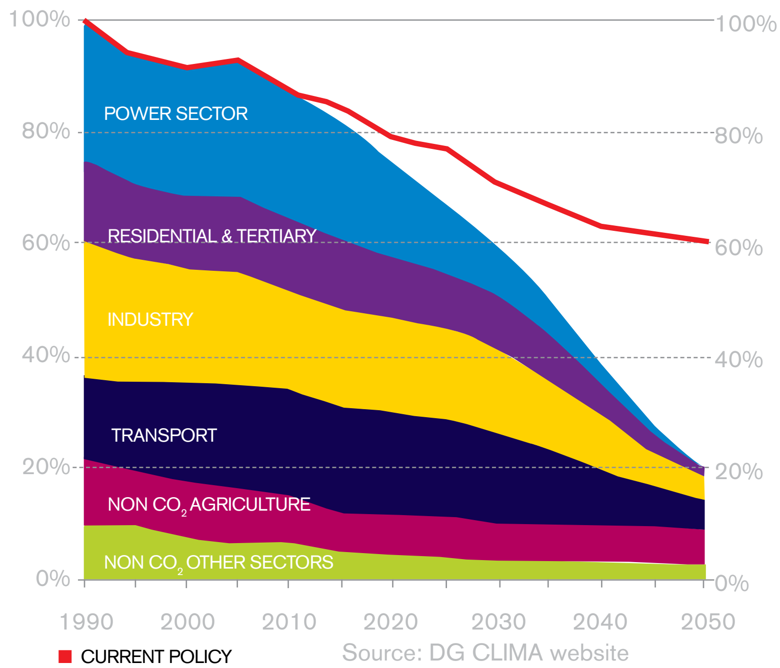
On 1st June, 2017 the US announced that it intended to withdraw from the Paris Agreement. It had ratified the accord under the previous Obama administration. Since that announcement, the other major emitting countries have stated that they will continue to implement it. It is believed that much of the emission reductions in the US' original commitment will happen in any event, due to the advance of renewable generation and, potentially, the implementation of tighter emission standards for vehicles. The main impact may concern provisions in the Agreement for increasing ambition in emissions reduction.

The Agreement provides for better inventories of emissions and a 5 year cycle of stock-taking and 'increasing ambition' by governments. It is generally accepted that the current set of national reduction pledges or nationally determined contributions (NDCs) are not enough to limit global temperature rise within safe limits. This implies that the Paris review process will result in significantly increased ambition i.e. deeper targets than those set out by the EU, to maintain total emissions within the budget allowed for 2°C (Anderson, 2015).

TABLE 1 - EU CLIMATE TARGETS 1990 – 2015

TARGET TIME HORIZON	2000	2010 (2008-2012)	2020	2030
Time the target was set	1990	1997	2007	2014
EU target ambition	Stabilise at or return to 1990 levels	8% from 1990 levels original proposal 15%	At least 20% from 1990 unilaterally, 30% if a global deal	At least 40% domestically from 1990 levels
Enshrined at UN level	The general ambition was included in the UNFCCC (article 4) in text format (not as quantitative objective.)	8% from 1990 levels (original proposal 15%)	20% from 1990 levels	40% from 1990 levels
Internal EU Break down of targets to the national level	All MS (EU15) subscribed to UNFCCC goals	Internal EU15 burden-sharing (from +28% to -27%)	EU ETS National binding Non-ETS emissions (Effort-sharing) (rebased to 2005 levels)	EU ETS National binding Non-ETS emissions targets (rebased to 2005 levels)

FIGURE 2 - EU 2050 ROADMAP EMISSIONS TRAJECTORY BY SECTOR



1.2
THE EU COMMITMENT TO A LONG TERM LOW CARBON PATHWAY

The EU's policies on climate change have closely paralleled the UN developments and the succession of targets mirror the trend line emerging from the IPCC reports. This is illustrated in Table 1.

In 2007, the 2020 climate and energy framework - originally the EU's submission to the climate talks in Copenhagen – was adopted. On the 1st December 2009, the EU Council committed to the trajectory envisaged by the UN, of a 80-95% reduction in greenhouse gases in 1990 levels by 2050. The Commission prepared a Low Carbon Roadmap to chart a trajectory towards this goal (see Figure 2). The EU's 2030 framework, with the overall reduction target of 40% in line with this pathway, formed its submission in advance of the Paris Agreement.

BOX 1: THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (AR5)

Fundamental to the science of climate change is the fact that, within the range uncertainties, there is an approximate straight line relationship between average global temperature rise and cumulative greenhouse gas emissions. The IPCC assessment reports model a large number of possible emission pathways (or 'scenarios') chosen based on underlying assumptions about growth and technologies, to determine their likely impact on average global temperatures.

Each emission pathway is characterised by an emission level each year, giving a cumulative emission total from 2011. Since the world's countries have set a temperature rise of 2°C or possibly 1.5°C above pre-industrial levels as the level that will contain climate effects to safe levels, the scenarios that successfully achieve this with a probability greater than 50% are of particular interest.

AR5, for the first time gave the levels of cumulative emissions that corresponded to the probability of containing temperature rise to given levels.

The cumulative level of CO_2 that corresponds to a rise of no more than 2°C with a probability of 66% was 2,900 Gt of CO_2 equivalent. As 1,900 Gt had already been emitted by 2011, this effectively sets a budget of 1,000 Gt than cannot be exceeded from 2011 onwards to retain a 66% chance of a temperature rise of no more than 2°C.

Comparing this 'budget' with business as usual sets the scale of mitigation actions that need to be taken this century. A number of the scenarios that keep to this level by 2100, take a slower mitigation path and overshoot the cumulative budget, relying on a future widespread deployment of technologies that take CO_2 from the atmosphere ('negative emissions') in order to meet the budget by 2100. AR5 says that this 'overshoot' increases the risk of warming that exceeds the target level of 2°C. Also costs increase with the 'stringency of mitigation' so delays in acting will increase the cost as they would require stronger efforts later.

The report finds that the cost-effective pathway for mitigation shows the majority of electricity generation reducing to zero carbon by 2050 and reductions in emissions of between 50-100% across the economy. 'Accelerated electrification of energy end use' is a common feature of scenarios that achieve levels below 550ppm CO_2e by 2100.

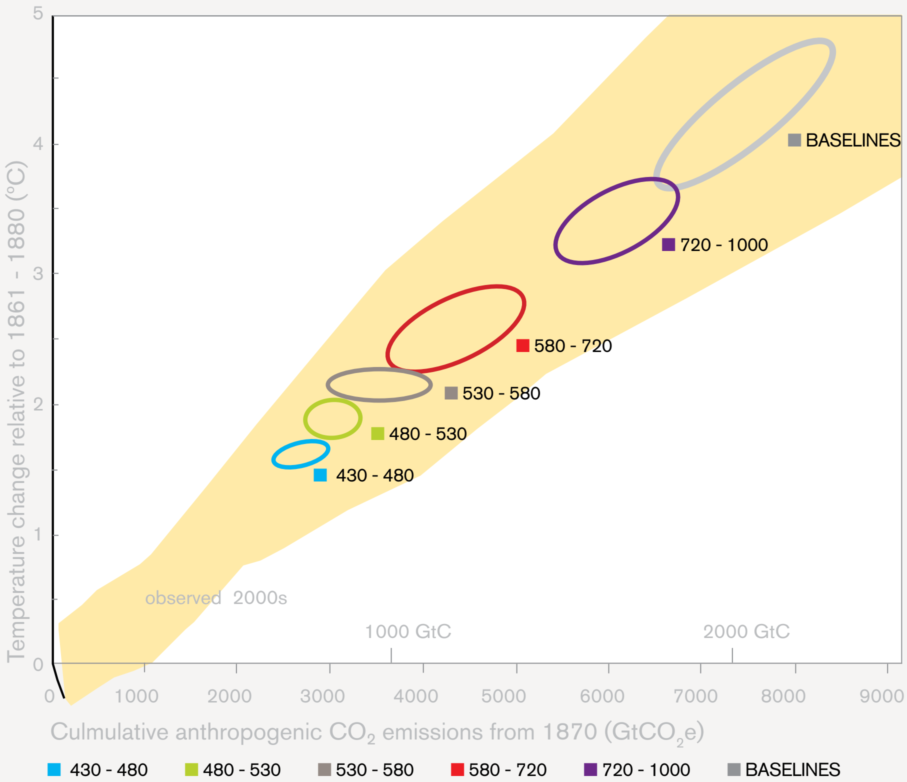
Some commentators (Anderson, 2015) have pointed out that if we take into account the plans of developing countries to reach an emissions peak later than developed countries, the budget figure of 1,000 Gt implies stark reductions in emissions from the developed countries. Even quite favourable assumptions about how quickly developing countries can peak and then start reducing would leave developed countries needing to make reductions of 10% per year: a virtual reduction precipice in their emissions.

The implication is clear: **there is a likelihood that the 5 year cycle of stock-taking and increased commitment set out in the Paris Agreement will result in a steeply escalating set of carbon targets beyond that currently contemplated by Government businesses and the public,**

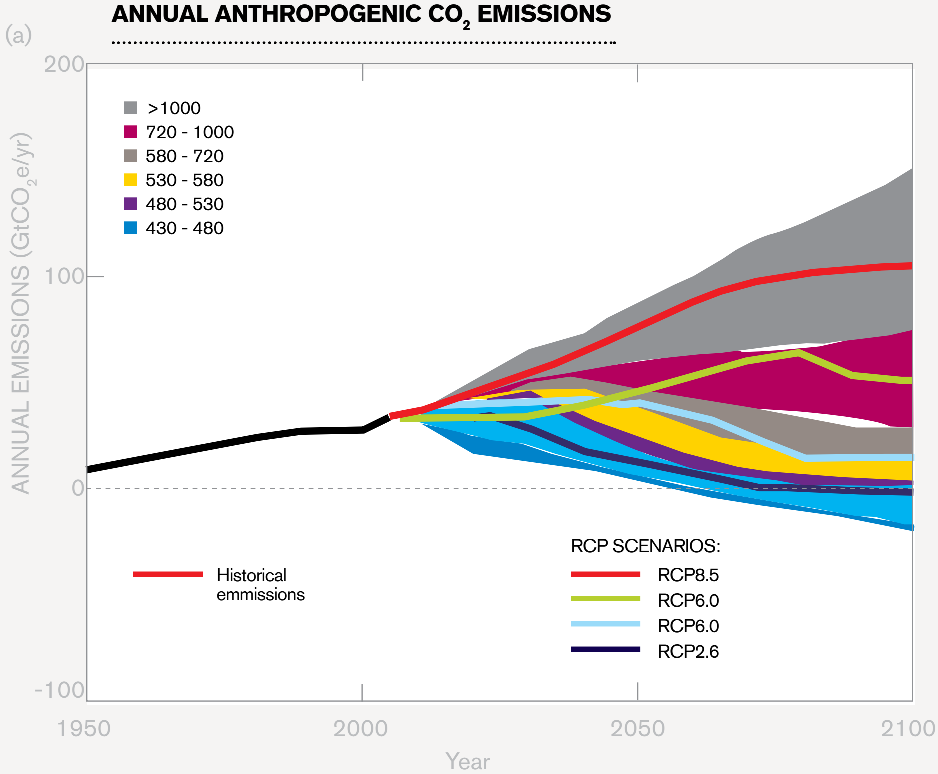
'...no agreement is perfect, including this one. Even if all the initial targets set in Paris are met, we'll only be part of the way there when it comes to reducing carbon from the atmosphere.'

- **Barack Obama, December 2015**

TOTAL HUMAN INDUCED WARMING (source: IPCC)



ANNUAL ANTHROPOGENIC CO_2 EMISSIONS



Source: IPCC

1.3 THE EU CLIMATE AND ENERGY FRAMEWORKS

The succession of EU climate targets is summarised in Table 2 below.

THE EU 2020 FRAMEWORK

In the 2020 Climate and Energy framework, the EU set out to achieve the overarching GHG target by a combination of the EU Emission Trading System (ETS see below) for large emitters and national binding targets for Non-ETS emissions. In addition the EU 2020 framework saw the addition of two further targets:

- An EU target for renewable energy of 20% of gross final energy use in electricity, heat and transport was introduced. Similar to Non-ETS emissions, this was divided between member states as national binding targets.
- An indicative EU target for a 20% reduction in energy use through energy efficiency measures completed the framework.

In 2014, as part of the initiative to create an integrated EU electricity market, the EU adopted an indicative target for total electricity interconnection between member states of 10% of total national generation capacity (in MW) (see Figure 3).

THE EU ETS

The EU Emission Trading System came into effect in January 2005. It is a cap and trade system whereby all large emitters – sites with a heat output of 10MW or more as well as certain designated industries like steel and cement, must register with the scheme and surrender a number of emission unit allowances (EUAs) equal to the number of tonnes of carbon dioxide they emit. Each member state has a share of the allowances each year. Some are allocated free of charge to energy intensive industries to protect their competitiveness in international markets. The remaining balance of allowances is sold in auctions held regularly during the year.

Since phase 3 of the ETS began in 2012, the number of allowances has declined by 1.7% per year (known as the linear reduction factor). This rate is set at a value that will achieve a 20% reduction in emissions by 2020. This factor is set to increase to 2.2% per year in 2021 to align with the goal of a 43% decrease by 2030 compared to 1990 levels.

The ETS is an EU-wide system and effectively sets a single price for EUAs across the EU. Since 2013, EU countries meet their UN climate obligations collectively under the EU umbrella, by a combination of implementing the ETS system which places obligations on emitters and national binding reduction targets for emissions outside the ETS (the 'Non-ETS'). Member states carry sole responsibility for meeting Non-ETS emission targets in respect of emissions within their boundaries. If they fail to meet them they must purchase unused emission rights from other member states or be subject to fines. They are not responsible for emissions from ETS-registered sites in their territories although they provide monitoring and regulation. Some of the implications of this are explored below (see ETS box.)

THE EU 2030 FRAMEWORK

The EU 2030 framework was agreed by the EU Council (national leaders) in October 2014. It followed similar lines to the 2020 framework, with the same number of targets. The overarching greenhouse gas target was a 40% reduction compared to 1990. This was divided between a reduction in ETS credits of 43% for large emitters (compared to 2005) and an average Non-ETS reduction of 30% (compared to 2005) to be divided into national binding targets. The EU Commission proposed a national Non-ETS target of a 30% reduction for Ireland in its effort sharing proposals published on the 20th July, 2016. These proposals are progressing through the EU legislative process and may be amended. (See box on Ireland's 2030 target below)

CHANGES FROM THE 2020 FRAMEWORK

The 2030 framework differs in a number of important respects from the 2020 framework:

- The **renewable energy target** will be binding at EU-level only. It is not to be translated into binding national targets. This is the result of competitiveness concerns advanced by some countries, including the UK, about the extra costs added by attempting to meet multiple, different targets in addition to the UN-derived greenhouse gas target. Other member states resisted this, leading to the concept of a binding EU target and a governance framework to coordinate national efforts in climate and energy (see below).
- At the time of writing, it appears that the energy efficiency target may be raised to 30% (from 27% agreed by the EU Council) and made binding at EU level.
- In recognition of the greater challenge for some member states, the Non-ETS proposals allow for two '**Non-ETS flexibilities**':
- A one-off ability for designated member states to cancel a number of ETS emission credits that they would normally auction in return for a credit against their Non-ETS emissions. This flexibility is subject to a stated maximum level of credits. Ireland is eligible for this flexibility up to a maximum level of 4%.

FIGURE 3 – EU 2020 AND PROPOSED 2030 CLIMATE AND ENERGY FRAMEWORKS

	2020	2030
Trading Scheme (sites$>10MW_{th}$)	-21%	-43%
National Targets	-10%	-30%
Renewable Energy	20%	27%
Energy Efficiency	+20%	+27%
Interconnection	10%	15%
Governance	---	5 year plans and reporting

The main policy targets across the three timeframes (2050, 2030 and 2020) at EU and national level are summarised in Table 2.

TABLE 2 - SUMMARY OF RELEVANT POLICY TARGETS

Timeframe	Sector	Target	Geography
2050	Energy	80% reduction over 1990 levels	Ireland
	GHG emissions	80% to 95% reduction over 1990 levels	EU
2030	GHG emissions	40% over 1990 levels	EU
	ETS	43% over 2005 levels	EU
	Non-ETS	30% over 2005 levels	EU
	Renewable Energy Supply (RES)	27% (non-binding) by 2030	EU
2020	Non-ETS	20% over 2005	Ireland
	RES	16% by 2020	Ireland
	RES-electricity	40% by 2020	Ireland
	RES-heat	12% by 2020	Ireland
	RES-transport	10% by 2020	Ireland
	GHG emissions	20% over 1990	EU
	RES	20% energy consumption share by 2020	EU
	Primary energy consumption	20% over 1990 levels	EU

- A flexibility whereby member states can receive a credit in respect of the carbon dioxide removed by new forestry. Previously the EU rules, unlike those of the UN, ignored absorption by forestry. Ireland is eligible for this flexibility up to a maximum level of 5.6%.

- For the first time, the 2030 proposals include a **Governance Framework**. Member states will prepare National Plans every 5 years, with energy and emissions projections as well as detailed actions to progress the framework goals. Each member state will consult with the Commission before finalising its plan. Member states will report to the EU Commission on a set of standard key performance indicators every two years. This 5-yearly planning cycle aligns with the stock-taking and commitment cycle in the Paris Agreement. In addition, each member state will set out a long term integrated national plan for the timeline to 2050.

The numeric targets and proposed targets for the 2020 and 2030 frameworks are shown in Figure 3.

TABLE 3 - EU ENERGY AND CLIMATE DIRECTIVES

TARGET	DIRECTIVE		TITLE	WHO
GHG	**Emission Trading**	**2009/29/EC**	Purchase emission credits	Large Emitters
	Effort Sharing Decision	**406/2009/EC**	Binding MS targets for GHG outside the ETS	MS
	Energy Tax	**2003/96/EC**	Minimum. tax levels	MS
RES	**Renewable Energy**	**2009/28/ED**	MS Target (2020 only)	MS
			Planning & Reporting	MS
			Sustain. Criteria	Biofuels
			Allowable RES-H	Heat Pumps
ENERGY EFFICIENCY	**Energy Efficiency**	**2012/27/EU**	Ind. MS Energy Target	MS
			Planning & Reporting	MS
			Public Building Renovation	MS
			Green Procurement	MS
			Obligation scheme	Suppliers
			Energy Billing	Suppliers
			Energy Metering	MS/ DSO
			Energy Audits	Large Customers
			Accreditation	Energy Services
			Promotion of CHP/DH[5]	MS
			CHP/DH CBA	Generators
	Energy Performance of Buildings	**2010/31/EU**	En. Performance Certs.	Builders
			Building Regulations	Builders
			Heat & Cool. Inspection	Large Customers
			Near Zero Energy Building	Builders
	Ecodesign	**2009/125/EC**	Min. energy Eff. Standards	Purchasers
	Energy Labelling	**2012/27/EC**	Efficiency classes	Consumers

[5] CHP = Combined Heat and Power. DH = District Heating. CBA = cost benefit analysis

1.4
EU DIRECTIVES

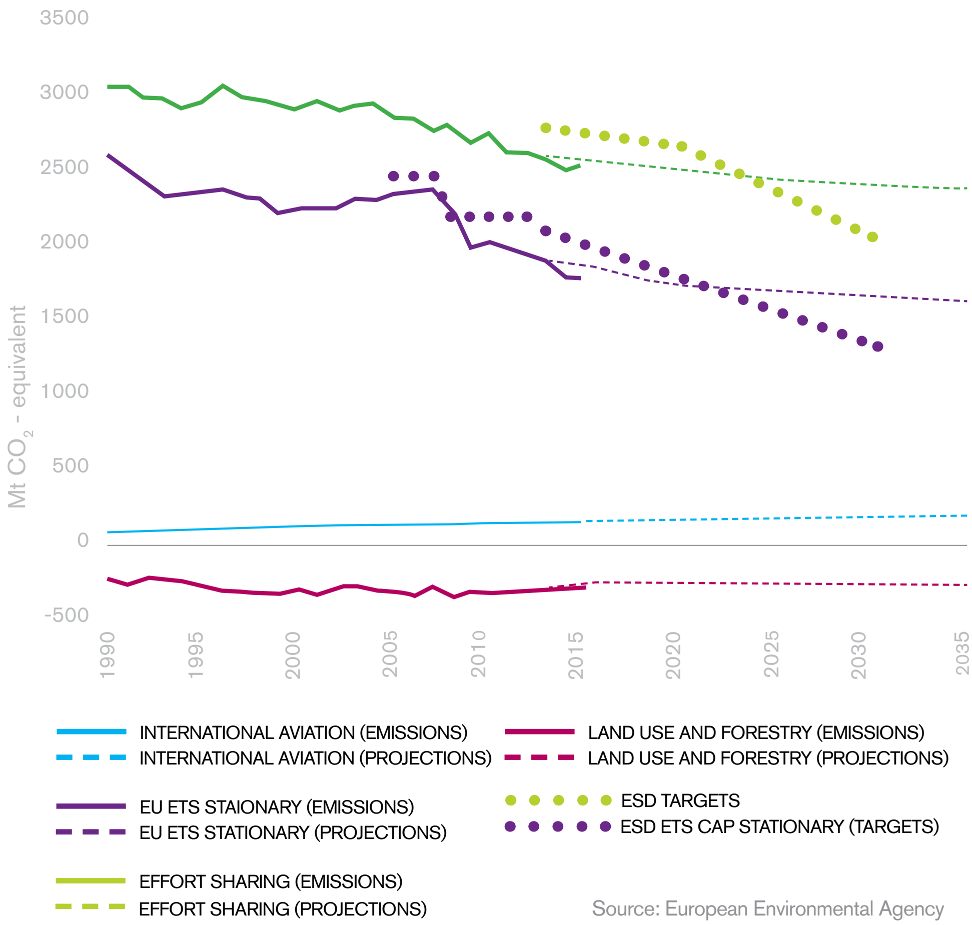
A set of EU Directives are used to implement the 2020 climate and energy framework. The three-target approach introduced by this framework led to an increase in the number and complexity of the enforcing directives. The directives and main provisions and instruments are listed in Table 3 above. In the absence of a binding requirement to meet the energy efficiency target, more directives and more instruments have been put in place to ensure it is achieved.

It is interesting to note that relatively few provisions have been put in place to support the greenhouse gas reduction goal, especially outside the ETS. The focus in the Non-ETS has been on energy efficiency which is not the same as carbon efficiency. The only substantive measure relating to carbon has been the setting of minimum taxation levels for fuels. On the other hand, four directives with multiple instruments address the issue of energy efficiency. A consequence is that the heat sector, which is central to the decarbonisation of energy, has not been addressed from the perspective of greenhouse gases. It has been targeted by a large number of policy instruments, all of which are motivated by the energy efficiency target. For a Member State which needs to transform its heat and transport sectors by 2050 (like Ireland), this can introduce a challenge. For example, a new oil boiler is more efficient than a biomass boiler but has far greater greenhouse gas emissions. The (efficiency-led) requirements need to be implemented in a way that aligns with the 2050 low carbon future as well as satisfying the need to show progress against short-term efficiency goals.

1.5
EU PROGRESS TO DATE

The EU reached its 2020 greenhouse gas emission target in 2014 (see Figure 4). It is also on course to achieve the renewable energy target and the energy efficiency target by 2020.

FIGURE 4 - EU GREENHOUSE GAS EMISSION TRENDS AND TARGETS ($MtCO_2e$)



Source: European Environmental Agency

BOX 2: THE ETS

The EU ETS is a cap and trade scheme, established in 2005, that restricts CO_2 emissions from the major emitting sectors in Europe. With over 11,000 installations and airlines, the scheme covers around 45% of the EU's greenhouse gas emissions. The 'combustion' sector, which largely comprises power and heat generation activities, represents 65% of the emissions in the EU ETS.

Installations are required to submit sufficient carbon allowances, known as EU Allowances (EUAs), to cover their emissions during the previous calendar year. At the heart of the scheme is the ability of companies to trade these EUAs. Companies for whom it is relatively costly to reduce emissions can purchase allowances from companies that can achieve emissions reductions at lower cost. Through this mechanism, emissions reductions can in theory be achieved at least cost to Europe overall.

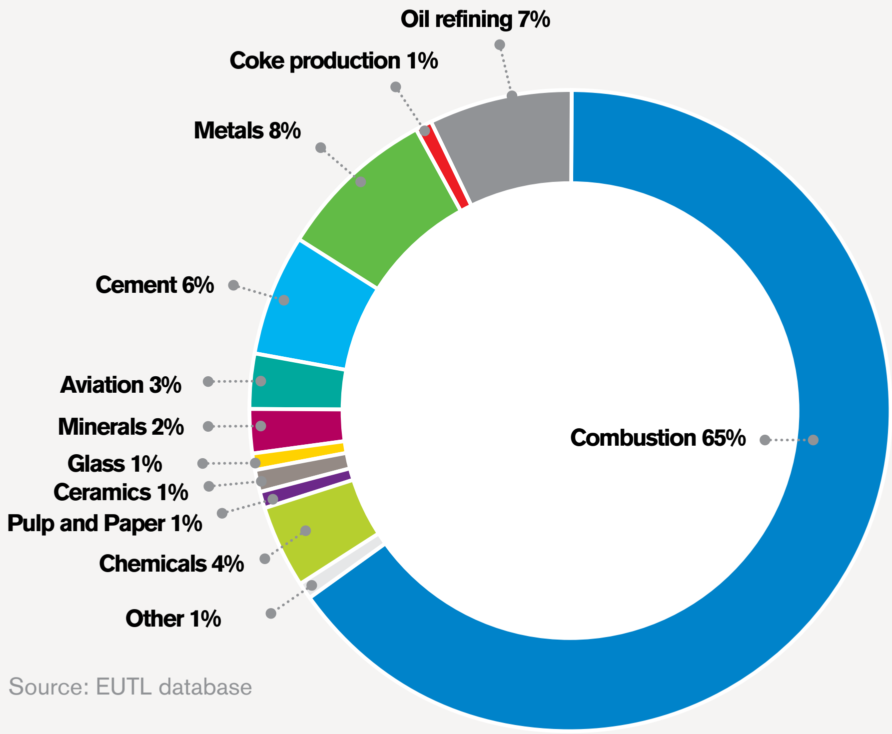
The overall cap reduces each year by a set percentage, currently 1.74% per annum. From 2021, this reduction will increase to 2.2% in order to achieve the 2030 target of a 43% reduction in emissions from the ETS sector over 2005 levels by 2030.

The start of phase 3 coincided with the close of the first commitment period of the Kyoto protocol when each ratifying country was accountable for all of its GHG emissions. From 2013, member states collectively meet their obligations under the EU umbrella, by a combination of implementing the ETS system (placing obligations on emitters) and binding reduction targets for individual member states for emissions outside the ETS (the 'Non-ETS').

Because the ETS sets a legal cap and pathway to the target set for the relevant companies, further reductions through Government subsidies and other measures do not reduce emissions overall, except perhaps in the short term. The unused allowances remain and will ultimately be used to permit the emissions at another installation at some other location. In this sense, national measures to further reduce ETS emissions do not reduce emissions overall (unless the member state also cancels the equivalent number of EUAs); they simply displace them in time and space. In addition they weaken demand, tending to lower the EUA price further.

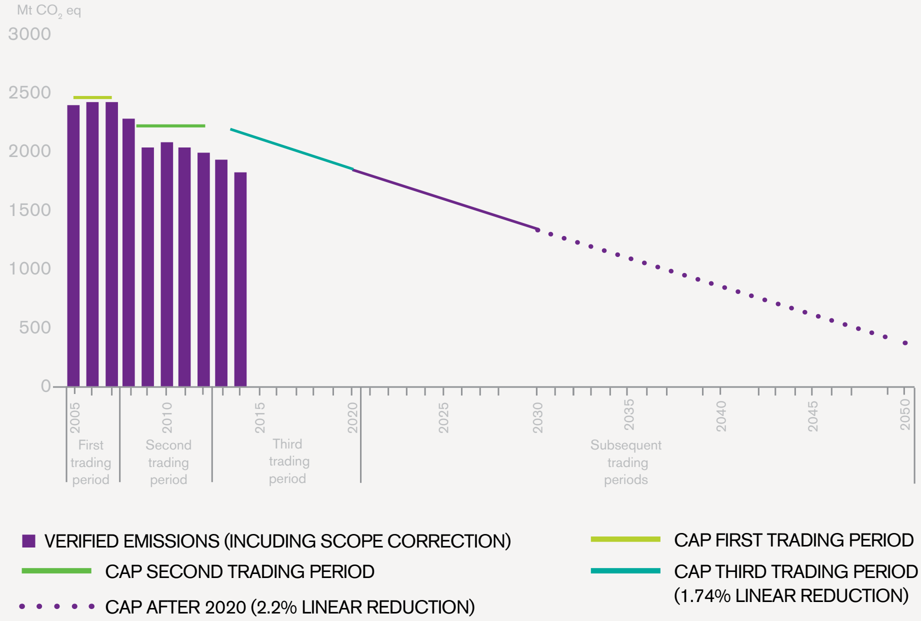
The other consequence of the ETS is that member state governments have targets in respect of the balance of the emissions outside the ETS system, mainly heat, transport, agriculture and waste. Incentives to reduce energy usage in installations within the ETS don't count towards national GHG targets because these targets are outside the ETS. In the same

ETS CONSTITUENT SECTORS AND EMISSIONS



Source: EUTL database

EMISSION TRENDS AND REDUCING CAP WITHIN THE EU ETS



Note: The data presented do not include the aviation sector.

Source: EEA, EU ETS Data Viewer

way, if heat demand is moved from the Non-ETS sector to the ETS sector, this counts as a full reduction of the original Non-ETS emissions against the Government's target. Any short term increase in ETS emissions does not affect member state targets.

Examples of technologies that can do this are electric heat pumps or large district heating schemes - which are generally also in the ETS because they exceed the 10MW threshold of heat output for registration. Where these technologies are efficient and fit in with the long-term 2050 low carbon vision, it makes sense to avail of this benefit. By following these initiatives, governments are reducing emissions in the short term and also putting the relevant premises on the long term path to low carbon.

A factor that is also under-appreciated about the ETS is that it is already a regulatory path to carbon neutrality backed up by legislation. It is safe to assume that electricity generation and other industries within the system will reduce emissions unless the political commitment – and the legislation – is changed. (In that event, the decarbonisation project as a whole will also fail.) Dissatisfaction with weak demand - and consequent low prices - for EUAs can often obscure the fact that this is the only sector that is subject to such a regime. If the annual decrements in allowances agreed for 2021-2030 continue to be applied into the future, extrapolation shows that there will be zero new credits auctioned from around 2056. In practice, the ETS is likely to be tightened beyond this level in future reviews. Since 2014, annual emissions in the ETS have already been reduced to levels that meet the 2020 target.

For these reasons and because of the pressing nature of carbon targets and the need for action on climate change, waiting until electricity is largely decarbonised before using efficient technologies to reduce emissions in transport and heating has no impact on emissions and simply introduces delay. It is a self-defeating and misguided strategy.

TABLE 4 - SUMMARY OF IRELAND'S GHG EMISSIONS TARGETS

Target	Baseline	2008-2012	2013-2020	2021-2030	2031-2050[4]
EU wide	1990	-8%	-20%	-40%	-80-96%
EU Wide	2005		-14%		
ETS - EU Wide	2005		-21%	-43%	-2.2%/year[5]
Non-ETS - EU Wide	2005		-10%	-30%	
Non-ETS - Ireland	2005		-20%	TBD	
Ireland Ecomony Wide	1990	+13%			

1.6 IRELAND'S 2050 COMMITMENT

In conjunction with the passage of the Climate Action and Low Carbon Development Act, the Irish Government published a National Policy Position on Climate Action. The Position envisages that policy development will be guided by a long-term vision based on:

- an aggregate reduction in carbon dioxide (CO_2) emissions of at least 80% (compared to 1990 levels) by 2050 across the electricity generation, built environment and transport sectors
- in parallel, an approach to carbon neutrality in the agriculture and land-use sector, including forestry, which does not compromise capacity for sustainable food production.

The Act, enacted at the end of 2015, is the statutory basis for this long-term decarbonisation. It establishes the framework for achieving this transition consisting of two pillars:

- A National Low Carbon Transition and Mitigation Plan specifying how the Irish economy will move toward a low-carbon economy and society and setting out the policy measures to be adopted to achieve this. Annual progress reports will be provided to the Dáil by the relevant ministers. The Plan will be updated every 5 years. The first Plan was published on 20th July 2017. (Department of Communications, Climate Action & Environment, 2017)
- The Climate Change Advisory Council formed of independent experts to advise and make recommendations to Government and Ministers in relation to the Mitigation Plan. The Council will publish annual reports;

The 2015 White Paper on Energy underlines the commitment, calling for a reduction in CO_2 emissions from the energy sector of between 80% and 95%, compared to 1990 levels, by 2050, and falling to zero or below by 2100. This is in line with the European Commission's long-term framework. It is also broadly comparable with the UK's 2050 self-imposed legally binding carbon target (which includes NI) of reducing carbon emissions by 80% compared to 1990 levels.The Policy Position and White Paper use different wording to describe the mitigation goals. For the purposes of this report, we have taken an objective of an 80% reduction across the energy sector by 2050 compared to 1990 levels.

This objective spans the entire energy system and so includes both the large emitting sites in the EU ETS and the sectors such as heat and transport that are outside the ETS. On the other hand, the annual Non-ETS targets are likely to influence the least cost path to the target, at least in the short term. Of the two goals, the National Policy position target of an 80% reduction is used in reporting against target and in the reports of the Climate Change Advisory Council assessing progress. For that reason this 80% reduction goal is used in this report.

1.7 IRELAND'S NON –ETS CHALLENGE

It is important to understand how the sector mix in Ireland increases the challenge in meeting binding targets for the non-ETS sector. There are three contributory factors:

- Ireland has one of the largest non-ETS sectors by share of emissions due in part to the importance of agriculture in the economy.
- Ireland has proportionately the largest Agricultural sector of all the EU countries. A major proportion of this is beef and dairy farming. The digestive systems of ruminant (grass-eating) animals emit methane. In addition, when the manures decompose, they emit nitrous oxide. Both of these gases have a powerful greenhouse effect - greater than that of carbon dioxide. A tonne of methane is estimated to have an effect equivalent to 28 – 36 tonnes of carbon dioxide and nitrous oxide is estimated to have a carbon dioxide equivalent effect of 265-298 times[6] (United

States Environmental Protection Agency, n.d.). In Ireland, herds are pasture fed, that is they remain outdoors for the majority of the year. This is believed to have a lower overall greenhouse gas impact than housing cattle as is done in countries with harsher climates (Crosson, et al., 2011) (Lee & Carlson, 2017). However it makes it more difficult to try mitigation techniques such as trapping the emitted gases or collecting the manures for anaerobic digestion. Promising results have been achieved in laboratory experiments using additives to inhibit methane production in the digestive processes of ruminant animals (Kinley, et al., 2016). For the present, at current levels of knowledge, the practical scope for mitigation of emissions from pasture-fed livestock is limited. This is recognised in the National Mitigation Plan and the White Paper from December 2015:

"Ireland's circumstances are different from those of other EU countries. The Irish non-ETS sector is proportionately larger than in most other Member States. It accounts for approximately 70% of emissions in Ireland, compared to an EU average of 57%. Agriculture emissions in Ireland (in 2013) measured over 32%, compared to an EU average of 10% which means that a greater proportion of the burden sharing falls on the energy sector in Ireland. In the absence of emission reductions in agriculture, the large size of that sector in Ireland will lead to a greater share of the required adjustment falling to other non-ETS sectors (such as transport and heat)."

"The impact of the greater burden falling on the energy sector is that heat and transport will need to reduce emissions by a greater amount for Ireland to meet the 2030 GHG reduction target for the sectors outside the ETS. Our roadmap estimates that a reduction of around 30% will be required from these sectors by 2030 (see chapter 6).

[6] Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (generally, 100 years). Carbon dioxide equivalency thus reflects the time-integrated radiative forcing of a quantity of emissions or rate of greenhouse gas emission—a flow into the atmosphere—rather than the instantaneous value of the radiative forcing of the stock (concentration) of greenhouse gases in the atmosphere described by CO_2e.

BOX 3: CLIMATE AND IRELAND'S AGRICULTURE SECTOR

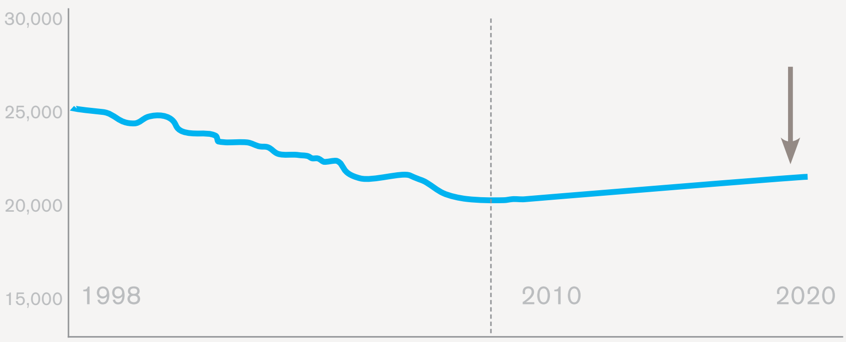
There are two main sources of agricultural emissions:

- methane – mainly from cattle and sheep, accounting for two-thirds of emissions; and
- nitrous oxide – mainly from synthetic fertiliser and slurry from livestock.

The national cattle herd is by far the dominant source of these emissions. The national cattle herd includes 6.3m animals, broadly evenly divided between dairy cattle and 'suckler' cows used exclusively for beef production. While emissions fell in 2010, Government policy is to expand milk production following the lifting of levies at EU level. The expected emissions path based on these plans is shown below.

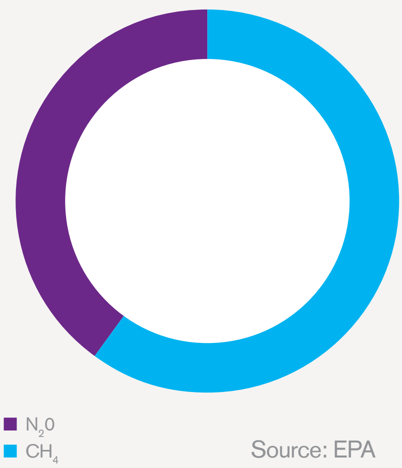
Mitigation is challenging with current levels of knowledge, especially in the case of methane emissions from pasture-fed cattle. The expectation is that, in the short to medium-term, mitigation could deliver a 5% to 10% reduction in current emissions, offsetting at best the expected growth in cattle numbers. The modelling supporting the National Mitigation Plan assumes that emissions from Agriculture will remain flat. While the projected increase in the herd is not certain and will

IRISH AGRICULTURE GREENHOUSE GAS EMISSION TRENDS ($MtCO_2e$)



Source: Teagasc

AGRICULTURAL EMISSIONS (2014)

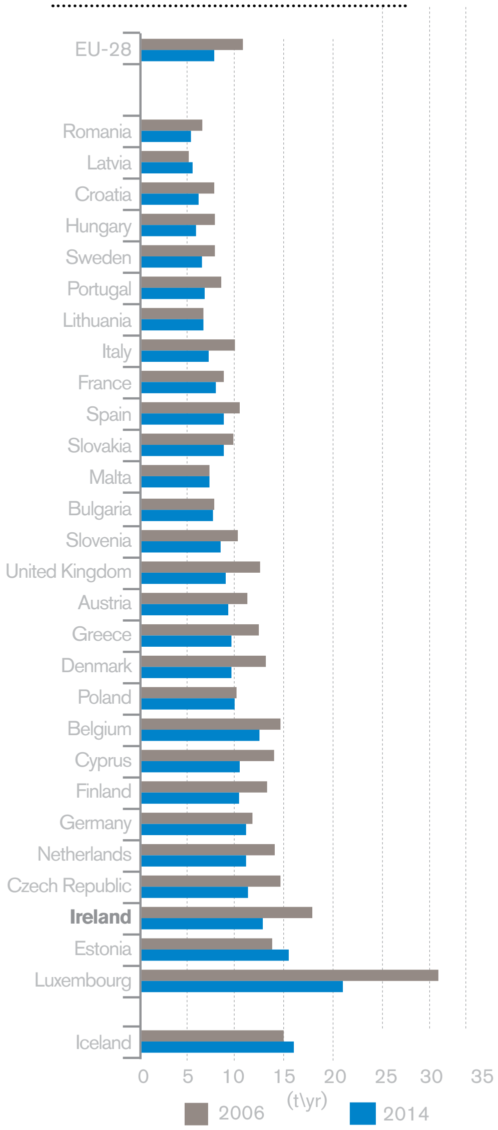


Source: EPA

depend on exports and the impact of Brexit, agriculture is unlikely to prove to be a major source of economic mitigation options in the short term.

There is also an ongoing wider debate about the appropriate role for agriculture in greenhouse gas mitigation and even the economic viability of specialist beef production into the future (Matthews, 2015). Aside from social considerations, this national debate does not affect the long term task before the energy sector. The Government has set a separate target of an 80% reduction in CO_2 emissions from the sector by 2050. This remains the priority for the energy sector to deliver. In the short to medium term, the assumption of no emission reductions in Agriculture does have an impact on energy sectors, effectively increasing the savings to be made in heat and transport. Our roadmap estimates that heat and transport will need to reduce by around 30% for Ireland to meet the 2030 GHG reduction target for the sectors outside the ETS.

FIGURE 5 - GREENHOUSE GAS EMISSIONS PER CAPITA IN EU



Total emissions, inlcuding international aviation and indirect CO_2 but excluding emissions from land use, land use change and forestry (LULUCF)
Source: European Environment Agency

PROPOSED 2030 NON-ETS TARGET

As outlined above, the EU Commission has proposed a 2030 Non-ETS GHG target for Ireland of a 30% reduction relative to 2005 by 2050. This is implemented as a series of annual reduction targets starting in 2021 and ending in 2030 at the 30% reduction. The sum of the annual targets or 'annual emission allocations' (AEAs) effectively forms a total GHG envelope or budget for the period. While annual targets can be exceeded in any year, member states are expected to stay within this aggregate budget over each period. If Ireland succeeds in exploiting the two available flexibility mechanisms to help reach the 30% reduction, the net Non-ETS mitigation required to reach the target might be as low as a 20.4% reduction.

Ireland's recent emissions trajectory and proposed targets (with maximum credits) are shown in Figure 6. This shows projected emissions exceeding target from 2017. When accounted for on a cumulative basis, the latest EPA analysis suggests that cumulative shortfall will be around 11.5 $MtCO_2e$ even if all other targets are met and could be as high as 13.7 $MtCO_2e$ if no additional policy measures are implemented (Environmental Protection Agency, April 2017).

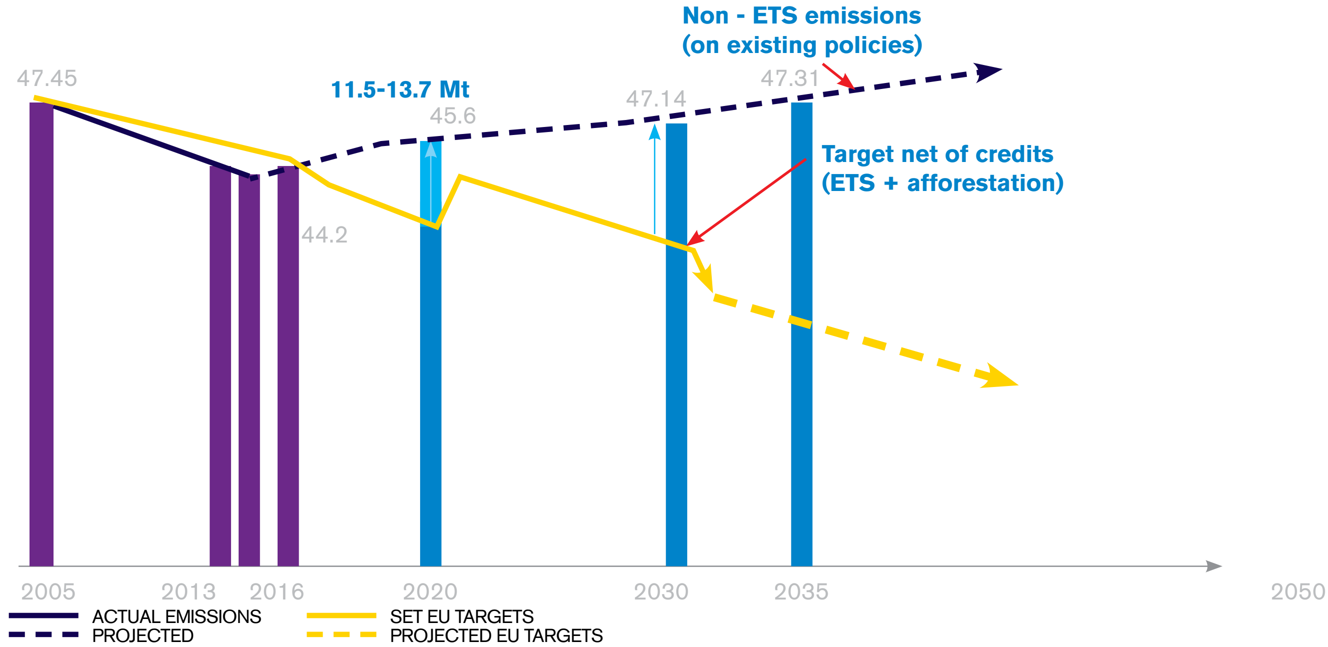
Turning to the projected target lines for 2021 – 2030, it is worth noting that the proposed starting point in 2021 was favourable to Ireland, being based on an average of actual emissions between 2016-2018 rather than on the 2020 reduction target of 20%. However the figure demonstrates that this is still a very challenging task for Ireland:

- Meeting the sharp downward trend of the targets would represent a reversal of recent trends in actual emissions.
- As can be seen there is a very wide gap between the trend line projected to 2030 and the sharply lower path to which Ireland's emissions must be confined.
- In addition the one-off flexibility from the ETS will not be available in 2031, further increasing the task from there.

Finally it is worth noting that the forestry credit will require an increase in the planting rate of new forestry for it to be achieved. This flexibility is based on real measures and is not without cost.

In summary, the proposed 2030 Non-ETS GHG target even after flexibilities, represents a profound transformation of the energy system and of land use in Ireland that will take time to bring about. Compliance will require a major policy focus now and over the next decade.

FIGURE 6 - IRELAND'S 2030 NON-ETS PATHWAY AND TARGET ($MtCO_2e$)



Source: Analysis based on (Environmental Protection Agency, April 2017); (European Commission, 2017)

BOX 4: PROGRESS TOWARDS IRELAND'S 2020 RENEWABLE ENERGY TARGET
(SOURCE: DCENR 2015)

Target	2020 (Target)	2015 (Actual)	Distance to Target
Renewable Energy (Overall)	16%	9.1%	7.4%
Renewable Electricty (RES-E)	40%	25.3%	17.3%
Renewable Heat (RES-H)	12%	6.5%	5.4%
Renewable Transport (RES-T)	10%	5.7%	4.8%

PROGRESS TOWARDS 2020 RENEWABLE ENERGY TARGETS

The Renewable Energy Directive that was implemented as part of the 2020 Climate and Energy Package establishes a target of 20% of final energy consumption across the EU to come from renewables by 2020. As was the case for the non-ETS emission targets, this pan-European figure has been transposed into specific targets for individual Member States. Ireland's legally binding Renewable Energy (RES) target is 16% of final energy consumption by 2020. Within this target there is a separate, legally binding, target applied to the transport sector, where 10% of energy must be renewable by 2020[7] .

No specific EU targets apply to renewable sources' share in electricity or heat, but the Irish government has set its own national target of achieving 40% of electricity consumption and 12% of heat consumption from renewable sources by 2020. These are summarised in the above table. Renewable energy targets both require a substantive shift in activity levels if they are to be achieved. The following examples outline the scale of change estimated by SEAI to ensure delivery:

- Renewable generation deployment (mainly wind) will need to be maintained at around 200MW to 250MW per annum out to 2020, which compares to 270MW installed in 2014 and an average of 177MW installed per annum over the last 5 years;
- Electric vehicles will need to form 20% of new car sales by 2020, compared to 562 vehicles or just 0.23% of new car sales in 2015. 50,000 EVs are projected for 2020. This is a marked reduction on the earlier goal of 250,000 EVs by 2020 but still an order of magnitude higher than the 1,000 or so cars currently on Irish roads.
- 300,000 homes or 3,000 businesses will need to install some form of renewable heat technology by 2020, compared with 40,000 homes and 550 businesses at present.

The ability to realise this change in activity is by no means certain and because of the interactions between the various targets, failure to do so will exacerbate the extent of any projected shortfall in the non-ETS target.

[7] It should be noted that, when assessing compliance with the RES-T target, specific biofuels (second generation) count double towards achievement. However, this double contribution is not applied in the assessment of performance against the overall 16% renewable energy target.

1.7.1 COSTS OF NOT MEETING THE TARGETS

As these targets are binding on the Irish government, failure to achieve the reductions in Ireland will lead to the requirement to comply by purchasing unused annual emissions allocations from other member states who have met their targets with capacity remaining. The potential costs up to 2020 are moderated by the impact of the recent recession which temporarily reduced emissions leaving Ireland with spare annual emission allocations from these years which can be offset against exceedances in later years. Based on earlier EPA projections similar to those in Figure 6 DPER estimated in 2014 that the projected shortfall against non-ETS emission targets to 2020 might result in a cost to the Irish economy of between €90m and €205m (DPER Department of Public Expenditure and Reform, 2014). This is equivalent to a charge of €75 to €170 per household [8] , between 6% and 14% of a current average annual electricity bill.

Beyond 2020, Ireland will be starting out on an emission path that is above target. Far-reaching reduction measures will be required to bring Ireland's emissions back towards the annual reduction path set within the EU in order to avoid very significant compliance costs. Compliance can again be achieved by purchasing surplus allowances from over-achieving member states. However the costs could be significant. The costs of purchasing residual compliance after the credits in the hypothetical case of no further policy steps being taken, have been estimated at between €50 and €100 a tonne after 2020 or between €2.2bn and €4.4bn to 2030 (Curtin, 2016).

In summary, Ireland is committed to a transition path that represents a transformation in the emission profile and therefore the energy system and of land use. Far reaching action will be required. Early action is needed to avoid the limited budget of emission allocations being used up early with high attendant costs for the country.

[8] Based on 1.2 million households.

2

Sources Of Ireland's Greenhouse Gas Emissions

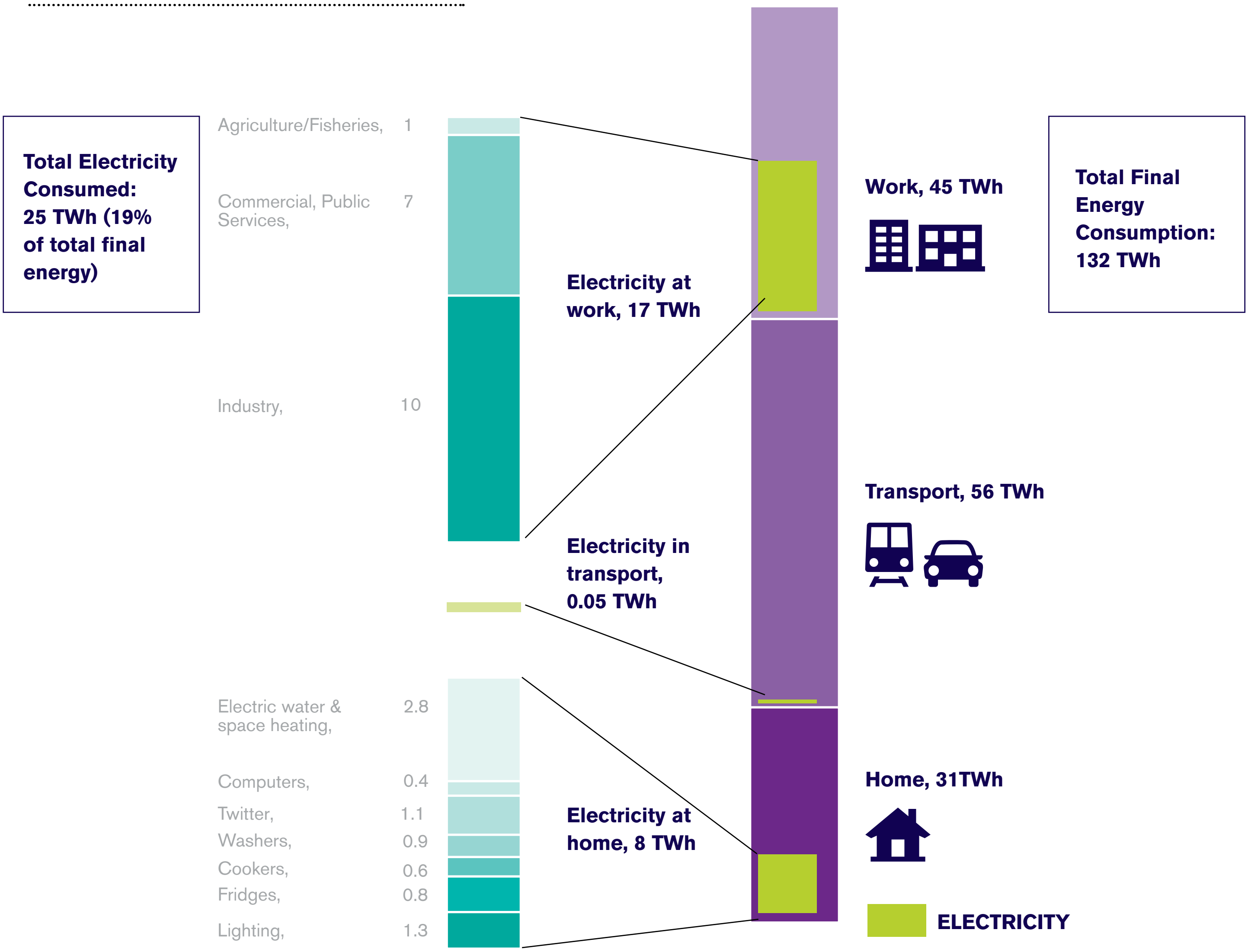
- Ireland's total greenhouse gas emissions were just under 60 Mt in 2015. Of this, electricity accounted for 19%, all within the ETS sector. Outside the ETS sector, heat represented 16% of the overall total, transport 20% and agriculture 33%.
- The Non-ETS sector includes agriculture which is a much larger part of the non-ETS sector in Ireland than elsewhere in the EU at 33% of emissions. As emission reduction in agriculture is more challenging than in energy, Ireland has prioritised Non-ETS energy - essentially heat and transport - to meet the targets.
- In transport, private cars and light and heavy goods vehicles are the principal sources of emissions.
- In heat, the residential and service sectors are the ones most amenable to decarbonisation as they are relatively low temperature applications.
- Oil is by some distance the dominant fuel in Ireland's energy system outside of the electricity sector, at 77%. To decarbonise, a strong direction of travel must be established away from oil and towards efficient technologies and low carbon energy sources.

2.1

WHERE IRELAND'S ENERGY IS USED

The split of final energy consumption in Ireland is provided in the figure below, which shows the final energy consumption across three main categories – work, transport and home. Transport is the largest of the three consumption sectors accounting for 40% of final energy consumption. A quarter is consumed in the home, and the remainder is consumed in 'work' (a combination of industrial, commercial, public sector and agriculture). Electricity represents about 20% of total energy use.

FIGURE 7 - WHERE WE USE OUR ENERGY...



Source: ESB analysis based on SEAI 2015 Energy Balance

2.2
WHERE IRELAND'S GREENHOUSE GAS EMISSIONS ARE GENERATED

This section gives a brief overview of Ireland's emissions inventory. In understanding the issue, the contribution of each sector and whether it is increasing is important. So also is the nature and contribution of each subsector. This understanding can guide choices on the subsectors that need to be addressed before looking at the candidate technologies in Chapters 3-5.

2.2.1
OVERALL EMISSIONS

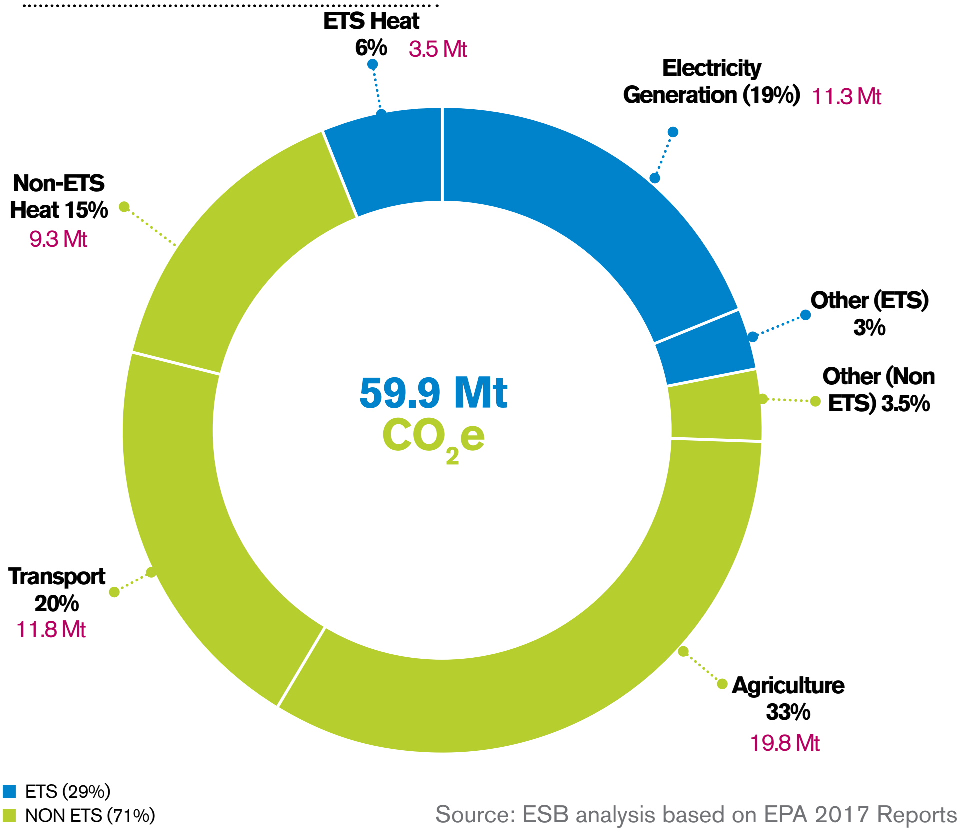
Total greenhouse gas emissions in Ireland in 2015 were 59.9 $MtCO_2e$ (Environmental Protection Agency, April 2017). Agriculture accounted for 19.8 Mt and Waste and F-Gases for 2.1 Mt, leaving 38 Mt due to combustion of energy and process emissions in industry. While Non-ETS emissions at 43 Mt were below the EU target for that year of 44.6 Mt, the EPA projects that Ireland will exceed annual EU targets from 2017.

2.2.2
BREAKDOWN BY SECTOR

Figure 8 illustrates the breakdown of emissions by sector.

Transport at 11.8 Mt is the largest energy-related sector and is growing strongly (4.2% annual growth in 2015). Electricity Generation at 11.3 Mt is the third largest sector. It grew by 5.2% in 2015, driven by an increase in coal and peat use. Residential emissions grew by 5.1% in 2015, to 6 Mt, though this would be influenced by the colder weather in 2015 compared to 2014.

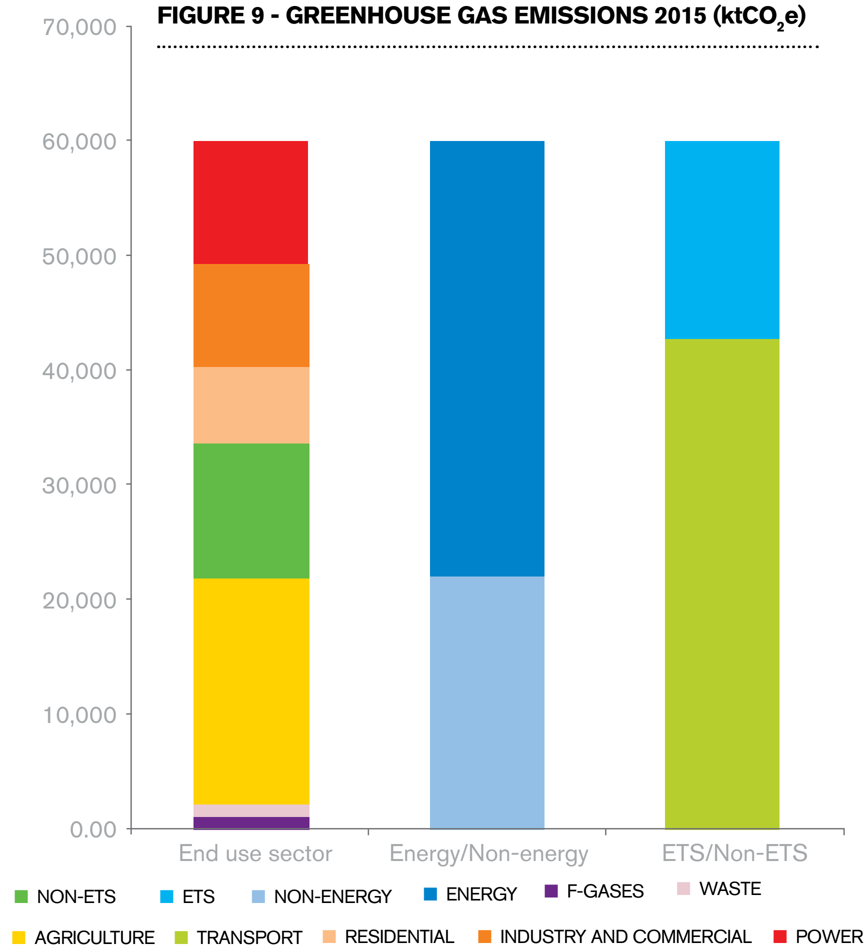
FIGURE 8 - IRELAND'S EMISSIONS CHALLENGE



Source: ESB analysis based on EPA 2017 Reports

The figure below shows the breakdown between energy and non-energy related emissions and emissions that fall within the ETS and outside it.

FIGURE 9 - GREENHOUSE GAS EMISSIONS 2015 ($ktCO_2e$)



Source: EPA (2017)

These figures illustrate a number of points:

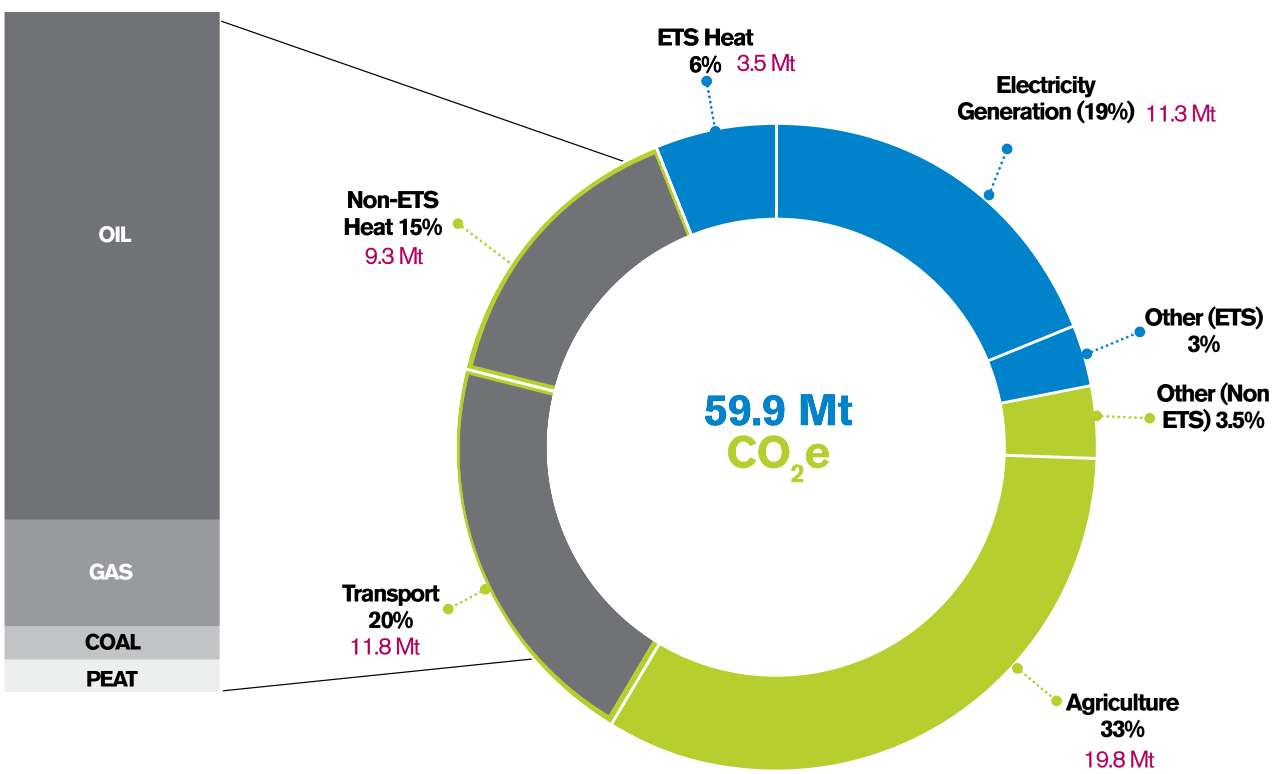
- ETS emissions are only 28% of total emissions. This is significantly lower than the EU average share of ETS emissions which is around 43% and is driven by the proportionately larger size of the agricultural sector.
- In Ireland the agricultural sector accounts for 33% of emissions, compared to 10% as an EU average.
- Total emissions for the energy sector approximate to all emissions excluding those in agriculture and waste [9]. In 2015, this was 63% of total emissions. Of this estimated total for energy sector emissions, 43% are monitored and controlled under the pan-European ETS trading scheme.

[9] It was 60% excluding process emissions, for example carbon dioxide emitted from cement manufacture

2.2.3
FUELS

Figure 10 shows a breakdown of heat and transport emissions by fuel. It is clear that, at 77%, oil is the dominant influence behind Ireland's Non-ETS emissions.

FIGURE 10 - IRELAND'S EMISSIONS CHALLENGE BY FUEL



Source: ESB analysis based on EPA 2017 Reports

2.2.4
POWER GENERATION

The power generation sector was responsible for 19% of greenhouse gas emissions in 2015. Total emissions, at around 11.3 $MtCO_2$, are slightly lower than the 11.4 $MtCO_2$ emitted in 1990 despite total final electricity consumption doubling over the same period (Sustainable Energy Authority Ireland, 2016). This has been achieved through a material reduction in the carbon intensity of generation over the same period, as illustrated in figure 11.

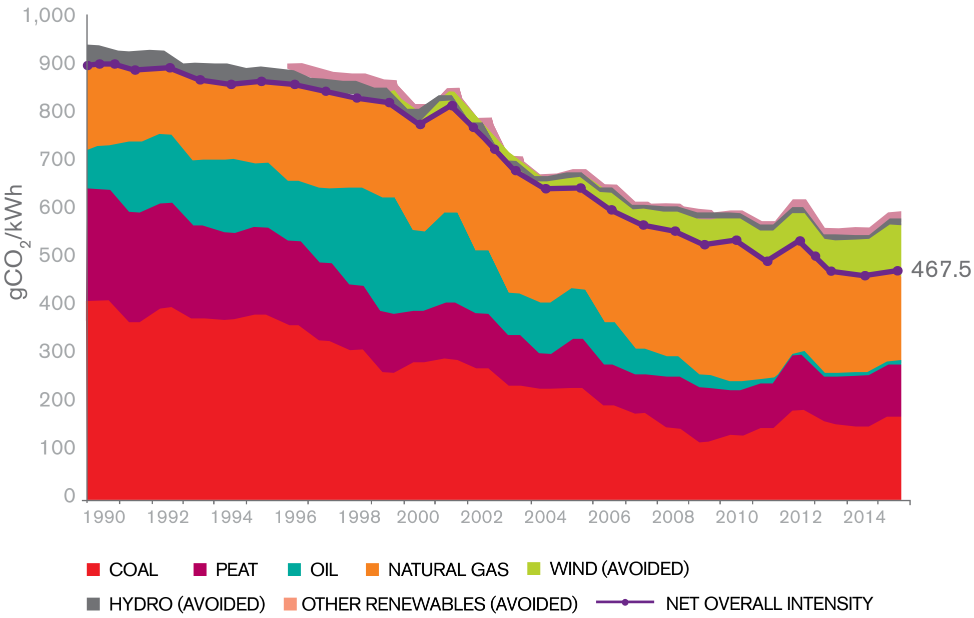
The carbon intensity of generation in Ireland[10] has more than halved over the period from 897gCO_2/kWh in 1990 to 467.5 gCO_2/kWh in 2015 through a combination of:

- The replacement of old, inefficient generating units with more efficient plant; and
- A switch to lower carbon fuels (i.e. gas) and renewables from fuel oil

The emissions from electricity are expected to further reduce as more renewable generation comes on stream to approach the 40% target for 2020. The technology options available to further reduce the carbon intensity of electricity are explored in Chapter 3.

[10] Note that the SEAI reports emissions from generators located in the Republic of Ireland and not the total emissions from all generation in the Single Electricity Market (SEM). Northern Ireland generation has a higher carbon intensity in recent years due to the slower adoption of renewable technologies so far.

FIGURE 11 - CO_2 EMISSIONS PER kWh OF ELECTRICITY SUPPLIED; WITH CONTRIBUTIONS BY FUEL



Note: 2015 values were 467.5 g/CO_2

Source: SEAI Energy in Ireland 2016 Report

2.2.5
TRANSPORT SUBSECTORS

The transport sector accounted for 20% of Ireland's greenhouse gas emissions in 2015 and was responsible for over a third of energy-related carbon emissions, the largest sector contribution. One of the main reasons for the high level of emissions is the dominance of oil in the transport fuel mix. A breakdown of emissions by transport subsector is presented in figure 12.

While emissions from other energy-sectors are broadly comparable to their levels in 1990, a rapid growth in vehicle ownership and usage - up from approximately 1 million road vehicles in 1990 to approximately 2.5 million in 2013 - has been a major contributory factor in the more than doubling of transport emissions over the period. This is despite improvements in the energy efficiency of vehicles, driven by tighter emission standards on new vehicles.

From the break down in figure 12, it is clear that, apart from aviation where compliance falls directly on the industry, there are two principal sources of emissions: private cars and light and heavy goods vehicles. Rail, public passenger and navigation are relatively small. Just under two-thirds of the emissions are from the three main road transport segments – heavy goods vehicles (HGVs), light goods vehicles (LGVs) and private cars. The low carbon technologies relevant to these high-emitting segments are explored in Chapter 4.

2.2.6
HEAT SUBSECTORS

Total CO_2 emissions from the heat sector in 2015 were estimated to be 12.6 Mt (Sustainable Energy Authority of Ireland, 2016). The breakdown of emissions is given in figure 13.

A number of points are evident about the composition of Ireland's heat demand compared to most other member states:

- The proportion represented by space and water heating is high
- Space cooling is relatively low
- Process heat represents a small proportion of the total demand

As we will see in Chapter 5, space and water heating tend to be well suited to low carbon technologies such as heat pumps or district heating. It follows that low carbon space and water heating technologies are likely to have the potential to reduce or remove the majority of emissions from the production of heat in Ireland. This is explored in Chapter 5.

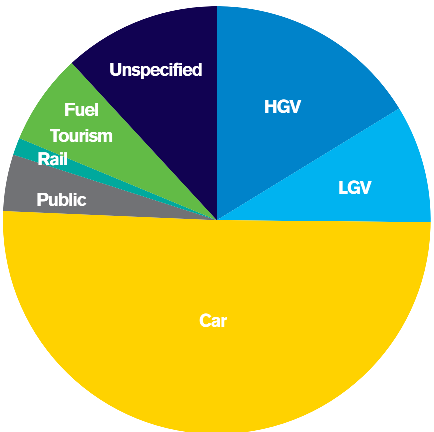
Table 5 - Sectors and Heat Demand (ktoe)

Segment	Temperature	
	Low <= 60°C	High > 60°C
Residential	2,079	-
Commercial	753	-
Industrial	-	1,436

Source: Figures from SEAI

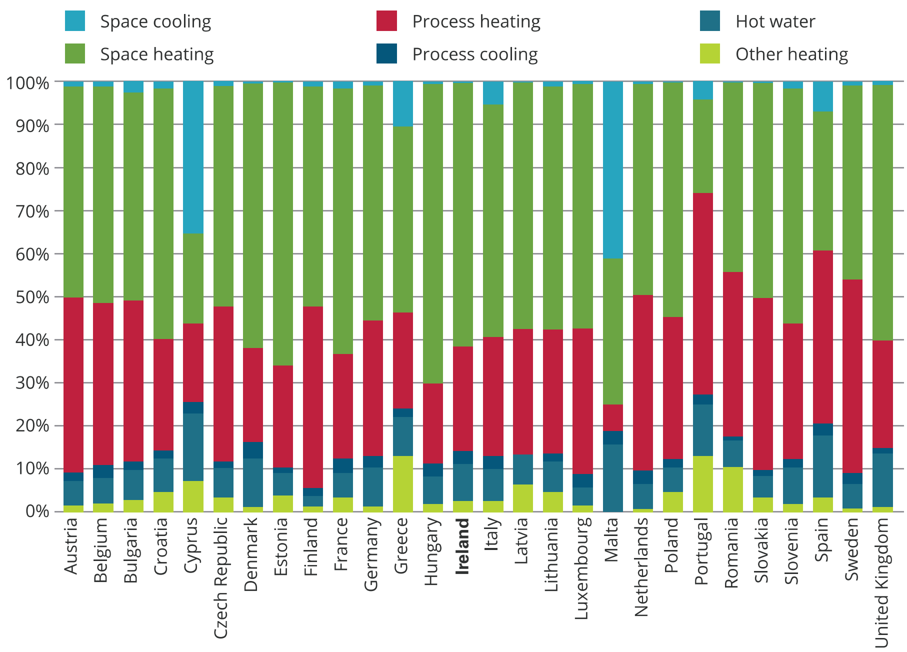
FIGURE 12 - SOURCES OF TRANSPORT EMISSIONS

EMISSIONS BY MODE IN IRELAND 2013



Source: Energy in Transport SEAI (2014)

FIGURE 13 - COUNTRY COMPARISON OF END USE OF HEAT



Source: Heat Roadmap Europe

3

Technology Options For Decarbonisation – Electricity

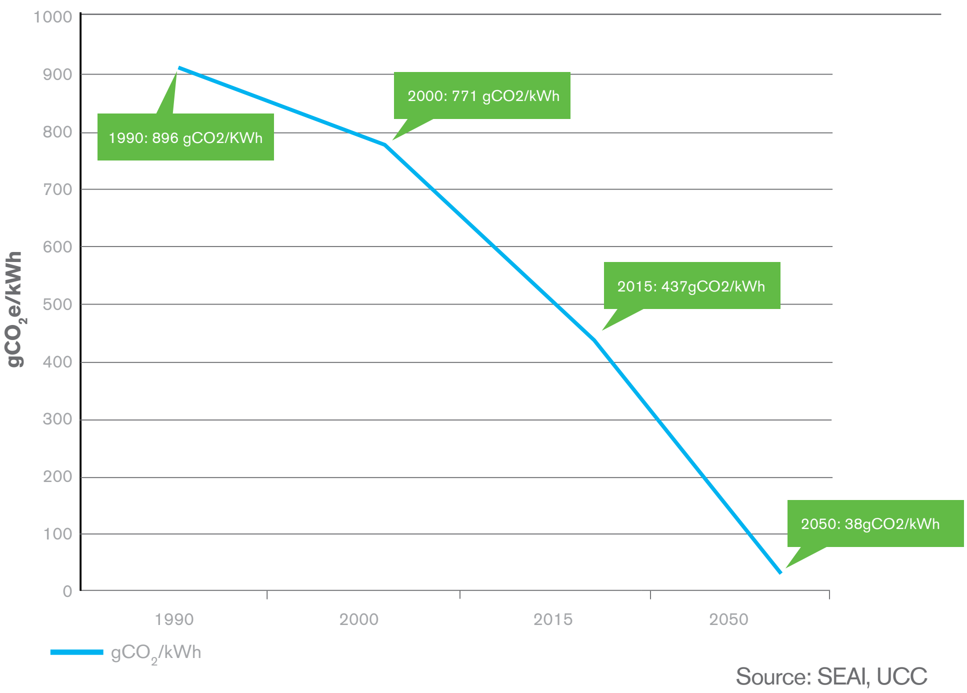
- Electricity accounted for almost a fifth of Ireland's total greenhouse gas emissions of 60 Mt in 2015.
- To achieve the goal of an 80% decarbonisation of the energy system by 2050, UCC modelling projects that generation carbon intensity will need to fall from 437 gCO_2/kWh in 2015, to 38 gCO_2/kWh in 2050.
- Renewable electricity has been critical in reducing the carbon intensity of electricity and is targeted to reach 40% of generation output in 2020 with 37% coming from wind. Beyond 2020, while there are obstacles, intermittent renewable generation is likely to increase beyond this level as wind and solar continue to grow market share.
- Therefore while we can be confident that the Irish electricity system will be around half way towards full decarbonisation in the 2020s, the optimal mix of technologies to achieve the second 50% is yet to be determined.
- The suite of options to complete the pathway to full electricity system decarbonisation includes:
  - Further (beyond 50%) Intermittent RES in conjunction with Interconnectors and storage and flexible demand side response
  - Biomass
  - Carbon Capture and Storage (CCS)
  - Nuclear power
- Each of these technologies presents significant challenges. Based on current information, it is very likely that gas generation with CCS will form a significant part of the low carbon generation mix along with renewable generation and possibly biomass.

- Carbon Capture and Storage (CCS), a key candidate technology, is technically proven. Its commercial feasibility is likely to depend on sharing of CO_2 pipeline and storage infrastructure and the creation of a low risk legal and regulatory framework. CCS is likely to be particularly important for Ireland given the limited options available to complement intermittent renewable sources. Steps to maintain the availability of potential storage sites and the preparatory work on a regulatory and legal framework need to start shortly so the investment decisions can be taken soon after 2025 – or earlier, if necessary.

3.1
INTRODUCTION

As seen in Chapter 2, the Government has set a policy goal of an 80% reduction in greenhouse gas emissions from the energy system. Flowing from this, the UCC 80% reduction scenario (Deane, et al, (2013)) projects a carbon intensity for electricity in 2050 of 38 gCO_2/kWh, compared to 437 gCO_2/kWh in 2015[11] . This is illustrated in Figure 14.

FIGURE 14 - CARBON INTENSITY OF ELECTRICITY - HISTORIC AND PROJECTED



Source: SEAI, UCC

To achieve this reduction, it will be necessary to exploit a range of technologies with lower emissions than the conventional thermal generation which contributes the majority of today's generation capacity.

In this section of the report we describe and compare the key technologies in power generation, including those that feature in short- and long-term future scenarios for the generation sector.

3.2
GENERATION TECHNOLOGIES

The technologies that are anticipated to be present in the future generation mix - to a larger or smaller extent - are outlined below. We have split these into three categories of technology:

- conventional thermal – coal, gas and oil-fired power stations;
- renewable – including wind, solar, hydro, marine, biomass or biomass combined heat and power (CHP);
- Carbon capture and storage (CCS); and
- Nuclear Power

Because of their ability to absorb excess energy at times of high renewable generation and to release it when renewable generation is low, both energy storage and interconnection can be important facilitators of increasing the proportion of renewable generation. These approaches and their practical limits are discussed below alongside the generation technologies.

3.2.1
CONVENTIONAL THERMAL TECHNOLOGIES

Thermal power stations take heat energy and convert it into electrical energy by driving a turbine which is connected to an electrical generator. The turbine is generally a steam turbine where water is heated in a boiler and the steam drives the turbine or a gas turbine where the turbine is driven by the combustion of natural gas.

Dispatchable plant

Thermal plant has access to stored fuel or gas in pipelines, it can be directed to generate any time it is required by the system with a high degree of certainty, subject to thermal and start-up constraints. For this reason, this plant is referred to as dispatchable.

Inertia of plant

Plant with steam turbines, when running, have a large degree of mechanical inertia. By this we mean that, when there is a disturbance on the electrical system to which they are synchronised, they tend to keep spinning and resist the disturbance. This inertia is helpful to system operators to manage a stable electricity system.

3.2.1.1
COMBINED CYCLE GAS TURBINE (CCGT)

The majority of gas-fired plant is combined cycle gas turbine (CCGT) plant due to their higher efficiency. In a CCGT, the waste heat from the primary gas turbine is used to generate steam that drives a steam turbine. This increases the overall efficiency of the generation process. Current installed CCGTs in Ireland have thermal efficiencies of around 55%.

As carbon constraints tighten and renewable penetration increases, it is unlikely that CCGTs will continue to operate at baseload and they will be expected to operate much more flexibly. CCGTs have the capability to perform this role, though it has implications for technical performance and cost. CCGTs can generate with emission levels of about 350 -380g/kWh so ultimately in the longer term CCS will be required if CCGTs are to continue to form a significant proportion of the generation in Ireland.

3.2.1.2
OPEN CYCLE GAS TURBINE (OCGT)

Open cycle gas turbines (OCGTs) do not have the secondary steam cycle that is employed in the CCGT design. They are generally smaller units and are designed for much more flexible operation – typically as peaking plant. They have a lower

[11] Data obtained from (http://statistics.seai.ie)

thermal efficiency than a CCGT, ranging between 33% and 40% depending on design, and are often built to switch between gas and gasoil.

In a future where fossil-fuel generation will be limited, the smaller size and lower unit capital and fixed costs of OCGTs compared to CCGTs may mean they would play an increasing role in delivering flexibility to the system for short periods as they are more cost effective at lower load factors. While gas turbine manufacturers have traditionally set a significant minimum generation limit, this is changing in response to market needs.

3.2.1.3 COAL

Coal-fired power stations use coal to generate steam in the boiler. Two coal fired generators operate in the all-island Single Electricity Market, Moneypoint in Co. Clare is the largest single technology station on the system (Eirgrid and SONI, 2016) and the Kilroot plant is located in Carrickfergus, Co. Antrim in Northern Ireland.

New coal technologies using a so-called 'supercritical' process can have a thermal efficiency as high as 44% - considerably above the mid-thirties for conventional coal-fired plant. Increasingly strict air quality emission limits on, for example, SOx and NOx impose progressively more onerous requirements for emissions scrubbing equipment to meet. In addition, the high carbon content of coal means that there are very limited prospects for operation into the longer term without measures to capture and store the CO_2, though there are potentially viable opportunities for extending the life of existing plant through full conversion or co-firing with biomass.

Scrubbers can be fitted to reduce SOx and NOx and to capture carbon dioxide for storage (see below), reducing the carbon emitted. However simulations suggest that, even with current CCS technology, coal will have too high a level of residual CO_2 emissions to be part of the electricity system in 2050

3.2.2 RENEWABLE TECHNOLOGIES

3.2.2.1 WIND

Onshore wind generation is a mature form of renewable generation. Over the years the technology has benefited from development and economies of scale in the size of turbines. Due to the fact that wind is variable, wind generation is classed as an intermittent source, with implications for its contribution to security of electricity supply. The typical load factor for wind generation in Ireland has recently averaged between 26% and 31%[12] although the capacity factor applied is 31% (Eirgrid and SONI, 2016).

Wind farms can be sited onshore or offshore. Onshore farms benefit from lower construction costs but can be constrained by social acceptability. Offshore facilities have more favourable wind conditions but cost more to build.

Wind – onshore and offshore - is expected to contribute 37% of the 40% renewable electricity target for 2020. There are wider developments (through the DS3 programme)[13] being progressed to ensure that the system can accommodate higher levels of wind generation than currently (Eirgrid, et al., 2014).These are aimed at ensuring that adequate levels of flexibility exist in the system to maintain stability in the absence of large amounts of conventional plant.

[12] 2011-2015 EU Energy Statistics. Available at https://ec.europa.eu/energy/en/data-analysis/country

[13] Programme Delivering a Secure, Sustainable Electricity System

3.2.2.2 SOLAR PV

Solar technology includes Photovoltaic (PV) and Concentrated Solar Power (CSP). While the latter is only likely to be economically viable in Southern European or North African locations since they require direct normal irradiance (DNI) levels of 2,000 $kWh/m^2/yr$. According to the International Renewable Energy Agency (IRENA, 2012), photovoltaics are in widespread use, notably in Germany

and, increasingly, in Great Britain, where attractive feed-in tariffs have encouraged developers.

Technically, and economically PV technology continues to improve: thin film PV technology, for example, uses less silicon and is cheaper to manufacture than conventional photovoltaics. There are no operating solar farms in Ireland at present though there is at least one in Northern Ireland. Solar is also an intermittent, or variable, form of generation dependent on weather and time of day. In Ireland, load factors are expected to be in the region of 11% (Irish Solar Energy Association, 2015).

Roof-mounted PV in Ireland exists mainly in response to the renewable energy requirement in the building regulations. While the cost of energy from roof-mounted PV is high, as the costs of PV reduce, it is possible that, for existing homes and small businesses, the average cost of electricity produced by PV may approach that of mains electricity (so-called 'grid parity'). This is because current tariffs are designed for import-only customers and recover some of the fixed cost of the networks through the unit price.

3.2.2.3 BIOMASS

Dedicated biomass-to-electricity plants around the world have typically been relatively small units which take the biomass fuel from a local catchment area. Recent years have seen the development of large scale biomass power/heat generation facilities, either through fossil fuel conversions or dedicated builds. These builds have mainly occurred in Western Europe, notably UK, Belgium, Denmark and the Netherlands and Asia, notably Korea and Japan.

The unit scale of these larger plants is around 300MW in the UK, each consuming typically 2.4m tonnes of woodchips per year.[14] Wood chips have about 60% of the energy per unit weight as coal.

Biomass power generation plant can provide a suitable, zero-carbon solution to deliver back-up capacity but also essential system services and flexibility to the power system in order to complement variable renewables. However, like conventional thermal plant, they face uncertain costs of the fuel used because the market for biomass is small and still developing (SEAI, 2012a).

In order to ensure that bioenergy is used in a way that delivers real environmental benefits, its use must be underpinned by robust, clear, credible structures that effectively distinguish sustainable bioenergy fuel cycles from those that should be avoided. In this respect, the inclusion of biomass sustainability criteria in the recently proposed Renewable Energy Directive is welcome.

The efficient use of forest resources is mainly driven by market forces e.g. it would be uneconomic to divert valuable wood that is suitable for use in construction or furniture to energy use. In the US and northwest Europe, afforestation has been a feature over the past 50 years and an economic outlet for the forest resources is a key component of maintaining and in certain cases increasing forestry levels. The recent mobilisation of forest and sawmill residues for energy use enhances the forests' economic and environmental benefits.

Through its policies, the EU has sought to ensure that biomass, will be used in the long term in the most efficient and sustainable manner possible. In the Clean Energy Package of proposed legislation, it is proposed that biopower plants, or generation stations using biomass, will be required to generate both electricity and usable heat (see CHP below).

This requirement to generate heat, effectively restricts locations for significant electricity generation from biomass to places where there is a large enough demand for heat. These are generally city centres. It also requires heat networks to be developed if biomass is to be used for electricity generation. This is a significant restriction for an island system that requires dispatchable plant for stability but has limited options to choose from. By focusing on the end point rather than the need for a transition, this requirement could arguably prolong the use of fossil fuels.

3.2.2.4 HYDRO

There are three main forms of hydro power. Dam based schemes are centred on an artificial lake or reservoir which can store enough water for several months (in some cases, for over a year): in this way production can be maintained against variable amounts of rainfall. Run-of-river schemes simply operate on the natural flow of the water and therefore are much more prone to interruption on account of the weather. Pumped storage schemes pump water to a height and use the stored energy to generate at a later time.

There are four major dam-based hydro stations in Ireland, all of which were first commissioned at least 50 years ago. Ardnacrusha is the largest hydro plant in Ireland and contributes 85MW to a total conventional hydro capacity of 220MW.

Ireland has limited hydro resources compared to other countries. There is very limited scope for further hydropower development in Ireland with the SEAI noting that the focus is on development of small scale future projects (i.e. between 1MW and 10MW capacity).[15]

In addition to dam-based and run-of-river hydro generation, pumped storage schemes pump water electrically from a lower lake to a reservoir high up a mountain, and then generate electricity by flowing it back down. Such plant can turn on and off extremely fast – enabling the system operator to manage situations like demand peaks or failure of other power stations. It must be noted that because of the volumes and heights required, large scale storage with such schemes is rarely financially feasible with today's market structures.

Pumped storage schemes are net users of electricity as the round trip efficiency is less than 100%. Therefore they fall within the category of energy storage rather than generation.

The 290 MW Turlough Hill station is Ireland's only pumped storage. Its maximum storage capacity is 1,800MWh - approximately 6 hours at full output.

There are some possible sites for new pumped storage schemes but these are expected to be limited. The 'Spirit of Ireland' proposal for 2GW of generating capacity with up to 200GWh of storage – enough to run the plant at full load for 100 hours – envisaged the flooding several valleys

[14] Renewable Energy Focus.com 10th August, 2009

[15] As far back as 1985, the Department for Energy had identified a potential of around 38MW and a more recent ESBI estimate of 72MW is reported by SEAI.

with seawater and appears highly challenging from a planning and commercial feasibility perspective.

3.2.2.5
MARINE

Tidal and wave energy technologies are still in the pre-commercial stages of development and has not yet been deployed beyond the demonstration phase. As its scale and feasibility is not yet proven, most low carbon roadmaps do not show marine energy playing a significant role. Therefore it has not been included in the roadmap in Chapter 6. The Irish Government's earlier Energy White Paper in 2007 set an initial target of at least 500MW of installed ocean energy capacity by 2020 (Department of Communications, Marine and Natural Resources , 2007) and the Offshore Renewable Energy Development Plan (Department of Communications, Energy and Natural Resources, 2014) proposed ranges of deployment by 2030 of between 75MW and 1500MW which, at a maximum average load factor of 31% (National Grid, 2013) would deliver between 200GWh and 4TWh of electricity to the Grid.

3.2.3
OTHER TECHNOLOGIES

3.2.3.1
CCS

Carbon capture and storage (CCS) technology is the capture of carbon emissions from generation that uses a CO_2 emitting fuel, allowing the conventional thermal plant to be low carbon. This is conventionally achieved by capturing CO_2 from the flue gases (although oxy-fuel approaches are being developed). Designers estimate that, the current generation of conventional CCS can capture and store around 90% of the CO_2 at the point of generation. For example, the UK CCS Cost reduction task force (The Crown Estate; Carbon Capture and Storage Association; Department of Energy and Climate Change, 2013) reported that a CCS gas plant would have a carbon intensity of generation in the order of 30 – 40 gCO_2/kWh, compared to an unabated gas plant with a carbon intensity of 350 - 380 gCO_2/kWh. The technology is still in the early phases of implementation with a limited number of large-scale projects in operation globally and only one operational power sector project (the Boundary Dam project in Canada which became operational in October 2014).

The technology has high capital costs and the efficiency of operation of the power plant is significantly reduced relative to operating in unabated mode (Pöyry Management Consulting, 2010). In addition, the power plant is dependent on a connection to an operating CO_2 transport and storage infrastructure – usually a pipeline to a geologically stable underground storage site such as a depleted natural gas field.

It is expected that the viability of CCS plant will depend on clusters of generation plant being able to share the costs and risks of this infrastructure. Since the CO2 transport and storage infrastructure must be operational for a CCS plant to run, the ability to secure investment finance for any new plant will require the risks associated with this new type of infrastructure to be reduced or managed. Examples of these risks are the regulation of access arrangements and access charges, payments to generators if an outage of the infrastructure forces them to shut down and also who is liable in the event of a CO_2 leak from the infrastructure. After the cancellation of a competition for CCS projects in the UK in 2015, it was concluded that the scale of these risks significantly increased the return that is required by the bidders on the investment in order to secure finance, thus raising the prospective costs for customers (National Audit Office (UK), 2017). It was concluded that governments may need to underwrite some of the risks of the infrastructure in order to allow CCS to grow and develop.

Apart from these questions, there is also the question of how to develop confidence among potential investors that CCS plant will be able to secure sufficient hours of operation in Europe's wholesale electricity market in order to earn a return on their investment.

TABLE 6 - COMPARISON OF ALTERNATIVE TECHNOLOGIES

		Carbon intensity (gCO_2/kWh)[16]	LCOE range (£/MWh)[17]		Technical maturity
			2015	2030	
Renewable	Hydro	-			Mature
	Wind (onshore)	-	75-115	45-72	Mature
	Wind (offshore)	-	157-208	85-109	Developing
	Solar PV (ground mounted)	-	114-131	52-73	Mature/ Developing
	Marine	-			Pre-commercial
	Biomass	-	106-117	-	Mature
Nuclear	Nuclear			69-99	Mature/ Developing (new tech)
Gas	CCGT	350-380	73-75	97-100	Mature
	OCGT		155-175	207-224	Mature
	CHP	-			Mature
	CCS (gas)	30-40		120-131	Pre-commercial
Coal	CCS (coal)	80-150		-	Pre-commercial
	Coal	750-900			Mature

Note; Levelised cost of electricity (LCOE) is the average net present value of the total electricity produced from a generation asset over its lifetime.

[16] Source: DECC (2013), UK CCS Cost Reduction Task Force, Final Report

[17] Source: ESB, (based on DECC figures)

Notwithstanding these issues, many projections of the future energy mix see CCS as a critical technology to deliver power sector decarbonisation due to the absence of alternative options for low carbon dispatchable plant. Given Ireland's island system and limited scope for other modes of dispatchable low carbon generation, it is particularly important for Ireland that CCS projects are developed within the EU to build and transfer knowledge and thus to lower costs.

The application of CCS to biomass can lead to 'negative emissions' (i.e., because the CO_2 has recently been taken from the atmosphere by the biomass, then when CO_2 is captured from the combustion or gasification of biomass through CCS, this represents a net removal of CO_2 from the atmosphere). Most feasible IPCC scenarios contemplate atmospheric levels initially overshooting the target and thus rely on very significant levels of this biomass plus CCS for global warming to remain below 2°C within a high degree of probability.

Therefore the development of CCS is also of crucial global importance (Intergovernmental Panel on Climate Change, 2014).

3.2.3.2 COMBINED HEAT AND POWER (CHP)

In general large power stations are designed with electricity production in mind, with 'waste' heat being rejected either to the atmosphere in cooling towers or to rivers or the sea, depending on location.

However some of the 'waste' heat from power stations can be used for residential heating – as in the district heating systems in many cities and towns in Nordic countries– or in energy intensive businesses such as refineries and pulp mills where the plant provides heat and part of the electricity. These applications will depend on the economic viability of the project. This joint production of heat and power can improve the overall energy efficiency of the facility and lead to lower carbon emissions by displacing some of the heat that would otherwise need to be separately generated.

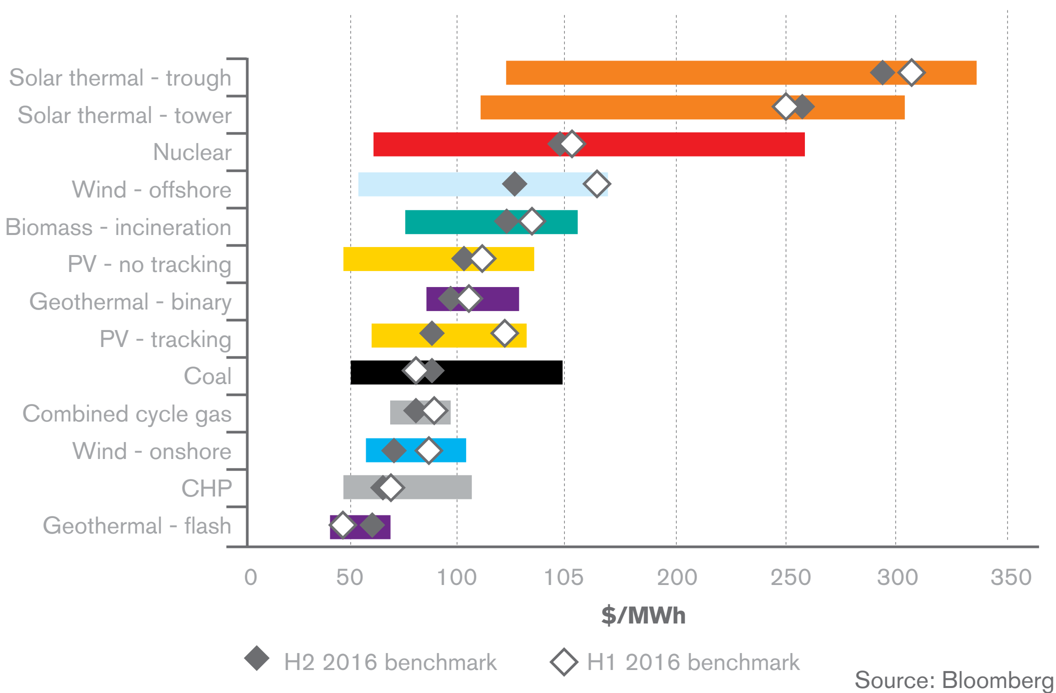
Such combined heat and power (CHP) units, can be run on a wide range of input fuels including gas, gasoil and biomass.

3.2.3.3 NUCLEAR

At present, Ireland has statutory provisions that do not allow nuclear fission power stations to be built or operated in the country. However, in several European countries (e.g. France, Finland and the UK), new plant is either under construction or is planned. An overview of new nuclear technology can be found in (Parliamentary Office of Science and Technology, 2014), with a more comprehensive, but older study published by MIT in 2009 (Deuth, et al., 2009).

Apart from the legal position, the minimum size of nuclear power plant currently available is over 1,000 MW. This is too large relative to the peak load on the electricity system in Ireland to permit reliable operation. Therefore nuclear power is not included in the roadmap in Chapter 5 as this is based on current technologies. The expected development of small modular reactors (SMRs) with smaller size and greater flexibility may make nuclear power more feasible in the future. Should this happen, it would be appropriate to reconsider nuclear power as an option.

FIGURE 15 - EMEA LCOE RANGE BY TECHNOLOGY ($/MWh, H2 2016)



A more recent assessment of the LCOE for key technologies has been produced by Bloomberg New Energy Finance (BNEF, 2016) and is reproduced in Figure 15. The estimates presented suggest that:

- onshore wind is competitive with CCGT technology; and
- UK solar LCOE reduced by 22% on H1 estimates but is still much more expensive than gas or wind.

This raises a question about the implementation of further renewable support beyond 2020 commitments.

Source: Bloomberg New Energy Finance (2016)

3.2.4 ENERGY STORAGE AND INTERCONNECTION

Energy storage and electricity interconnection are not generation technologies but both can help facilitate the integration of variable renewable generation on an electricity system. These are briefly described below:

3.2.4.1 ENERGY STORAGE

Energy storage has the ability to store energy at times it is plentiful for later use when it is scarce. It can be used to absorb surplus renewable generation at times when generation exceeds demand and release it when renewable generation output is low. There are several types of storage including pumped storage, discussed above, battery storage and thermal storage.

The limiting factor with using electrical or pumped storage in conjunction with renewable generation technologies is the scale required to store enough energy for a full day's operation of the electricity system without wind (or strong sunshine). As an example, we can consider the storage capacity required to store the average daily electrical energy requirement of the all-island single electricity market on a windy or sunny day for use the following dark or calm one.This would require a storage capacity equivalent to approximately 60 Turlough Hill pumped storage stations or 14 million Tesla Power Wall[18] version 1 batteries (6 per household) or the batteries in some 4 million electric vehicles. The issue of grid scale energy storage is not an easy one to solve. Storage has many uses over short time scales but current storage technologies cannot economically provide the scale of capacity to operate an electricity system on variable renewable generation and storage alone.

[18] Tesla Powerwall version 1 with 7 kWh capacity.

3.2.4.2 ELECTRICITY INTERCONNECTION

Electricity interconnectors enable the trading of electricity between different systems. When the generation available exceeds demand, some of the surplus can be traded across the interconnectors. Likewise when the output of variable renewable generation falls, electricity can be imported to meet part of the demand. Electricity interconnection is seen as an integral part of the low carbon grids of the future.

Interconnection has some limitations in its potential to support a high level of renewable generation in real time. Firstly, where interconnectors are underwater cables as in the case of Ireland, they are direct current. Direct current, as opposed to alternating current, interconnectors do not automatically support the system in very short timescales in the event of sudden loss of generation[19]. When interconnected by alternating current transmission lines or interconnectors, conventional generating plant on the same system or a neighbouring system is able to respond to these disturbances due to a property known as inertia, and can help to maintain the system within standard. This property is lost with DC interconnectors. The result is that, in order to safeguard system stability, operators set an upper limit on the amount of variable generation that can be running at any one time as a proportion of locally running generating plant. This limits the role of interconnection in integrating renewable generation while these technical barriers remain.

3.3 SUMMARY OF TECHNOLOGY OPTIONS

A summary of the key characteristics of the alternative technology options described above, based on data from the former UK Department of Energy and Climate Change (The Crown Estate; Carbon Capture and Storage Association; Department of Energy and Climate Change, 2013), is presented in table 6 above. We note the following:

- Emission factors are only shown for the fossil-based technologies and are reported at point of generation not full lifecycle emissions. Ranges reflect the different thermal efficiency of plant;
- The levelised cost of energy[20] (LCOE) is based on reported figures taken from the UK Department of Energy and Climate Change (DECC) and depend on assumptions over future fuel costs, carbon costs and learning rates;
- Illustrative potential is taken from a variety of sources – the UCC 80% reduction scenario sees wind and existing hydro as the only renewable sources in the mix in 2050 and gas CCGT and CCS providing the remainder of the capacity.

[19] They can, in principle, be intentionally operated in this way but this is not current practice.
[20] Levelised cost of electricity (LCOE) is the average net present value of the total electricity produced from a generation asset over its lifetime.

4

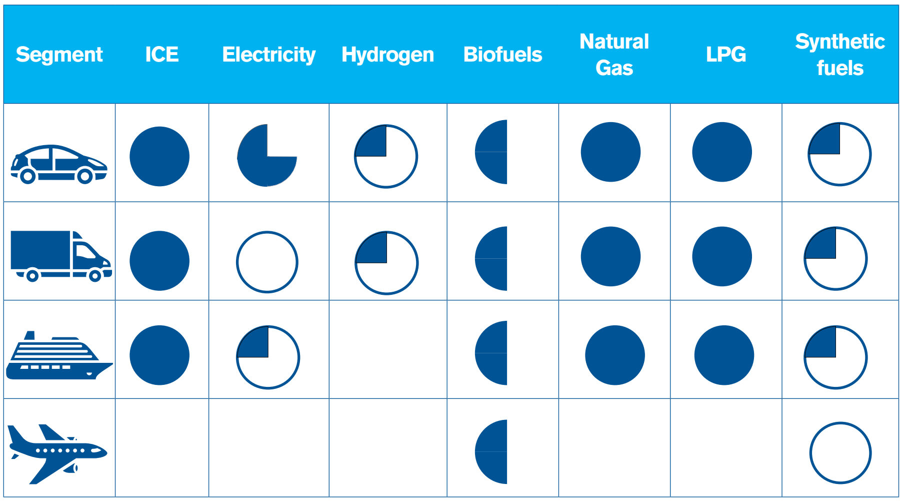
Technology Options For Decarbonisation - Transport

- Emissions from transport accounted for 20% of Ireland's total greenhouse gas emissions of 60 Mt in 2015.
- Transport emissions are a challenge for Ireland. They account for over a quarter of Ireland's Non-ETS emissions and, uniquely, are rapidly growing. This growth is the proximate reason for the projected breach of Ireland's Non-ETS target in 2017/2018 (Environmental Protection Agency, 2017).
- The expected improvements in emissions standards for conventional vehicles will not be enough to arrest this growth. After allowing for these improvements EPA still projects emissions growth of between 13 – 19% from 2013 to 2020 and a further 14% to 2035. Transport would then form 35% of Non-ETS emissions compared to 26% today.
- Current transport sector energy use is almost exclusively (98%) oil-based.
- Today, a new diesel car travelling average mileage will emit 2.9 tCO_2 per annum. With stricter EU emission standards, by 2021, a new diesel will emit 2.2 tCO_2 per annum. This improvement is not sufficient to address the problem.
- Increased take up of electric cars is possible and has been achieved in other markets. An EV will remove 100% of emissions from the Non-ETS and, even with the current generation mix will save 46% in overall emissions.
- The main challenges for electric vehicles are around range and capital cost. However, technological improvements are reducing those barriers (the new Tesla Model 3 is projected to have a range of 350km).
- Private cars are parked most of the time. Traffic modelling has shown that shared transport models can offer significant savings in costs and emissions while dramatically freeing up road space normally occupied by parked vehicles (International Transport Forum, 2015) (International Transport Forum, 2017). A study is already in progress for Dublin. Serious consideration should be given to an early pilot of this approach.
- Long term electric solutions are not yet available for Heavy Good Vehicles. In the short term, the promotion of compressed natural gas (CNG) for HGVs should be considered. This would reduce CO_2 emissions by 25% and also cut other harmful pollutants, such as particulate matter, with positive implications for human health. Biofuels are also a potential solution, though until biofuels that don't affect food production ('second generation' biofuels) are fully developed, they still raise concerns over long-term sustainability.

4.1 INTRODUCTION

Within the energy sector, transport emissions are higher currently than any other segment including power generation and have been rising since 2012, after a period of declining emissions from a peak of 14.4 $MtCO_2$ in 2007. In 2015, total emissions were 11.8 $MtCO_2$ and the EPA's latest projections (Environmental Protection Agency, April 2017) estimate emissions to increase by a further 10% to 12% by 2020. This projected increase is one of the main reasons the EPA expects Ireland's binding non-ETS target to be breached in the next few years.

TABLE 7 – ALTERNATIVE FUELS AND USE ACROSS TRANSPORT SEGMENTS



Range of Suitability: ○ = experimental ● = established

4.2 TECHNOLOGY OPTIONS

The available technology options considered in this report are listed below. There is a wide degree of variation in their state of development and maturity.

- Internal combustion engine vehicles (petrol and diesel);
- Electricity;
- Hydrogen;
- Biofuels;
- Compressed or liquefied natural gas;
- Liquefied petroleum gas (LPG); and
- Synthetic fuels.

These technologies also vary in the modes of transport to which they are currently applicable – road, rail, marine and aviation. This is illustrated in Table 7. In general, the marine and aviation segments have a narrower set of possible alternatives than road transport.

As emissions from international shipping and aviation are beyond the scope of national targets, the focus of the discussion below is on road transport alternatives. However it is worth noting the following two points:

- Aviation and marine transport appear to be dependent on biofuels in order to reduce emissions. As it is expected that the supply of biofuels will be constrained by sustainability criteria, it is likely that the non-biofuel options for road transport will need to be availed of;
- Electrification options are emerging for inland ferries and are in the early stages of development for some aviation applications. Therefore electrification may form part of the low carbon pathway in the longer term.

The various technologies are briefly described below.

4.2.1 DIESEL AND GASOLINE INTERNAL COMBUSTION ENGINE VEHICLES

The majority of the global road transport fleet is based around an internal combustion engine (ICE) fuelled by gasoline or diesel. As the name implies, the combustion process takes place inside the engine itself, with the energy released being used to drive a piston which in turn rotates the crankshaft and ultimately moves the vehicle. The ignition of the fuel in the ICE is either a spark ignition (gasoline) or compression ignition (diesel).

A new diesel car will, on average, emit around 121g CO_2/km. With average annual mileage in Ireland, this is equivalent to annual emissions of 2.9 tCO_2 per annum. A petrol car has similar emissions per kilometre but on average will emit less – 1.8t CO_2 per year partly due to lower annual average mileage. There are further improvements being made in ICE technology as well as increasingly stringent vehicle emissions standards. In a recent study, the International Council for Clean Transportation (ICCT) surveyed the scope for strengthening technology improvement policies for road transport such as vehicle efficiency standards. (International Council on Clean Transportation, 2015). The impact of these is shown in Table 8. It should be noted that these improvements relate to test condition emission standards and the ICCT note that real world driving conditions will increase emissions above these levels by around 35% to 40%.

TABLE 8 - COMPARISON OF EMISSIONS FOR NEW ICE ROAD VEHICLES

	Current	2021		2050	
	Emissions (gCO_2/km)/ Annual average (tCO_2)	Emissions (gCO_2/km)/ Annual average (tCO_2)	Total savings on current fleet ($MtCO_2$)	Emissions (gCO_2/km)/ Annual average (tCO_2)	Total savings on current Irish fleet ($MtCO_2$)
Passenger car (diesel)	121.1/2.87	95/2.25	0.43	50/0.95	1.17
Passenger car (gasoline)	120.5/1.77	95/1.39	0.45	50/0.59	1.24
LGV	162.4/3.43	147/3.11	0.08	75/1.59	0.44
HGV	1,369/21.4	N/A	N/A	685/10.7	N/A

Source: SEAI (2014) Energy in Transport 2014 Report, Cambridge Econometrics (2016), Oil Market Futures: A report for the European Climate Foundation, April

4.2.2
ELECTRICITY

There are several electric vehicle (EV) options that use electricity to a greater or lesser extent in the drivetrain. Of these, conventional hybrids are essentially petrol vehicles with an ICE engine and an electric motor. Due to the fact that they derive all their power from gasoline or diesel, they are excluded from most assessments of the electrification of transport. The three main electric alternatives are:

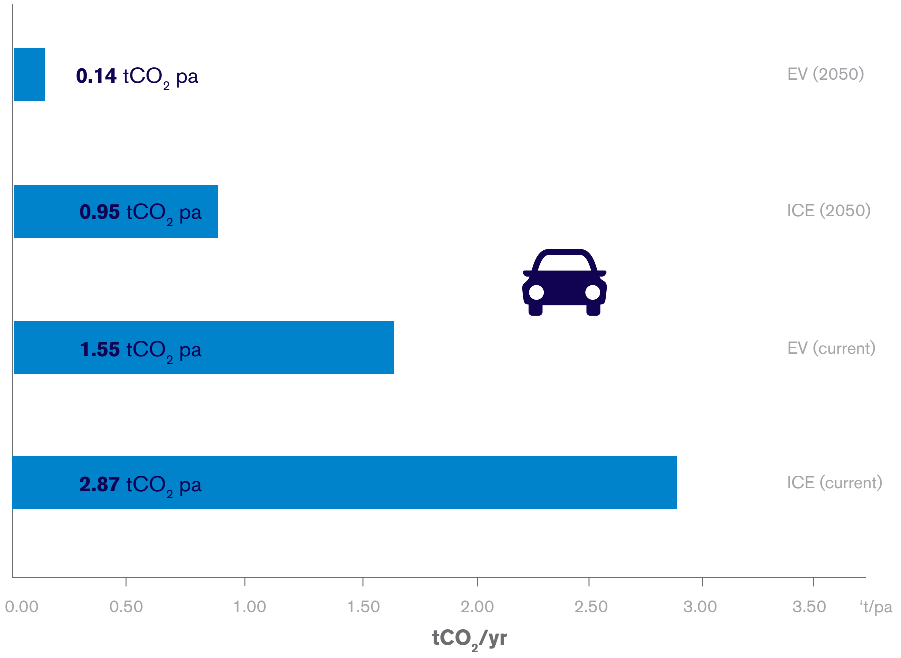
- Battery electric vehicles (BEVs) that are fully electric;
- Plug-in hybrid electric vehicles (PHEVs) which combine electric motors and combustion engines in parallel and are able to connect directly to the grid to charge the battery; and
- Range extender electric vehicles (REEVs) where an auxiliary power unit (generally a combustion engine) can be used to generate electricity to charge the vehicle's battery, but the drivetrain is purely electric.

In 2016, IEA analysis indicated that just over half of the existing EV stock from these three main vehicle types was BEVs, though this varied significantly between countries, largely dependent on the structure of incentives provided for EV take-up. For example, the IEA found that, in Norway, over 80% of EVs are BEVs because they are largely exempt from registration taxes and VAT, whereas in the Netherlands, most new EVs are plug-in hybrids, because there were similar tax reductions for BEVs and PHEVs. (International Energy Authority, 2016)

The emissions of a battery electric vehicle are the indirect emissions of the electricity required to charge the battery. These emissions depend on the carbon intensity of generation and will progressively diminish as electricity decarbonises. In Figure 16, we show the emissions for an equivalent electric vehicle with the current carbon intensity of generation (436 gCO_2/kWh) and the carbon intensity projected by UCC in 2050 (38 gCO_2/kWh).

Even at the current carbon intensity of generation, a fully electric vehicle (with

FIGURE 16 – ANNUAL AVERAGE EMISSIONS COMPARISON (DIESEL ICE AND EV)



Source: IEA (2016), Global EV Outlook 2016: Beyond one million electric cars

an assumed electricity use of 150 Wh/km) has 46% lower emissions than a new conventional ICE car. This is because the energy efficiency of an electric vehicle is much higher than that of an ICE. An average petrol ICE has a tank-to-wheel fuel efficiency of around 22%, compared to 72% for a lithium-ion battery, implying that the electric vehicle would use a third of the energy of an ICE (European Association of Battery Electric Vehicles, 2009).

As decarbonisation of the power sector continues, the savings from BEVs continue to increase. Even with the required improvements in test emission standards for ICEs by 2021 (down to 95 gCO_2/kWh), a diesel car will still emit over 2.2 tCO_2 per annum, and that assumes that the ICE can replicate the fuel efficiency from test conditions in real world driving situations. Even in its assessment, the ICCT notes that real world emissions are generally in the region of 35% to 40% higher than laboratory test levels.

Only if ICEs achieve the most ambitious efficiency improvements (leading to emissions of around 40 gCO_2/kWh in ICCT's assessment) will a diesel car produce less than 1 tCO_2 per annum, and by that time the emissions from EVs are expected to be around a tenth of that (0.1 tCO_2 per annum, see Figure 17).

In a recent study (Transport & Environment, 2015), the additional adverse effect on local air quality was highlighted. It concluded that the majority of new cars that currently met the Euro-6 standards under test conditions, significantly exceeded the threshold levels under real world conditions (see Figure 18).

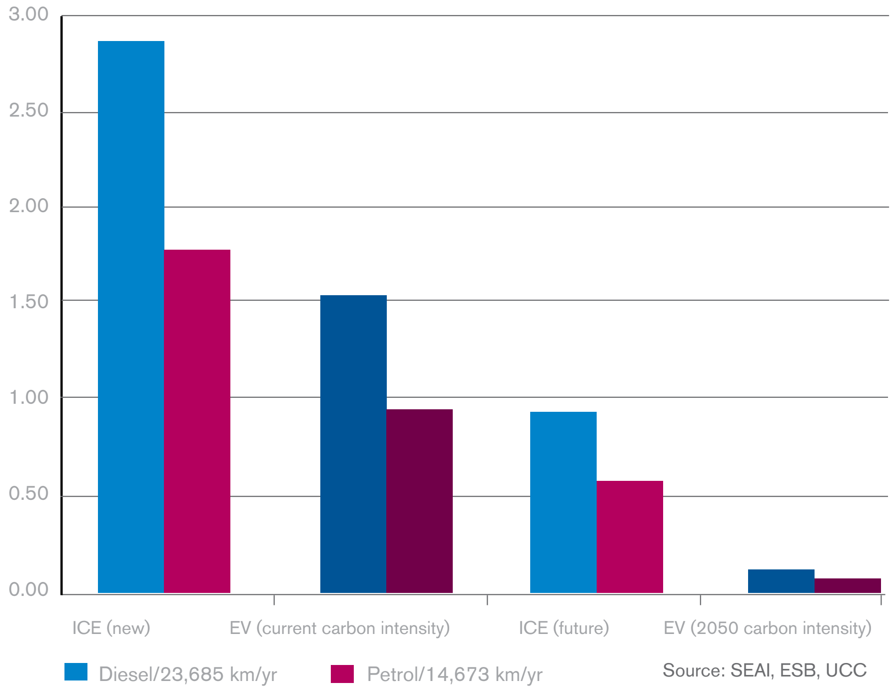
The lower energy requirement of BEVs also translates into lower running costs. Estimates vary depending on the assumed oil and electricity prices, but, on a per km basis, a BEV has operating costs of around 25% of an ICE (SEAI, n.d.). And, as the range improves on BEVs – the new Tesla Model 3 has projected range of up to 350km per charge – the difference in range between BEVs and ICEs will become less important.

Electricity is a proven option for cars; it is still in demonstration for buses and in development for heavy goods vehicles. Therefore the roadmap in Chapter 6 only considers electricity as an option to replace cars. However it should be noted that BEV HGVs are in development and Sweden has launched a pilot of hybrid HGVs that use electricity when on the motorway, powered from overhead conductors.

4.2.3
HYDROGEN VEHICLES

Hydrogen vehicles are a separate class of electric vehicles that use hydrogen as the on-board fuel. A fuel cell electric vehicle (FCEV), combines the hydrogen with oxygen in an electrochemical reaction to produce electricity to drive a motor. The motor and drive train are the same as in an electric vehicle. In theory, FCEVs can combine the benefits of BEVs (zero emissions) with the range and refuelling convenience of conventional ICEs. Passenger FCEVs have a range of around 340 miles with similar refuelling times to an ICE car. Vans and buses can also use the FCEV technology. For example, Transport for London runs a fleet of 8 hydrogen fuelled buses, the first of which was introduced in 2011.
However, there are numerous challenges for the large scale adoption of hydrogen-based transport solutions, the most salient of which are:

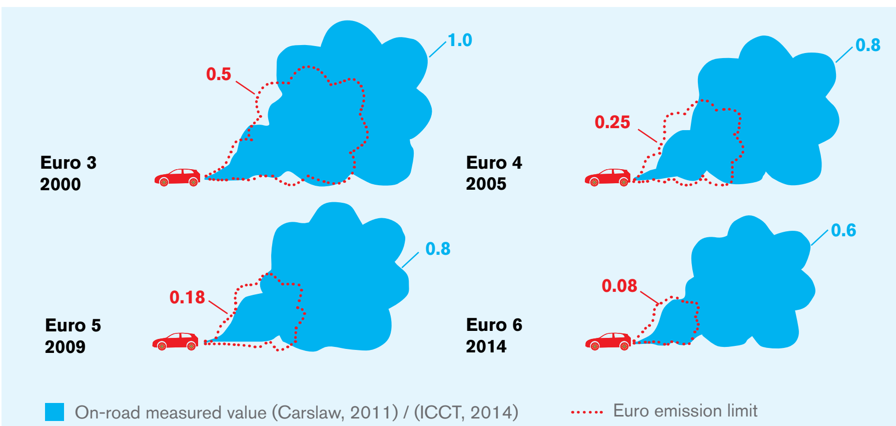
FIGURE 17 – COMPARISON OF EMISSIONS FROM ICEs AND EVs (tCO_2/yr)



Source: SEAI, ESB, UCC

- cost of vehicles – the first generation FCEVs, of which there are only three at present (produced by Toyota, Hyundai and Honda) are being marketed in the UK at around £60,000, around twice the cost of a BEV such as the BMW i3;
- life of the fuel cell – there are reports of short operating lives with current fuel cell technology (Centre for Climate and Energy Solutions, 2011).
- operating costs – whereas BEVs and PHEVs have running costs around a third of a conventional ICE (depending on the oil price assumed), it is estimated that FCEVs have a similar operating cost to conventional cars;
- access to refuelling stations – hydrogen vehicle deployment is concentrated in Japan, California and Germany, where there are a network of refuelling stations. Large scale deployment in a market would require the establishment of a refuelling infrastructure. In GB at present there are only eight public hydrogen filling stations, and there are none in Ireland; and
- supplies of sustainable hydrogen –

FIGURE 18: LABORATORY AND ACTUAL ROAD EMISSIONS OF NITROGEN OXIDE COMPARED (NO_x IN g/km)



Source: International Council on Clean Transportation (2014) currently most hydrogen is produced from hydrocarbons, a process that emits carbon dioxide. This is because the alternative of producing hydrogen by the electrolysis of water is currently inefficient. It has been suggested that in countries like Ireland with large wind resources, hydrogen can be produced from excess wind generation. However there will be other competing uses for this low cost electricity. It is noteworthy that in markets with negative electricity prices at times of high wind generation, hydrogen production has not emerged to date as the optimal use; and

- transmission and distribution of Hydrogen – Hydrogen can be transported by tanker in its liquid state or by pipe as a gas. Transport of hydrogen in pipelines is more challenging than natural gas. The H2 molecule is very small – a hundred times smaller than a methane molecule - and may leak or infiltrate into the crystal structure of pipeline materials, embrittling them (Takahashi, n.d.).

Some of the above questions around Hydrogen are explored in more detail in Chapter 5. Given the relative maturity and ongoing price reductions amongst electric vehicles, as well as the challenges listed above, hydrogen vehicles have not been considered in the low carbon roadmap for road transport.

4.2.4 LIQUID BIOFUELS

Liquid biofuels include biodiesel, bioethanol and bio-jet fuels that can be used alone or blended with conventional liquid fuels for use in a combustion engine. The biofuels can be produced from a range of feedstocks with first generation biofuels relying on energy crops such as sugar beet, maize, vegetable oils, etc., and more advanced (second and third generation biofuels) being derived from non-food crops such as lignocellulosic biomass, woody crops or from animal by-products or from waste or algae.

Biofuels can be used exclusively, or blended with gasoline and diesel. In general, most consumption is through blending of biofuels. 167 million litres of biofuels were used for transport in Ireland in 2014 (Sustainable Energy Authority of Ireland, 2016), largely incentivised through the Biofuels Obligation Scheme (BOS).

As part of the Renewable Electricity Directive each EU Member State is obliged (through Article 3, Item 4 of the Directive) to ensure that the share of energy from renewable sources in all forms of transport in 2020 is at least 10% of the final consumption of energy in transport. As part of its approach to meeting this target, Ireland has implemented the Biofuels Obligation Scheme (BOS) which places an obligation on suppliers of mineral oil to ensure that a fixed proportion of the motor fuels they place on the market are produced from renewable sources. Since 1 January 2017, the obligation is for 8.695% by volume (Department of Communications, Climate Action & Environment, 2015).

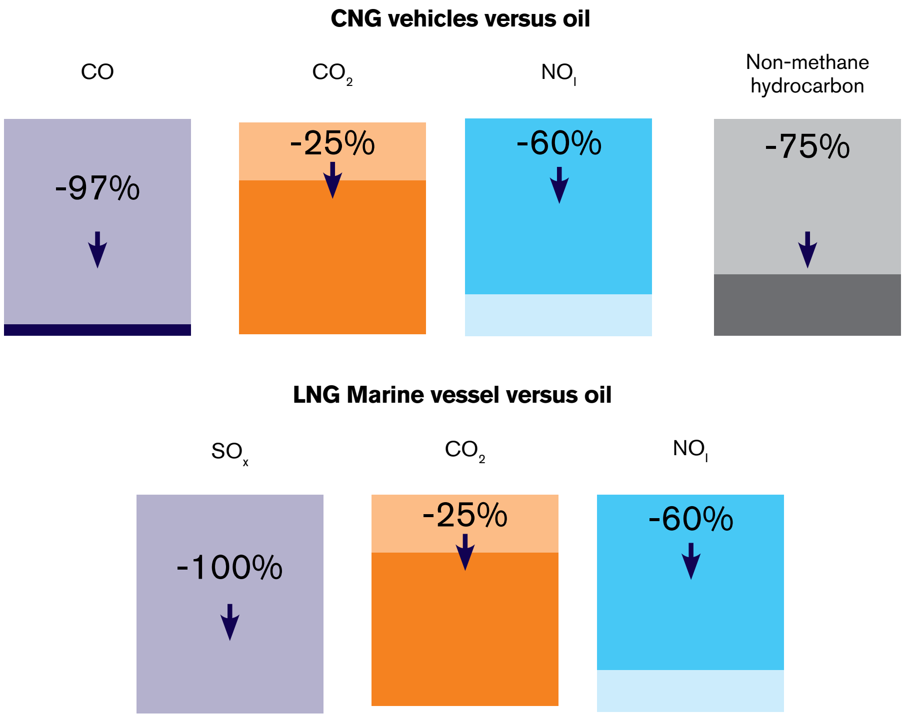
Many of the concerns over expanding the use of biofuels have been linked to the sustainability of the input feedstocks used in the process. In particular, the more established, first generation feedstocks typically occur on land that would otherwise be used for other agricultural products (ie. food or feed) and may therefore lead to further indirect land use change (i.e. because the food production is displaced to previous non-crop land). To mitigate this, through an amendment to the Directive (European Commission, 2015), a limit of 7% of the 10% target has been placed on land-based crops, and the contribution of second-generation feedstocks (which are not displacing existing crop production) is double-counted in the contribution to the target to further encourage their use.

4.2.5 NATURAL GAS

Natural gas vehicles run on either Compressed Natural Gas (CNG) or Liquefied Natural Gas (LNG). Bio-methane can also be used in these vehicles to lower the effective (non-renewable) carbon content of the fuel. Natural gas is used in road and marine transport. In road transport it is used in the light and heavy goods segments of the market.

Natural gas vehicles can provide emission benefits versus oil-based transport. As shown in Figure 19, natural gas vehicles (in both road and marine settings) can reduce CO_2 emissions by around 25% (up to 17% allowing for the biofuel obligation scheme) compared to a diesel vehicle and can also

FIGURE 19 – COMPARISON OF EMISSIONS ICE VERSUS NATURAL GAS



Source: Gas Naturally

lead to significant reductions in other air pollutants from oil-based fuels, including SO_x, NO_x and particulate matter. Further carbon reductions could be achieved if natural gas were substituted with bio-methane or synthesis gas (syngas).

While compressed natural gas is used in passenger vehicles, it has not been a major success due to space considerations and because electric vehicles are seen as the key technology. However, in heavy goods vehicles, the use of LNG is increasing in Europe following its widespread use in the United States associated with the growing network of filling stations supported by the blue highway initiative.

4.2.6
LIQUEFIED PETROLEUM GAS (LPG)

LPG is composed of propane and butane gas. It has a lower carbon to hydrogen ratio than other hydrocarbons, which means it generates less CO_2 per unit of energy produced. A 2009 study (Atlantic Consulting, 2009) showed that the LPG had an automotive carbon footprint broadly equivalent to that of diesel and lower (by around 11% tank to wheel) than gasoline. The main benefit relative to diesel is linked to NOx emissions which can be five times lower than the equivalent diesel engine and particulates, where one diesel vehicle may emit up to 120 times the fine particulates of an LPG car. (Drivelpg, 2017).

4.2.7
SYNTHETIC FUELS

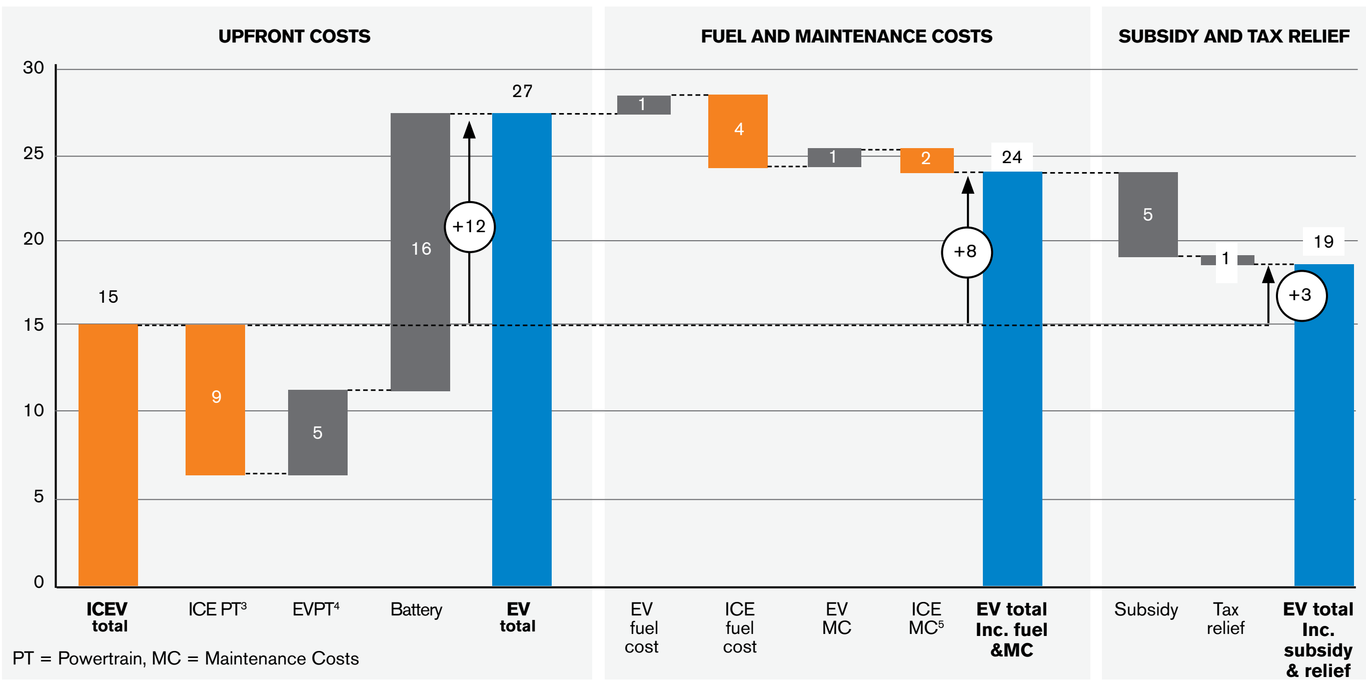
Synthetic diesel and gasoline can be obtained via the production of syngas derived from coal or natural gas or from solid biomass or biogas or from the methanation of hydrogen produced by electrolysis. Gas to Liquid, Coal to Liquid and Biomass to Liquid options could be pursued. Particularly for Biomass to Liquid (European Biofuels Technology Platform, 2016), development is at early stages and even for gas to liquid and coal to liquid, production capacity is centred mainly on the US, China and the Middle East.

It should be noted that these synthetic fuels would still use the conventional ICE. The main difference would be in the overall lifecycle emissions associated with their derivation (Ying, 2014).

4.2.8
COST OF BATTERY EVS

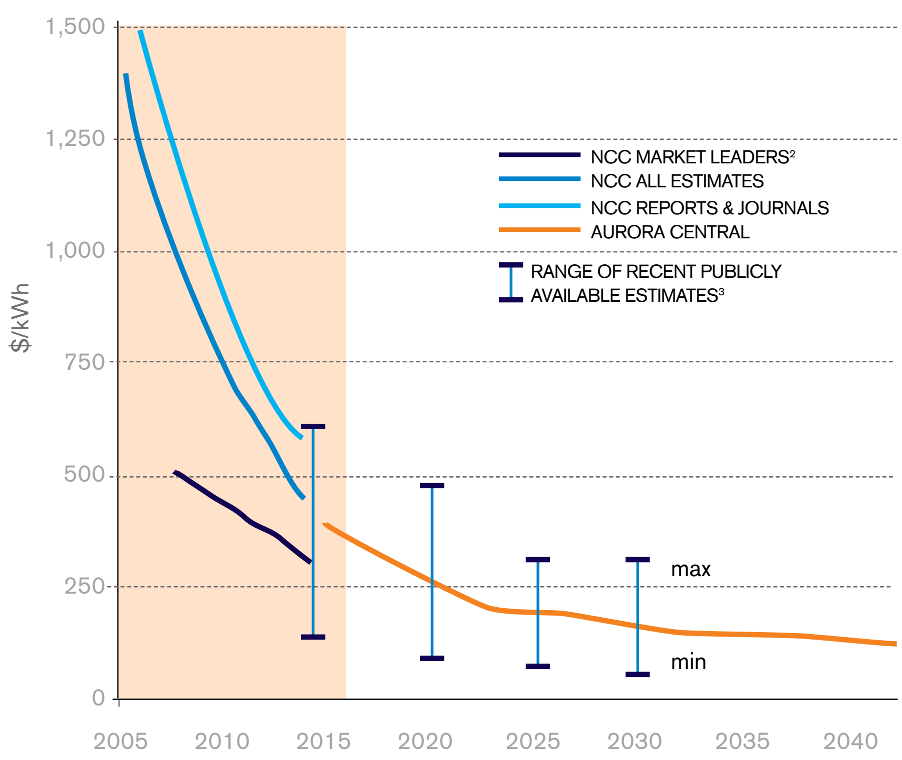
At present, BEVs are more expensive than conventional ICE vehicles, despite having lower fuel and maintenance costs and even when subsidy payments and tax relief is taken into consideration (as shown in Figure 20). The major driver of this higher cost is the upfront capital cost and, in particular, the battery cost. However, as shown in Figure 21, there is an expectation that battery costs will fall in the future as technical improvements occur and market growth enables manufacturers to benefit from economies of scale.

FIGURE 20 – COMPARATIVE COST OF EVs AND ICE VEHICLES (k£)



Source: Aurora Energy Research (2016)

FIGURE 21 - PROJECTED FALL IN BATTERY COSTS FOR EVS



Source: Aurora Energy Research (2016)

4.3
SUMMARY OF TECHNOLOGY OPTIONS

TABLE 9 – COMPARISON OF TECHNOLOGY OPTIONS

Fuel option	Potential coverage	Commercial feasibility	Timescale	Emissions	Limitations
ICE	All road transport	High	Current	121gCO_2/km (current, new)	Very inefficient. The low carbon pathway is limited
Electricity	Passenger vehicles, trains, buses	Medium	Current	low carbon emissions; no direct emissions; noise pollution	Cost; charging infrastructure access; time to charge; range; lack of awareness; confidence in producers
FCEVs	All road transport	Very Low	2030+	Zero from vehicle. 76g/km from H2 production[21]	Hydrogen networks; hydrogen production; vehicle cost
Biofuels	All road transport, aviation	Medium	Current	Dependant on land use. Treated as zero	Sustainability concerns arising from land use
Natural gas	All road transport	Medium	Current	25% reduction in CO_2 emissions; low air pollutants	The low carbon pathway is limited

[21] (Pike, 2012) 'Calculating Electric Drive Greenhouse Gas Emissions', ICCT

4.4
SHARED TRANSPORT MODELS

Recent work on shared transport models suggests that major emissions savings and efficiency gains may be available by these means. The International Transport Forum published the results of a traffic modelling study using real world data from Lisbon where a combination of taxis and taxibuses summoned by customers from their mobile phones complemented the existing metro. They found that this model could reduce emissions by a third, lower costs by half and free up 95% of the road space currently occupied by parked vehicles while eliminating congestion (International Transport Forum, 2016).
Studies are currently underway for Helsinki and Dublin. This could be an important direction for the future independent of vehicle type.

4.5
CONCLUSION

Any credible decarbonisation plan must bring about a halt and reversal in emissions growth in transport. This radical improvement will require a move away from the internal combustion engine (diesel and gasoline) as these are fundamentally inefficient.

Electric vehicles are emerging as the preferred option for decarbonising light vehicle passenger transport due to their higher efficiency, significantly lower emissions (of both carbon dioxide and local air quality pollutants) and avoidance of the sustainability considerations associated with the use of biofuels. Electrification is also being pursued for public transport solutions (i.e. buses) within urban centres, though this accounts for a much lower proportion of total transport emissions.

The main challenges for meeting ambitious EV roll-out targets are in terms of the cost and range of the vehicles and the charging infrastructure. Any roadmap will need to have specific actions to address these issues.

In other areas of transport emissions, electrification options are either unsuitable (e.g. aviation) or immature (e.g. HGVs). In these areas, there will have to be a role for other emission reduction policies that may range from promotion of other fuels (biofuels or natural gas) to more stringent vehicle efficiency standards.

5

Technology Options For Decarbonisation - Heat

- Heat represents approximately 21% of Ireland's total greenhouse gas emissions which were just under 60 Mt in 2015. Of this, heat within the Non-ETS sector is about 9.3 Mt or 15.5% of total emissions.
- Partly due to the large rural population, oil is the major fuel for heating in Ireland, unlike other EU member states.
- Oil has a large emissions footprint and needs to be progressively replaced with low carbon technologies for Ireland to meet its climate targets.
- Natural gas is likely to continue to be a major heating fuel to 2050 in an 80% CO_2 reduction scenario. As, in other homes, efficiency improvements coming from deep retrofit of the building fabric in houses heated by gas will be necessary to reach the targets.
- Low carbon gases - for example biomethane – can substitute for natural gas and will play an important role. Similar to biomass, the potential supply of low carbon gases is likely to be limited by the availability of sustainable feedstock and by cost. As a result, the available supply may in future need to be directed towards applications where there are fewer alternatives. Examples are high temperature process heat in industry and heavy transport.
- 'Deep retrofit' with electric heat pumps, insulation and airtightness is the leading candidate for a low carbon replacement of oil-fired heating in homes. Biomass will also play a role. Biomass for housing is likely to be confined to rural areas because of the need for space to store the fuel and emerging concerns about the health effects of fine particulate matter emitted by vehicles and wood burning in urban areas.
- It is important that a detailed heat map is compiled for Ireland to provide the basis for analysis to determine the least cost low carbon heating option for each area.
- Heat networks are likely to emerge from this as a solution for urban centres and rural towns with sufficient heat density – particularly for new developments or re-developed areas.
- Barriers in the way of decarbonising heating include the low price of oil and gas, the higher upfront capital cost of heat pumps, certain EU policies that work against electrification, a lack of customer familiarity and, for heat networks, the absence of an institutional framework.

5.1
INTRODUCTION

Emissions of CO_2 due to the production of heat were 12.8 Mt in 2015 [22] . This is 21% of Ireland's greenhouse gas emissions and just under 35% of GHG emissions from energy. These emissions are growing. Emissions in 2015 were 5.7% higher than the previous year (Sustainable Energy Authority of Ireland, 2016).

Heat demand can be classed under two broad categories: demand for space heating and hot water and heat for industrial processes. Space and water heating operate at lower temperatures – generally below 60°C. While they apply to all buildings, they are the principal heat load in residential and commercial buildings. Higher temperature heat (process heat) is used in industry for industrial processes such as milk evaporation, cement kilns, chemical reactors and the heat treatment of metals. High temperature heat requires fuels that burn at high temperature or specialist electrical energy processes. Space and water heating can use heat recovered from the environment or waste heat left over from high temperature processes or indeed from space cooling.

Heat demand in Ireland is unusual within the EU. Approximately 70% of heat demand is for space and water heating which is relatively high. Also the use of fuels is atypical. Oil is the most significant heating fuel at 35% of the total and as much as 69% for rural homes. The gas share is lower than elsewhere and, while some schemes are being developed, district heating is negligible in Ireland compared to between 10% and 40% in other member states (Central Statistics Office, 2014) (European Commission, 2016b). This comparison is illustrated in figure 22. The quantity and type of heat use by sector is shown in Table 10.

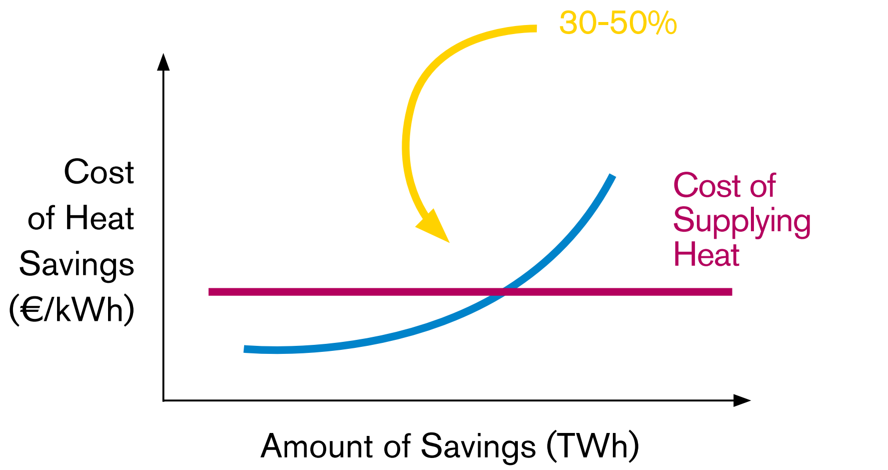
This chapter will mainly focus on space and water heating. This is the majority of heat demand and also where the initial focus of mitigation is likely to be because of the diversity of industrial processes and the greater difficulty in switching to low carbon. The technologies will be explained for the residential sector and then extended to the services or commercial sector. Finally the emerging technologies for high temperature process heat in industry will be outlined.

Table 10 - Sectors and Heat Demand (ktoe)

Segment	Temperature	
	Low <= 60°C	High > 60°C
Residential	2,079	-
Commercial	753	-
Industrial	-	1,436

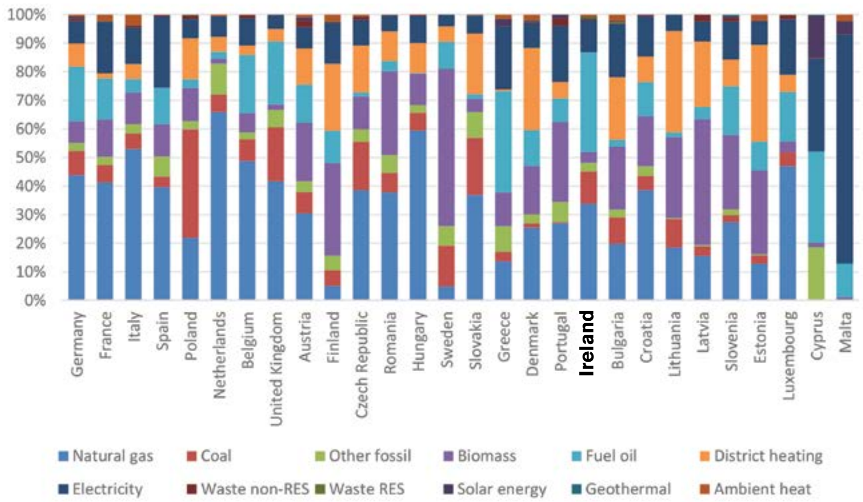
Source: Figures from SEAI

FIGURE 23 - HOW MUCH SHOULD WE SAVE?



Source: EU Stratego project

FIGURE 22 – FINAL ENERGY CONSUMPTION FOR HEATING AND COOLING, EU MEMBER STATES, 2012



Source: European commission (2016)

Transitioning to low carbon space and water heating: an overview

In transport, there is the option to replace the entire system – the vehicle - with a more efficient one. In space heating the heating appliance can be replaced with a better model but a key part of the heating system – the building fabric - remains. This means that there are broadly three considerations when reducing the emissions of a heating system:

- The thermal performance of the building fabric: insulation and airtightness
- The performance of the heating system: heating appliance, controls and heat distribution
- The carbon content of any external - non-renewable - energy and whether there is a long term path to low carbon

For example in an oil heated home, we need to consider the performance of the fabric of the home, then the performance of the boiler, radiators and controls. Finally there is the carbon content of the external energy – the heating oil - coming in to the home and whether there is a feasible low carbon pathway for this oil supply.

[22] Includes ETS and Non-ETS. Heat in the Non-ETS sector is about 9.3 Mt or 15.5% of total GHG.

Energy efficiency retrofit (Superhomes scheme, oil to heat pump COP=3)					
(€)	Building energy rating (BER)	Heat required (kWth p.a.)	Capital cost	Operating cost1 (€ per annum)	Emissions1 (tCO2 per annum)
Start	D2	18,000	-	2,000	5.8
Finish	A3	-	28,000	470	1.4
Saving	-	-	-	1,530	4.4

Source: SEAI (2014b), Tipperary Energy Agency

Two observations can be made about this:

- improvements to the fabric of the home will reduce energy usage and any carbon emissions but it is unlikely to be economical to bring energy usage to zero – especially for an existing building.
- While there is some net energy use in the building, it can never get to low carbon if the energy source has a carbon content and cannot be economically migrated to low carbon

Reducing the heat demand of a building by improving the efficiency of the building fabric is a critical first step. Beyond a certain point (estimated as a 30-50% reduction in heat demand), it becomes more economic to replace the heating appliance and external energy source with a low carbon source rather than to reduce heat demand any further (see figure 23.) This second step – a low carbon external energy source - is also essential for reducing emissions towards zero.

The next section will look at technology options for space and water heating along these three themes of fabric, heat system and the present and future carbon content of the external energy source. These are addressed in the order in which they are generally implemented.

5.2 TECHNOLOGY OPTIONS : IMPROVING THE THERMAL PERFORMANCE OF AN EXISTING BUILDING

One way of reducing heat-related emissions is to reduce the heat demand of the building stock through energy efficiency measures that improve insulation and increase air-tightness. If less energy is required to heat homes, then the emissions will be lower whatever the primary heating fuel used. According to SEAI's Residential Energy Roadmap (Sustainable Energy Authority of Ireland, 2010b), a house built today uses around one-third of the heating energy of an average existing dwelling. This reflects tighter building regulations providing for, among other things, improvements in building fabric standards such as loft and cavity wall insulation, double glazing, improved doors and overall enhanced airtightness. In addition, heating appliances and controls must be of higher efficiency and a minimum level of renewable energy must be used in the building (Department of Housing and Local Government, 2011).

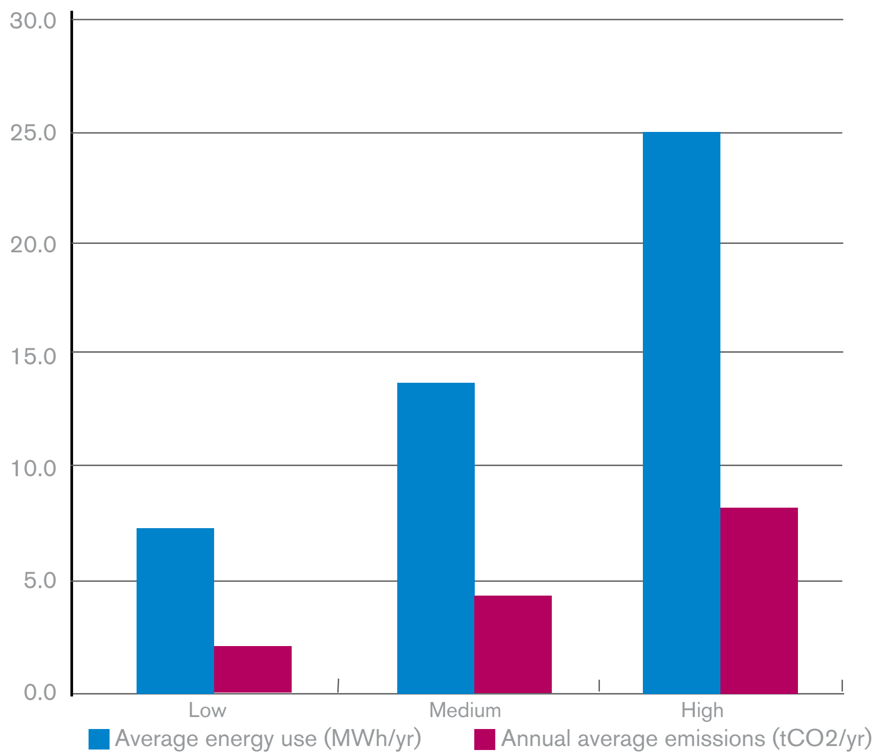
For example, figure 24 shows how the average energy use and the emissions of an average oil household vary depending whether the energy demand is low (i.e. energy efficiency performance is high), medium, or high. Low energy demand households, however, only make up around 10% of the current housing stock (gas and oil), a major reduction in emissions from heating through energy efficiency would require a comprehensive retrofit of almost the complete housing stock in Ireland.

Deep retrofit schemes are available (e.g. the Superhomes scheme offered by Tipperary Energy Agency that looks to raise the Building Energy Rating (BER) from D2 to A2/3). Such schemes include measures to improve insulation and air tightness. As a result of improved airtightness, ventilation is provided to ensure air quality. Above, indicative figures for operating costs and emissions for a 3 Bed Semi-D house are shown with an illustrative capital cost based on the experience within the Superhomes programme. The change in building energy rating from D2 to A3 is indicative of the improved fabric performance. In the Superhomes scheme the heating appliance is replaced with a heat pump and this cost is included in the table. In this way, all three factors are addressed, improved building performance, low carbon heat source and external energy supply that has a migration route to low carbon. The cost and benefit of these changes varies depending on the size of the property and the existing heating technology.

5.3 TECHNOLOGY OPTIONS: CHANGING THE HEATING APPLIANCE

Most heating and hot water requirements are provided through a central heating system where a hot water boiler is connected to pipes and radiators to deliver hot water and heat. The boiler may be a regular boiler (i.e. it provides hot water when programmed to do so and stores it in a hot water cylinder) or combi-boiler (i.e. it produces hot water only when needed and removes the need for a hot water storage tank). Regular boilers are more efficient than combi-boilers in generating hot water, but will lose some heat in storage, so for some households combi-boilers may be more efficient to use.

FIGURE 24 - COMPARISON OF ENERGY EFFICIENCY ACROSS OIL-FIRED HOUSEHOLDS (MWh/yr)

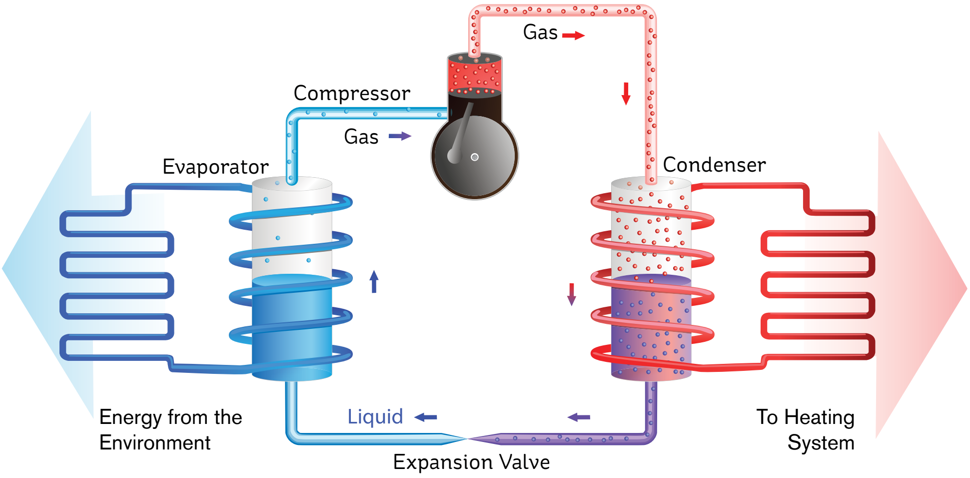


Source: SEAI

Boilers can operate off a range of fuels – gas, oil, LPG or biomass – and differ mainly in cost and carbon emissions depending on the fuel used. Where there is a hot water cylinder, it may have an electric immersion element fitted as back up for water heating.

The costs for a range of heating appliances of different kinds – boilers and others – are all summarised below for a medium-size house with a BER in the A-B range (AB-Medium) with an annual heat demand of 7,130kWth. This heat demand is much lower than average heat demand. It reflects a newly built home required to comply with current building regulations.

FIGURE 25 – HOW A HEAT PUMP WORKS



5.3.1 GAS

Natural gas (new home, central heating and hot water) excludes the cost of gas connection)						
Efficiency	**Heat output (kW_{th}) output**	**Capital cost (€)**	**Annual operating cost (€)**	**LCOE (€/MWh)**	**Average lifetime (years)**	**Emissions (tCO_2 per annum)**
90%	7,130	1,700	703	134	15	1.60

Source: ESB analysis

5.3.2 OIL

Oil (new home, central heating and hot water)						
Efficiency	**Heat output (kW_{th}) output**	**Capital cost (€)**	**Annual operating cost (€)**	**LCOE (€/MWh)**	**Average lifetime (years)**	**Emissions (tCO_2 per annum)**
90%	7,130	2,000	784	135	15	2.04

5.3.3 ELECTRICITY

Direct Electric Heating

In Ireland and GB, electric heating uses storage heaters for space heating and immersion heaters for hot water. (In some countries in Europe 'instant' direct electric heating is used for space heating.) Storage heaters heat up overnight, using cheaper off-peak electricity and release the heat during the day. It is common in apartments and rented accommodation and is often perceived to be one of the more expensive forms of home heating, especially in older systems where storage heaters were harder to control than radiator-based systems.

New electric boilers with high energy efficiency are now emerging that connect to a wet central heating system in the same way as described for the previous section. An indicative cost, based on a small, low demand domestic household, is presented above. This is derived from an alternative set of assumptions than the natural gas and oil boiler figures.

Storage Heating

Storage heaters store energy during periods of low demand and release heat when needed. Modern storage heaters use sophisticated control systems that can better match heat provision with the requirements of the home. They do not deliver water heating. The figures below are for a 3 bedroom semi-detached house and assume that 6 Glen Dimplex Quantum units are installed and operate on a night rate tariff (of 9 c/kWh).

Heat Pumps

Heat pumps extract heat from the environment and upgrade this to a higher temperature to provide heat via a refrigeration cycle. As the environment is ultimately heated by the sun (or sometimes geothermal energy), any heat extracted from the environment is renewable. Most models extract heat from the air (air source heat pumps - ASHPs) and others extract it from the ground (ground source heat pumps - GSHPs). Some heat pumps used in commercial buildings extract heat from ground water or a body of water such as a lake or canal (water source heat pumps).

How a Heat Pump Works

Heat pumps extract heat from the source at low temperature (air source heat pumps can operate in temperatures as low as -15 degrees C) into a refrigerant circuit. The refrigerant evaporates, absorbing heat from the source. The refrigerant is then compressed, returning it to the liquid state. This causes the latent heat of evaporation to be rejected at a higher temperature where it is transferred to the water in the central heating and hot water circuits of the home.

Because an electric motor drives the compressor, a heat pump requires electrical energy to operate. This energy is small compared to the renewable heat extracted from the environment. This ratio of heat produced by the heat pump to the electricity

Electricity (new home, direct electric central heating boiler and hot water)						
Efficiency (%)	**Heat output (kW_{th})**	**Capital cost (€)**	**Annual operating cost (€)**	**LCOE (€/MWh)**	**Average lifetime (years)**	**Emissions (tCO_2 per annum)**
100%	6,550	1,760	1,307	214	15	2.86

Source: SEAI (2015a)

Electricity (storage heating)						
Efficiency (%)	**Heat output (kW_{th})**	**Capital cost (€)**	**Annual operating cost (€)**	**LCOE (€/MWh)**	**Average lifetime (years)**	**Emissions (tCO_2 per annum)**
100%	6,550	4,050	640	139	15	2.86

Source: ESB analysis

used is known as the coefficient of performance (CoP). A heat pump with a CoP of three will produce three kWh of heat for every kWh of electricity. Of the three kWh of heat, one will be from the electrical input and two will be renewable heat from the environment. In current domestic ASHPs, the CoP is reported as being in the range 2.5 – 4.7, dependent on conditions and building design/ quality, with an average CoP of 3.0. There is a similar range for GSHPs.

Heat pumps work much more efficiently when there is a low temperature difference between the heat source and the heat sink. This means that the hot water circuit and radiators run at a lower temperature than fossil fuel systems. This would tend to require radiators that are larger (or are fan assisted) or underfloor heating in order to transfer the heat.

The design and build quality of a new home or where a heat pump is installed as part of a deep retrofit (recommended) ensures that the heat loss rate is minimised, tending to counteract this effect. Thus, heat pumps are operated to maintain a constant temperature in a home with a low heat loss rate rather than a scenario whereby a central heating boiler is operated infrequently to output high temperature water to heat a home with a high heat loss rate.

Air and Ground Source Heat Pumps (new home, central heating and hot water)						
Efficiency	**Heat output (kW_{th})**	**Capital cost (€)**	**Annual operating cost (€)**	**LCOE (€/kW_{th})**	**Average lifetime (years)**	**Emissions (tCO_2 per annum)[1]**
300%	7,130	4,850	517	130	20	1.04

Note:1 Based on current generation carbon instensity of 437 gCO_2/kWh

Source: ESB analysis

5.3.4 SOLAR THERMAL

A solar thermal system uses solar panels (collectors) fitted to the roof which collect heat from the sun and use it to heat up water (possibly via a thermal fluid) which is stored in a hot water tank. They are generally not used for space heating as the potential contribution to heat demand is not considered worthwhile given the seasonal nature of space heating when the contribution from solar is limited. A boiler or immersion heater is often used in conjunction with a solar thermal system as a back-up to ensure water can reach the required temperature for safety or comfort purposes. There may be a need to increase the size of the existing hot water tank to increase storage capacity or to install one if the current heating system uses a combi boiler. An indicative cost, based on a small, low demand domestic household, is presented here.

Solar thermal (indicative cost for small new home)						
Efficiency	**Heat output (kWth)**	**Capital cost (€)**	**Annual operating cost (€)**	**LCOE (€/kW_{th})**	**Average lifetime (years)**	**Emissions (tCO_2 per annum)**
-	1,820	5,400	66	307	20	-

Source: SEAI (2015a)

5.3.5 BIOMASS BOILERS

Biomass boilers are central heating boilers that run on logs, pellets or wood chips. Most biomass boilers have automatic feeding systems that replenish the boiler with wood pellets. Installing a biomass boiler may require additional space for the feeder, flue and for additional fuel storage. Building and local emissions regulations – especially concerning particulate matter – may be barriers to expansion of biomass heating in built up areas.

Biomass boiler (larger new home, central heating and hot water)						
Efficiency	**Heat output (kW_{th})**	**Capital cost (€)**	**Annual operating cost[1] (€)**	**LCOE (€/kW_{th})**	**Average lifetime (years)**	**Emissions (tCO_2 per annum)**
85%	8,040	12,000	481-575	179 - 191	20	-

Note:1 The operating cost is based on an assumed range for wood chips and pellets of between 35 and 40 €/MWh

Note:2 Biomass is counted as zero emissions. Any net GHG impact appears under land use and forestry.

Source: SEAI (2015a)

5.4 SUMMARY OF TECHNOLOGY OPTIONS FOR CHANGING THE HEATING APPLIANCE

5.4.1 RESIDENTIAL

The technology options of the various heat sources are summarised in Table 11 below. We note the following:

- The natural gas boiler has the lowest capital cost, about half that of a heat pump.
- Biomass has the highest capital cost. Heat pumps have the second highest and higher than gas or oil
- Heat pumps have lower operating costs than gas or oil, though this advantage is marginal at current fuel prices
- The levelised costs of heat energy for heat pumps, gas boilers and oil boilers are very close to each other at current fuel prices. Heat pumps are marginally lowest.
- Heat pumps have significantly lower emissions than natural gas even with today's carbon intensity of electricity

In reality, the economics in a house depend on the heat demand and efficiency of its fabric (particularly whether new-build or existing retrofit). The figures presented in Table 11 refer to high energy efficiency or new build properties. The comparison of carbon emissions in a more typical residential dwelling is provided in Figure 26.

Some implications:

- All of the low or zero carbon options have a higher upfront cost. This will affect the decision to adopt the technology when compared using a payback period analysis (i.e. the number of years of operation that is required for annual operating cost savings to repay the higher upfront capital expenditure). For example, we estimate that the payback period for a heat pump - the time it takes for the annual operating cost savings to offset higher capital costs of the technology - is around 9 years when compared with an oil or gas boiler.

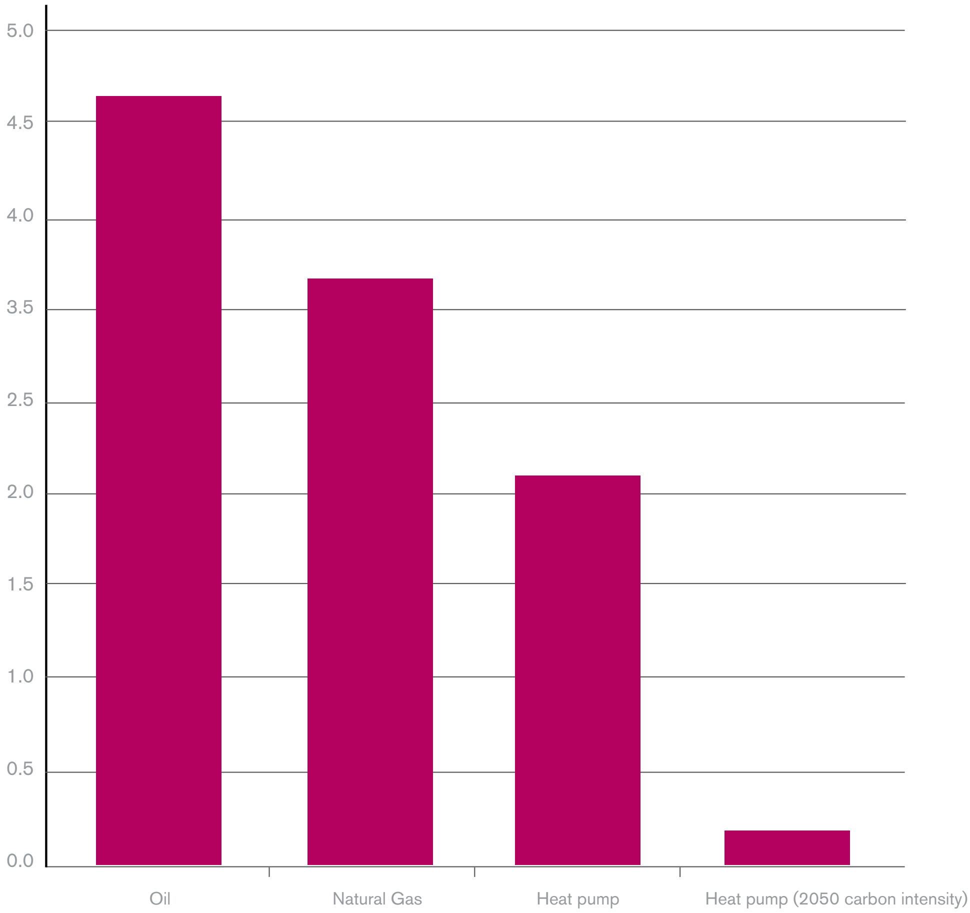
- In the current environment, with low fossil fuel prices, the payback periods are extending as the operational savings from the heat pump are eroding, making it harder to encourage conversion amongst households.

EMISSIONS COMPARED FOR A LARGE DOMESTIC HOUSE

Here, we compare the emissions from the different heat sources for a large domestic house with moderate energy demand of 14.5 MWh/yr. This is the predominant type of existing house for both oil and gas-fired heating in Ireland (totalling around 775,000 houses) and is used in Figure 26.

- The emissions when using a heat pump with a coefficient of performance of 3, at 2.1 tCO_2 per annum, are less than half those of a house currently heated by oil (4.7 tCO_2) and over 40% lower than the same house heated by gas (3.7 tCO_2). This is at the current carbon intensity of generation.
- If all these houses were converted to use heat pumps, annual carbon savings would be 1.75 $MtCO_2$ or around 20% of total domestic heat emissions at current carbon intensities. Because of its operating characteristics, we anticipate the heat pump installation would be accompanied by a deep retrofit of the property.
- Savings would increase thereafter as electricity decarbonises. Even if there are no further improvements in heat pump technology, with the anticipated 2050 generation mix, the equivalent emissions would be less than a tenth of today's level or 0.2 tCO_2.

FIGURE 26 - ANNUAL EMISSIONS OF AN AVERAGE HOUSEHOLD BY HEAT TECHNOLOGY (tCO_2e/yr)



ESB Analysis based on SEAI data

TABLE 11 – COMPARISON OF TECHNOLOGY OPTIONS (RESIDENTIAL, HIGH ENERGY EFFICIENCY)

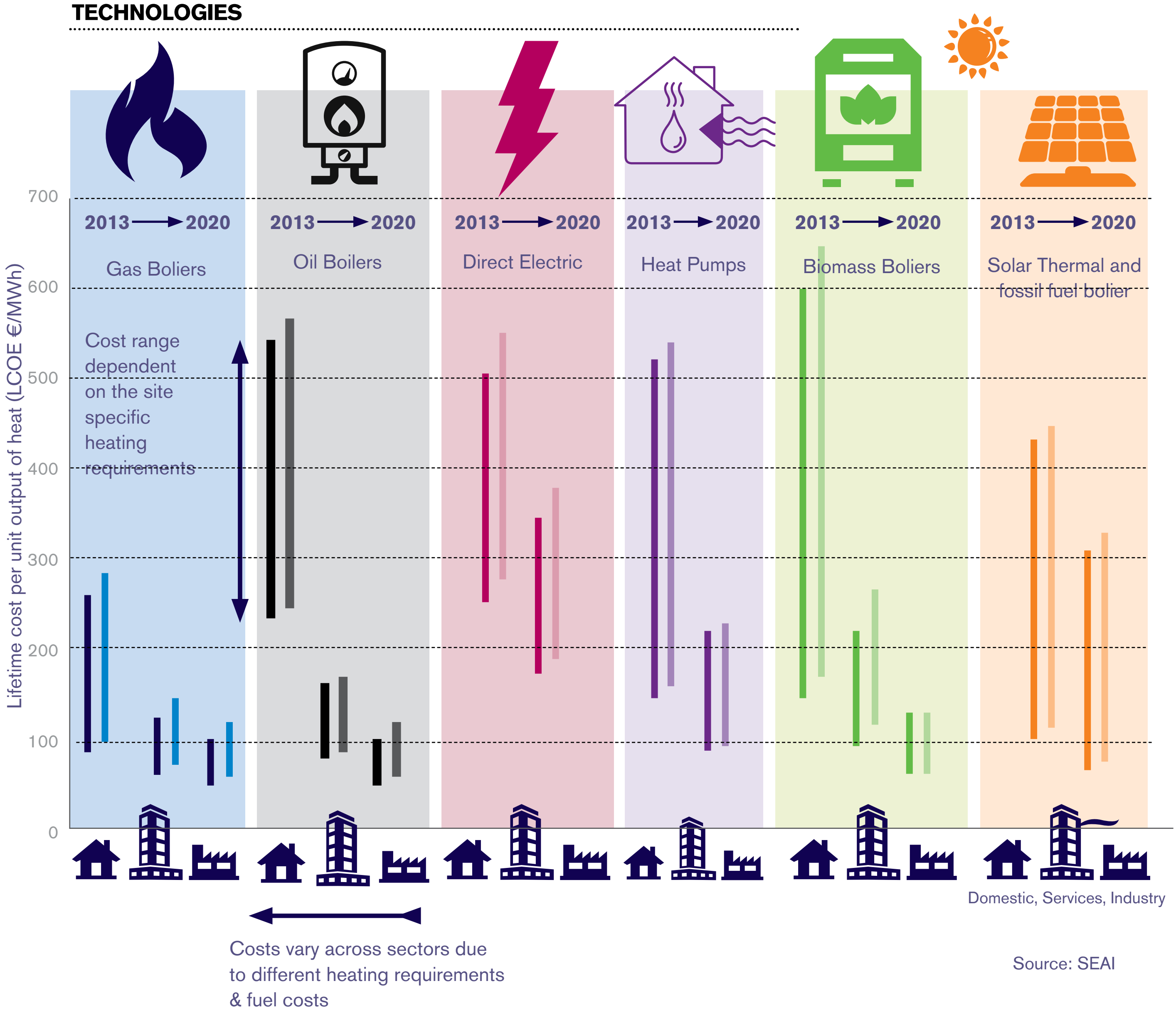
Heat Source	Efficiency (%)	Heat output kW_{th}	Capital cost (€)	Operating cost[1] (€ per annum)	LCOE (€/MWh)	Av. life (y)	Emissions[1] (tCO_2 per annum)
Oil	90%	7,130	2,000	784	143	10	2.04
Gas	90%	7,130	1,700	703	140	10	1.60
Direct Elec.	100%	6,550	1,760	1307	214	15	2.86
Bio-mass	85%	8,040	12,000	481-575	179 - 191	20	
Solar Thermal	-	1,820	5,400	66	307	20	-
Heat Pump	300%	7,130	4,850	517	130	20	1.04

5.4.1.1

CORROBORATING COMPARISONS

In its analysis of renewable heat potential to 2020, SEAI compared the lifetime costs of different

FIGURE 27 - COMPARISON OF LIFETIME COSTS OF HEAT TECHNOLOGIES



Source: SEAI

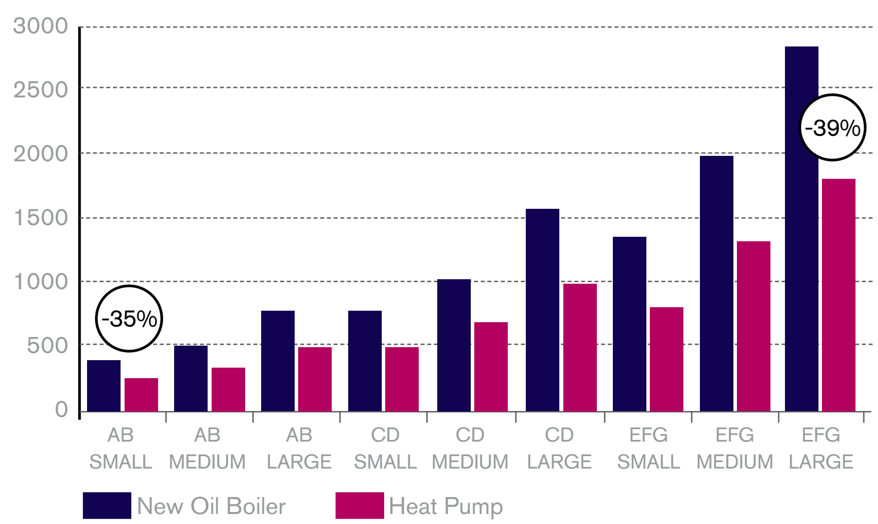
technologies across the sectors (see Figure 28). What this demonstrated was that:

- currently, gas heating was considered the most competitive of the conventional technology choice options (gas boiler, oil boiler or direct electric heating);
- electric heating was comparable to oil heating, at least for a subset of building types;
- heat pumps and biomass boilers could be cost competitive for some households, especially in comparison with oil and direct electric heating;
- a combination of solar thermal and fossil boilers is considered most cost competitive by 2020.

In a similar assessment to that of ESB, SEAI reviewed the capital cost and operating costs of different heating options across a range of domestic dwelling types (differentiated by size and energy efficiency ratings), as shown in Figure 28. This

FIGURE 28 - COMPARISON OF ANNUAL RUNNING COSTS AND INSTALLATION COSTS (OIL BOILERS VERSUS HEAT PUMPS)

AVERAGE ANNUAL HEATING BILL PER DWELLING (€) BASED ON AVERAGE 2014 PRICES



Source: SEAI

demonstrated that:

- heat pumps are more efficient and generally have lower cost to operate once installed – although this will depend on the relative costs of fuels. Generally, heat pumps have around 30% lower running costs than oil boilers;
- installation costs in retrofit properties are significantly higher with a typical heat pump costing between €7,500 and €10,000 compared to around €2,000 for an equivalent oil boiler. Heat pump installation is often done in combination with a fabric retrofit to improve the building's energy efficiency;
- the relative benefit is greater in larger and less energy efficient houses – since the annual energy consumption is higher in these dwellings.

On the basis of the data presented in Figure 28, SEAI concluded that around 460,000 households would see a payback on their investment in a heat pump in 11 years or less. In only the largest and most efficient households would the payback be in less than 10 years (7 years is the projected payback period).

5.4.2 EMISSIONS COMPARISON (COMMERCIAL)

Commercial heating technology options are similar to those for domestic properties. The performance and cost characteristics for each are summarised in Table 12. Solar thermal is not considered here and for large commercial properties, neither is direct electric heating as this is not reported as an existing heating source for large scale commercial properties in the relevant SEAI database. As this is based on published SEAI analysis SEAI (2015a) it does not explicitly look at CHP solutions, nor does it look at future cooling demand and the impact that could have on energy use in the commercial sector.

5.5 CARBON CONTENT OF EXTERNAL ENERGY SOURCES: POSSIBLE LOW CARBON PATHWAYS

Natural gas, biomethane, hydrogen, electricity and district heating can all be described as sources of external energy to buildings, either heat energy or energy that can be transformed into heat. In considering the lowest cost routes to an 80% reduction on energy emissions by 2050, it is important to consider the potential of these means of transporting energy to become zero carbon. In other words, does a clear migration path to zero carbon exist for these sources?

If the answer to this is negative for any source, then that means of energy transport may need to be abandoned at some point in the transition and is unlikely to be part of a least cost pathway. In the first and second parts of this chapter, we have outlined the options of a retrofit of the building fabric and then compared the different end-use technologies and their current level of emissions. This section examines the long term potential of the energy sources used by these technologies to become low carbon. As the low carbon path for electricity was previously considered in chapter 3, this section will consider the potential of gases and district heating as low carbon energy delivery modes.

5.5.1 RENEWABLE AND SUSTAINABLE GAS

INSTALLATION COST PER DWELLING (€)

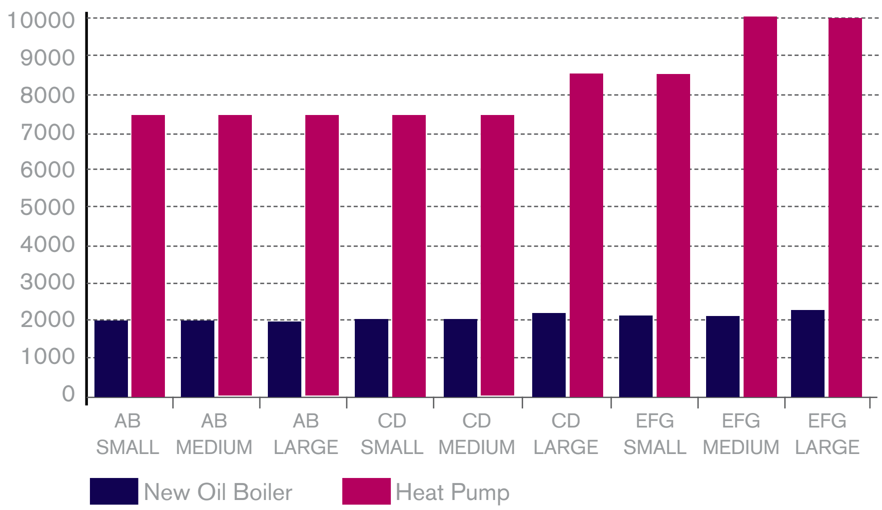


TABLE 12 – COMPARISON OF TECHNOLOGY OPTIONS (COMMERCIAL)

		Average annual demand (MWh_{th})[1]	Efficiency (%)	capital cost (€)	Annual operating cost (€)	LCOE (€/MWh)	Lifetime (yrs)	Annual emis--sions (tCO_2)
Small comercial	Oil	80.3	91%	3,629	46,259	82.3	15	22.7
	Gas	80.3	91%	3,024	4,174	55.6	15	17.8
	Electricity	80.3	100%	9,870	8,101	112.7	15	35.1
	Biomass	80.3	81%	18,900	4,224	75.3	15	-
	Heat pump	80.3	350%	25,200	2,928	66.7	15	10.0
Large commercial	Oil	774.2	91%	38,880	60,482	83.0	15	219.0
	Gas	774.2	91%	32,400	40,402	56.2	15	171.8
	Biomass	774.2	81%	20,2500	41,555	78.9	15	-
	Heat pump	774.2	350%	27,0000	28,925	71.0	15	96.7

Source: SEAI (2015a)

Note: 1 The average reported demand for small commercial oil and electricity consumers differ from the figures in the table, they are reported by SEAI as being 286.9 MWh and 50.3 MWh respectively. We have used a single demand assumption for ease of comparison across the technologies

If the natural gas in the network could ultimately be replaced by low carbon gas, that could be an attractive route to low carbon heat. Options include:

- Biogas or Biomethane: biogas is methane gas with carbon dioxide and impurities created through anaerobic digestion of grass, organic wastes and manures. Biomethane is biogas that has been refined by removing the carbon dioxide and impurities and is suitable for injecting into the gas network.
- Hydrogen: Hydrogen (H_2) that is manufactured by a process with low levels of CO_2 emissions e.g. by electrolysis of water using renewable electricity or from methane using a chemical process known as steam reforming with capture and storage of the CO_2 produced as a by-product.
- Syngas: gas created synthetically through chemical processes. One route is to create methane by adding CO_2 to hydrogen in a process known as methanation.

These are examined in turn below.

5.5.1.1 BIOGAS

Biogas is a mixture of biomethane (65% - 70%) and carbon dioxide (30-35%) with trace amounts of other gases. It is created by the anaerobic digestion of energy crops such as grass or organic wastes such as sewage, manure, food waste and landfill. Anaerobic digestion (AD) is the biological breakdown of biological materials by microbes in the absence of oxygen. The biogas can be upgraded to biomethane (i.e. increasing the concentration of methane to over 95%) so that it is equivalent to natural gas.

Unrefined biogas can be used in a CHP plant for local power generation and direct heating applications. On the other hand, if the CO_2 and impurities are removed from biogas, the resulting gas – biomethane - can be injected directly into the gas grid or used as a transport fuel in the same way as LNG or CNG (see section 4.2.5).

These processes are illustrated in Figure 29 with indicative cost ranges reflecting alternative AD processes, feedstock costs and upgrading process costs. The range of production costs presented potentially overstates the uncertainty as it adds together the minimum and maximum costs for each stage in the process whereas the combination of component stages for different production and upgrading may not allow the lowest or highest cost options to be paired. The IEA bioenergy task force uses a smaller range of between 7.1 and 9.6 c/kWh. This is around twice the current natural gas wholesale price but doesn't include the price of carbon avoided.

The potential supply of biogas in Ireland depends on the availability of feedstock and on the efficiency of the production processes. Table 13 quantifies the volumes of the various waste streams available for anaerobic digestion in Ireland. Agricultural slurry, organic waste streams from refuse collection, slaughter waste and surplus grass – grass not used for agricultural purposes – are included. We have excluded sewage waste. It is clear from the table that the key feedstock for biogas production via anaerobic digestion in Ireland is surplus grass. Based on this analysis of the available feedstocks and assumptions on the proportion that can feasibly be collected, we have estimated potential biogas production at 4,200 GWh per year. This is equivalent to about 9.6% of the total demand for natural gas in 2015 or 7.5% of the projected natural gas demand in Ireland in 2020.

Differing conclusions are possible based on extending the range of feedstocks and allowing for technological developments in gasification and other emerging techniques. Gas Networks Ireland, in its network development report (Gas Networks Ireland, 2016), has projected biomethane production in the order of 21% of current gas demand by 2030.

A recent comprehensive report by Ricardo Energy and Environment, commissioned by SEAI, looks at the potential production of biogas in Ireland over a range of scenarios and economic assumptions (SEAI (Ricardo Energy and Environment), 2017). It gives a thorough overview of the technologies for producing biogas, biomethane, hydrogen and synthetic gas as well as combinations of these on one site. It analyses four different biogas production scenarios of increasing scale:

- Waste-based AD
- Increased biomethane
- All AD feedstocks
- Exploratory.

Waste-based AD makes maximum use of food waste and slurries. These are the cheapest wastes with the highest GHG savings. As well as the feedstocks in table 13 above, sewage is included as a feedstock. As it is relatively small in volume it doesn't greatly affect the comparison.

Increased biomethane builds on the waste-based AD scenario, adding some grass silage to inject biomethane into the gas grid at the 42 lowest-cost points. This scenario is closest to that in Table 13 above.

All AD feedstocks makes the maximum use of available feedstocks for anaerobic digestion in Ireland. It assumes extra injection points. Unlike the quantities assumed in Table 13 where grass from unused land was assumed, this scenario assumes, based on work by Teagasc, that more efficient management of grazing land can free up land currently used for grazing to provide extra silage for AD. This more than doubles the energy available from grass compared to the analysis above from 4,200 GWh to 9,700 GWh.

The Exploratory scenario adds gasification of biomass, a developing technology, to show what capacity could be added to the All AD scenario through the gasification of wood pellets and energy crops. Power to Gas technology was discussed but not included because of the difficulty of obtaining data.

The report found that the potential biogas production across the 4 scenarios ranged from 3.2% to 7.1% of 2015 gas demand in 2030 and from 3.7 to 33.4% of 2015 gas demand in 2050. These results are abstracted in the table below.

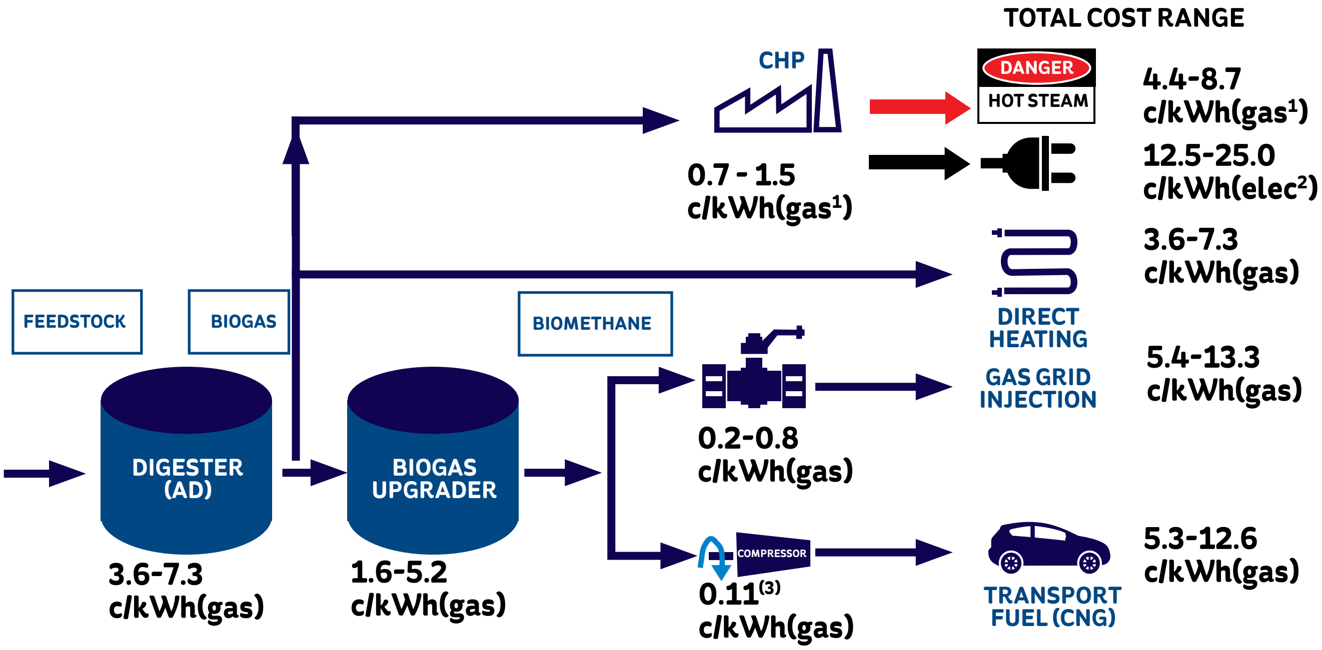
The biogas output of the Increased biomethane scenario is close to that in our analysis in table 13. The output from All AD feedstocks scenario is considerably greater. The Waste based AD and Increased biomethane scenarios result in projected

TABLE 13 - POTENTIAL BIOGAS PRODUCTION IN IRELAND BY 2020

Feedstock	Quantity (million tonne p.a.)	Recoverable rate (%)	Biomethane production potential (GWh p.a.)
Agricultural slurry	32	12%	520
Organic fraction municipal solid waste (OFMSW)	0.87	25%	160
Slaughter waste	0.42	50%	190
Surplus grass	N/A	N/A	3,330
TOTAL			**4,200**

Source: ESB Analysis

FIGURE 29 – COSTS OF BIOGAS AND BIOMETHANE (euro cent per kWh)



Source: ESB Analysis based on cost data from Joint study by IEA Bioenergy Task 40 and Task 37

TABLE 13a - SUMMARY SCENARIOS IN SEAI/RICARDO STUDY

Scenario	Potential biogas production (% of 2015 gas demand) 2030	2050	No. of digesters by 2050	Cost benefit 2050 (€000m)
Waste-based AD	3.2	3.7	250	69
Increased biomethane	5.4	8.5	300	23
All AD feedstocks	7.1	27.8	850	-29
Exploratory	7.1	33.4	850	-1,400

net benefits to the economy in the base case, allowing for cost of avoided carbon and increased employment. The All AD feedstocks scenario produced a net benefit if economic conditions favourable to AD are assumed. However this was relatively small and based on more than twice the investment in the form of number of digesters. Also the benefits reduced in 2050 suggesting that the later investments in the scenario are more marginal. The Exploratory scenario was economically unfavourable in all cases. This could change in future years as biomass gasification is a still-developing technology as pointed out by the report.

A challenge outlined in the report is that AD based on silage has a net CO_2e savings level that is marginal based on the minimum sustainability criteria that are likely to emerge from the proposed amended Renewable Energy Directive. This, as well as increasing cost of silage reduces the net financial benefit of the All AD feedstocks scenario. There is scope for improvement based on a range of improvements such as increased yield from the AD process, lower cost of upgrading biogas, reduced biogas leakage and optimising grass growing to maximise CO_2 retention in the soil. For now this adds to the uncertainty of AD based on large quantities of silage.

Recent analysis (Wall, 2015) has suggested that mono-digestion of grass causes deficiency in essential nutrients and is prone to process imbalance causing process failure. Co-digestion with animal slurry on a 50:50 or 60:40 mix is seen as optimum for long-term digestion. On this basis, availability of slurry becomes the constraining factor for biogas production through AD and therefore the potential production would be much lower, at around 6% of projected gas demand. Projections for higher levels of production are contingent on a breakthrough in the microbiology of the digestion process to overcome this constraint.

5.5.1.2
HYDROGEN

Hydrogen can be used as a fuel, it is not a greenhouse gas, and does not emit CO_2 when burnt or converted to energy. It can be burnt in a suitable boiler or directly converted into electricity and heat through electrochemistry in a fuel cell. All of this means that Hydrogen has potential applications in the power, heat and transport sectors. In the heat sector, hydrogen has two main potential contributions – in industry and in providing heat for buildings. Because of its properties, it is seen as a potential replacement for natural gas in existing gas pipelines if practical issues with its sustainable supply and safe distribution can be resolved.

Such a supply of hydrogen would have potential to be used both to supply low-temperature heat for space heating and high-temperature heat for industrial processes (e.g. steel production or cement). In buildings, as well as burning it in boilers, hydrogen can be used in fuel cell combined-heat and power (CHP) systems (micro-CHP or larger). There is much work underway in Great Britain into how the distribution and use of hydrogen would work. At this point it must be regarded as unproven.

A limited number of fuel cell micro-CHP units are commercially available at present (E4Tech, et al., 2015). In the absence of a supply of hydrogen, these models are fitted with a device called a reformer which converts natural gas to hydrogen. Larger scale fuel cell CHP units are not yet commercially viable, but there is an expectation that improvements will make the technology cost competitive in the next decade (E4Tech, et al., 2015).

Around 95% of global hydrogen is produced and consumed on the same site (E4Tech, et al., 2015), normally as part of an existing industrial process. Network infrastructure to deliver hydrogen in the same way as natural gas is not in place at the moment, though there is increasing interest in converting existing natural gas networks to hydrogen in the longer term (i.e. post-2030).

Some initial feasibility studies have been undertaken. The most recent is the Leeds CityGate, H21 project (Northern Gas Networks (2016)) which has investigated the potential for converting the natural gas distribution network supplying the City of Leeds to a hydrogen. This conversion would be for around 6TWh of annual average gas demand (equivalent to around 10% of projected gas demand in Ireland in 2020).

The study concludes that:

- the gas network has the potential to be converted to run on 100% hydrogen;
- the transition could be delivered incrementally over a three year period to minimise disruption;
- there would be limited need for new energy infrastructure; and
- the project would be based on existing technology processes with the hydrogen produced through steam methane reforming with carbon capture and storage of hydrogen in salt caverns.

Projected costs for the conversion are in the region of £2bn investment (around half of that linked to appliance conversion) and ongoing operating and maintenance costs in the order of £139m. This cost is projected to raise the distribution network charges for consumers by between 7% and 50% depending on the method through which the costs are recovered and the applicable customer base (lower rises apply when the cost is assumed to be socialised nationwide.

The study notes that there is limited recent experience of major appliance conversion programmes – the most recent occurred in the Isle of Man and involved around 15,000 consumers – the Leeds scheme would involve conversion at around 265,000 properties. It also highlights that the supply chain is very immature and that it remains a challenge to encourage equipment manufacturers to produce hydrogen appliances (or hydrogen ready appliances) given the lack of commercial incentives at present.

In addition, there remain safety concerns with hydrogen. Compared to natural gas it is flammable over a much wider range of concentration (4% to 75% compared to 5.3% to 15%) and the effect of hydrogen leaks in a domestic house are at early stages of investigation. The Leeds study refers to the HyHouse experiment in Scotland that concluded hydrogen leaks are unlikely to lead to the high concentrations where damaging explosions may occur. This remains a key uncertainty and risk for longer-term hydrogen use in the home.

Production of Hydrogen: Steam Reforming

The most economical way to produce hydrogen at volume is from natural gas using a chemical reaction known as steam reforming. The chemical reaction at the core of steam reforming produces CO_2 as a by-product. For this reason, production of hydrogen by this method requires carbon capture and storage (CCS) technology and infrastructure in order to be a low carbon option.

Production of Hydrogen by Electrolysis and Power to Gas (P2G)

Hydrogen gas (H2) can be produced from water by passing a direct electrical current through it in the process known as electrolysis. The conversion efficiency of this process using existing methods is low, typically around 50%-70% (Mazloomi, et al., 2012). This currently limits the commerciality of the process. Research work is in progress to find a suitable catalyst to raise this efficiency.

The concept of Power-to-Gas (P2G) is generally used to describe the use of excess renewable electricity to create hydrogen at times of low electricity demand. It can thus serve as a form of chemical energy storage. Fuels are a much more compact form of energy storage than many other forms such as batteries or pumped storage[23] (Battery University, n.d.).

When hydrogen is produced using electrolysis, the oxygen is either sold or consumed onsite and the hydrogen can be:

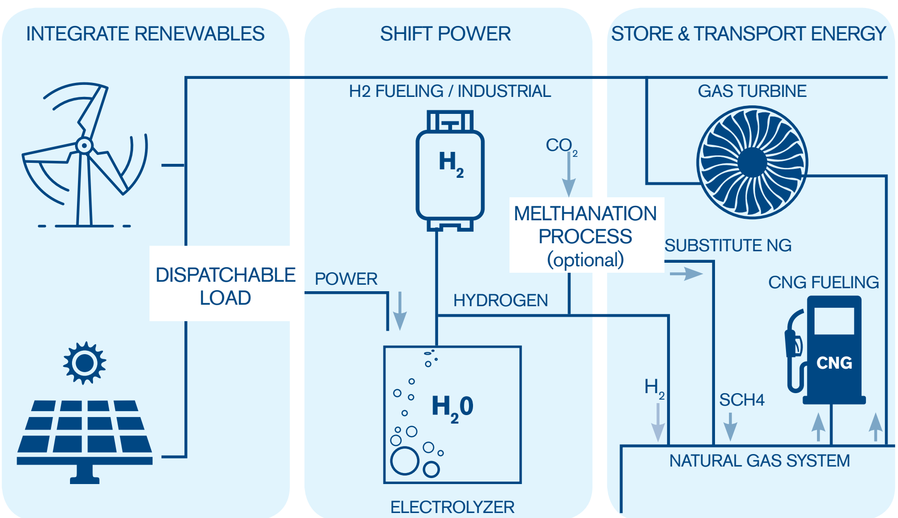
- injected directly into natural gas pipelines and analysis is ongoing to determine what proportions of hydrogen can be supported; or
- converted to methane either catalytically or biologically through reaction with CO_2, which can be injected into natural gas pipelines.

Another option would be for use in transportation instead of pipeline injection. Compressed hydrogen, compressed natural gas (CNG), or liquefied natural gas (LNG) could be manufactured on site for direct use in vehicles.

There are approximately 30 P2G plants at various levels of pre-commercial production throughout Germany and neighbouring countries. The technology is currently at the stage of pre-commercial demonstration projects and research is concentrating on power to gas methanation due to the limited capabilities of hydrogen gas grid injection.

[23] For example petrol has 60 times the energy storage capacity by weight as a lithium ion battery

FIGURE 30 - POWER-TO-GAS BRIDGES THE POWER, GAS AND TRANSPORT NETWORKS WITH NEW OPTIONS FOR ENERGY STORAGE



Hydrogen injection is assumed to be limited to the range of 5-10% concentrations.

5.5.1.3
SYNTHETIC GAS (SYNGAS)

Synthetic gas generally refers to methane manufactured in a refinery to replace natural gas. (Connolly, et al., 2016). The process suggested is the manufacture of hydrogen by electrolysis – as described above - followed by methanation of the hydrogen to produce methane. The overall process efficiency of these two steps is low (although some research suggests improvements are possible in electrolysis efficiency), making it expensive.

A power to methane process requires cheap electricity (such as that which would otherwise have been curtailed) and cheap sources of CO_2 and water. The efficiency of the methanation process is thermodynamically limited to about 80%. In practice, overall power to methane efficiency varies widely on a case-by-case basis and efficiencies in the region of 55 - 80% may be expected (Ahern, 2015).

It is seen in roadmaps as coming into play only at the later stages of a transition to 100% renewable energy for sectors that are otherwise difficult to decarbonise. An ESB literature review (2016) found that, even ignoring the cost of water and assuming a free source of CO_2 on site, it could at best be marginally economic today.

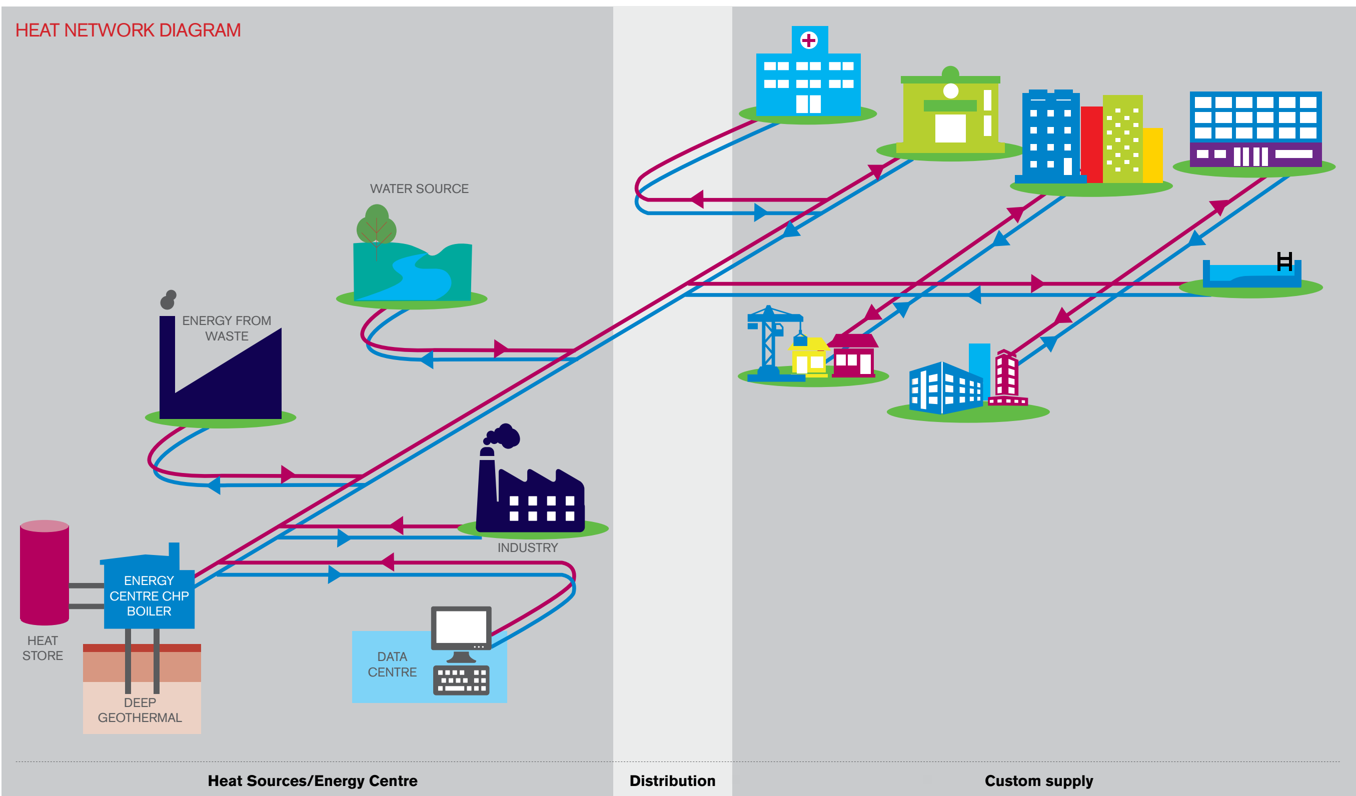
5.5.1.4
SUMMARY

As Ireland has supplies of low cost waste, it appears likely that biogas will be an important part of our energy future. As a biofuel, it is valuable and the more that Ireland can source, the more it will displace other, more difficult alternatives. It appears likely that biogas supply can reach 6% of 2015 demand, the limit outlined by Wall concerning the ratio of grass to manure (2015). Assuming this barrier can be overcome, then the Increased biomethane scenario producing up to 8.5% of 2015 gas demand and somewhat beyond that level is very plausible. Beyond that point, the potential to increase supply appears uncertain. Increasing the volume of biogas significantly requires the use of silage to very significant levels. Based on current knowledge, significant technical and logistical barriers will need to be overcome to come close to the All AD feedstock scenario with its biogas output of 28% of 2015 demand. While Ireland is a leader in this research and progress cannot be ruled out, on balance it appears challenging.

The likely feasibility of other low carbon gases such as hydrogen and synthetic gases in significant volumes is not yet clear as the technology is still in development. However, as the transition continues and there is a need for ever-lower emissions, they are likely to have application in areas that would otherwise have difficulty migrating to zero carbon and also in energy storage (Connolly, et al., 2016). The current evidence suggests that these developments will come in the longer term, beyond the horizon of an 80% reduction in energy emissions.

Based on the above, our outline roadmap in Chapter 6 sees quantities of biogas playing an important role in areas such as transport, electricity and heat production co-located with anaerobic digestion and in high temperature process heat. Due to the limited potential supply of biogas, we see it as likely to be a valuable option for high temperature process heating and transport, where it is a valuable low carbon option, compared to more challenging alternatives.

FIGURE 31 - COMPONENTS OF A DISTRICT HEATING SYSTEM



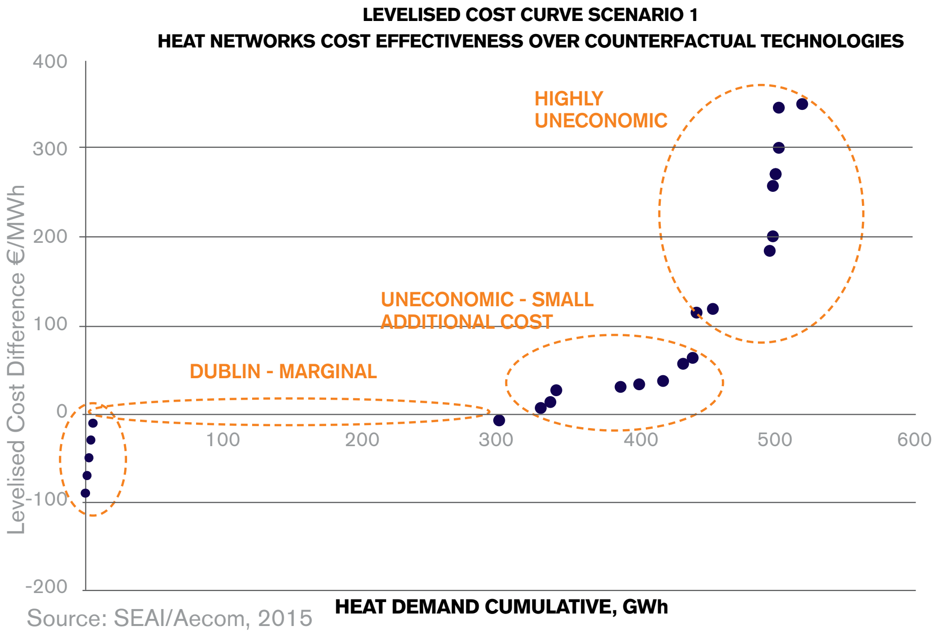
Source: SEAI/Aecom, 2015

5.5.2
HEAT NETWORKS

District or community heating networks offer an alternative model for distribution of heat to that of gas and electricity networks or oil distribution. Instead of transporting energy to the property for on-site conversion into heat, a heat network distributes centrally-produced heat (hot water at a temperature of between 60 and 95 degrees C) to residential and mixed-use developments. Instead of a boiler, buildings have a heat exchanger to transfer heat from the network to their central heating pipes. A heat meter measures consumption. In a similar way to an electricity grid, multiple heat sources can be connected to the heat network and this enables both fossil and renewable sources to be utilised. In addition to this, waste heat from existing power stations or from industrial processes or space cooling (e.g. data centres) can be used, to reduce fuel use and emissions, a unique and important benefit of heat networks. In its 2009 study on the potential of district heating networks, DECC found that the most cost effective schemes were those utilising waste heat from large power stations or industrial sites (see Pöyry/ Aecom, 2009).

As the upfront costs of developing heat networks is relatively high (Pöyry/Aecom, 2009), they tend to be suitable only in regions where there is a higher heat density. In a study for the ETI, Aecom identified a heating requirement per unit area, or heat density, of around 200MWh/ha as a threshold heat density above which heat networks may be considered viable (ETI, 2012). Below this level they found that the cost of network development outweighed the cost of individual heat technologies.

FIGURE 32 - COST COMPARISON OF HEAT NETWORKS WITH CONVENTIONAL HEATING OPTIONS



Source: SEAI/Aecom, 2015

In a recent heat mapping study (Sustainable Energy Authority of Ireland & AECOM, 2015) it was noted that 90% of the existing heat demand in Ireland is at densities too low to make district heating a viable proposition. The study found that large scale schemes in Dublin and Cork accessing waste heat from power stations as well as small schemes serving heat consumers currently off the gas grid were potentially viable. A later study by Codema (Codema, 2016) also identified potentially viable district heating schemes within Dublin. Two points need to be noted:

- Current building regulations mean that small district heating schemes are viable for apartment blocks
- The Aecom report used an approximation for heat density and there is reason to believe that a detailed heat map might reveal that a higher proportion than 10% of heat demand is viable

Based on these considerations, we conclude that heat networks are a viable option to address a share of the heating market in Ireland. The extent of the potential will require further studies to establish exactly. For the purpose of the roadmap developed in Chapter 6, we have not assumed an explicit role for heat networks, but note that the Aecom study identifies around 30,000 dwellings in high heat density areas (>10,000 MWh/km) around Dublin (or 1.5% of total heat demand) may be economically served by a heat network. However, outside of this area, where emissions savings are the goal, Aecom asserts that alternative building scale low-carbon technologies such as heat pumps are more cost effective than heat networks.

It is difficult to set out a cost comparison for a home heated from a heat network in Ireland as the networks do not yet exist and the costs will depend on the future network configuration, heat demand profile and sources of heat connected. Instead, Figure 32 illustrates the LCOE for a modelled heat network relative to a baseline counterfactual using conventional individual heating technologies. As can be seen, the levelised cost of operating the heat network is lower or comparable to other technology options for only around 300GWh of identified heat demand.

5.5.2.1
SUMMARY

District heating is an established technology that is likely to prove feasible as a pathway to low carbon heating in at least some areas in Ireland. More detailed studies are required to establish the exact extent.

l

5.6
PROCESS HEAT

In contrast to the domestic and commercial sector where heat demand is primarily for space and water heating, industrial heat demand includes high temperature heat for key processes. Typical processes include pasteurisation or production of milk powder in the food sector, kilns for cement or plaster board in the building materials sector or high temperature heating for chemical reactions in the pharma sector.

Much of the heat requirement for process heat is above 400 degrees C and has typically been provided from oil or gas boilers or CHP units. Decarbonisation of process heat has tended to focus on substituting the existing heat source with biomass boilers. The UCC study suggests fossil fuel firing with carbon capture and storage as the likely option by 2050.

There are certain processes where electricity can be substituted with improved efficiency. Examples are induction heating in the heat treatment of ferrous metals or infra red curing of paint or ultra-violet responsive inks in printing. More recently researchers have examined ways of applying electricity to the production of basic materials such as cement, glass steel, and chemicals (Lechtenbohmer, et al., 2016). While these avenues are promising, they are in the future. Collectively these are small sectors within the Irish industrial sector that is already small by international standards. We have assumed that biomass is used as a low carbon option in industry up to 2050.

5.7
CONCLUSIONS

The transition of the heating sector to low carbon will require three steps:

- Improved thermal performance of the building fabric: insulation and airtightness
- Improved performance of the heating system: heating appliance, controls and heat distribution
- A low carbon content of any external - non-renewable - energy and whether there is a long term path to low carbon

Investments that improve efficiency simply by switching to a more efficient way of burning fossil fuel will ultimately need to be replaced. Fossil fuel heating systems fitted to new homes and offices will also have to be replaced.

The thermal performance of the building fabric: insulation and airtightness

For existing buildings, deep retrofit of the building fabric will be essential. This will involve wall and ceiling insulation, good quality windows and doors and airtightness. Quality measures will be needed to ensure that new buildings are correctly built to the tighter standard.

The performance of the heating system: heating appliance, controls and heat distribution

Of the available heating appliances, gas boilers have the lowest capital cost. Heat pumps have the lowest emissions and lowest running cost but a higher capital cost than gas or oil. As a result, heat pumps have the lowest levelised cost of energy but gas and oil are close to the same level.

The carbon content of any external - non-renewable - energy and whether there is a long term path to low carbon

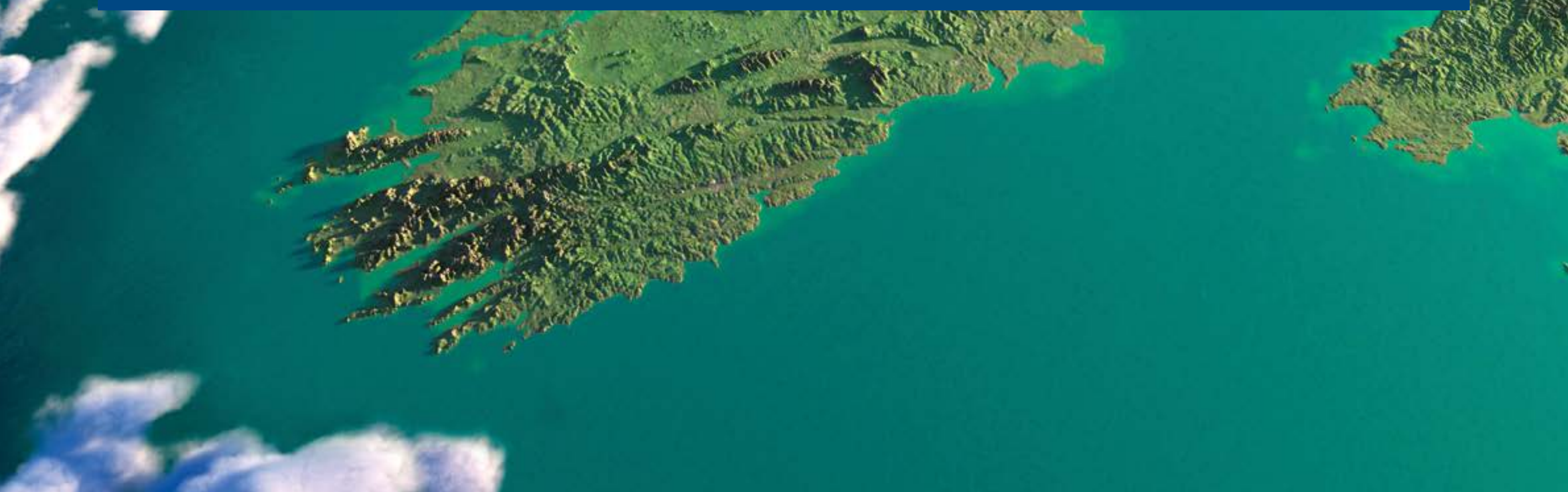
Bioenergy – biomass and biogas – as well as electricity are low carbon or on a plausible pathway to low carbon. Heat networks can also be migrated to low carbon and are likely to play an important role in Ireland's transition. A definitive expert study is required to determine where and how big the schemes should be. Biogas is likely to play a part in decarbonisation but currently cannot feasibly provide a high proportion of gas demand at viable cost. The feasibility of hydrogen as a future replacement for natural gas is unproven.

Ultimately all heating loads will need to switch to one of the above low carbon sources – or install CCS. As the paybacks for low carbon options are long, based on current energy prices, sources of low interest finance and expert, trusted and independent advice will be essential.

6

Roadmap For Decarbonisation

- The Irish Government has set a target of an 80% reduction in energy sector emissions based on 1990 levels by 2050. This means that energy sector emissions will need to fall from 36 Mt in 2015 to around 6 Mt in 2050 or 20% of their 1990 level. We estimate that non-ETS energy sectors (heat and transport) will have to make a major contribution to this decarbonisation, reducing to an estimated 4.1 Mt in 2050 compared to 21.5Mt in 2015 (based on EPA data). The ETS sector will correspondingly need to reduce to around 2 Mt from 11.3 Mt in 2050.
- A review of a representative sample of long-term decarbonisation studies revealed some common themes for future low carbon energy systems in 2050
  - There is a general trend towards electrification, with electricity's share of final energy demand generally doubling by 2050
  - Electrification occurs alongside the continued decarbonisation of the electricity sector, not after its completion
  - Heat pumps provide up to 60% of heating for households by 2050
  - Electric vehicles are around 60% of new car sales by 2030
  - Reducing emissions from energy beyond 80% still depends on sucessfu commercialisation and deployment of new technologies such as CSS, so there should be continued support for R&D
  - Bioenergy, which includes biomass, biogas and bioliquids, will play a much larger role. There is debate about the net contribution of bioenergy to emission reduction after the carbon impact of land use change. Generally studies assume a cap for total bioenergy in an energy system of around 10% of total energy use to limit the risks to future availability of supplies of sustainable bioenergy
  - Heat networks play an important role and need to be considered in any future strategy
- The main points that emerge for a 2050 Roadmap for Ireland's Energy System are as follows:
  - The Electricity System
    - Continued decarbonisation of electricity generation through renewable generation to reach 50% by the 2020s and through more use of gas plants (and less coal) as prices in the ETS increase.
    - As well as additional renewable generation (perhaps beyond 50%), a share of low carbon, dispatchable generation will be needed to complete Ireland's journey to full electricity decarbonisation at least cost. Based on currently feasible alternatives, our roadmap assumes CCS and biomass make up the remainder.
  - Transport
    - Progressive electrification of the light vehicle fleet through to 2025 and beyond
    - Compressed natural gas (CNG), biomethane, second generation biofuels and potentially in the medium term, electrical solutions for heavy goods vehicles
  - Heating in Homes and Workplaces
    - Containment of emissions from homes and workplaces through zero emission building standards for new builds
    - A national renovation programme for existing buildings with deep retrofit and switching to low carbon heating sources such as heat pumps and district heating.
  - Industrial Heat
    - This should be moved to a combination of low carbon fuels such as bioenergy, electricity and fossil fuels with carbon capture by 2050. Current research on methods to extensively electrify industrial processes may mature to supplant a portion of the fossil fuels and CCS component by 2050.
- Overall:
  - Ireland's population is expanding and the numbers of houses and transport miles are expected to grow strongly. An 80% reduction against this backdrop means that no sector will be untouched. This represents nothing less than a transformation of Ireland's energy system.



6.1

APPROACH TO CONSTRUCTING AN OUTLINE ROADMAP

The Government's long term vision to transform Ireland into a low-carbon economy by 2050 has important implications for the energy sector. As set out in its National Policy Position on Climate Action and Low Carbon Development, the Government seeks:

"…

- an aggregate reduction in carbon dioxide (CO_2) emissions of at least 80% (compared to 1990 levels) by 2050 across the electricity generation, built environment and transport sectors; and
- in parallel, an approach to carbon neutrality in the agriculture and land-use sector, including forestry, which does not compromise capacity for sustainable food production. "

The Energy White Paper (Department of Communications, Climate Action and Environment, 2015), sets out a vision of a low carbon energy system envisaging:

'….that greenhouse gas (GHG) emissions from the energy sector will be reduced by between 80% and 95%, compared to 1990 levels, by 2050, and will fall to zero or below by 2100.'

The most cost-effective pathway for this transition cannot be predicted with certainty. To demonstrate the changes that are likely to be necessary, we have constructed a feasible roadmap that will meet the Government's 80% energy sector emissions reduction target by 2050.

In the sections below, we quantify what an 80% target and trajectory to 2050 means for the energy system as a whole and also for the ETS and Non-ETS sectors separately. We have surveyed a wide range of existing roadmaps and studies to establish the common themes and approaches. These findings are combined with the insights into low carbon technologies and the structure of Ireland's energy use from earlier chapters, to set out the main programmes that are likely to emerge in a low carbon roadmap for Ireland's energy system.

6.2

KEY INSIGHTS FROM PUBLISHED ROADMAPS

Our review of published roadmaps, while not exhaustive, covers a representative sample of 20 roadmaps differing in geography, objectives (e.g. renewable energy share or greenhouse gas emission reductions) and modelling approach. It includes some of the leading modellers of the Irish energy system and of international studies of low carbon heat. The main studies reviewed are listed in Table 14. There is more detail on selected studies in Annex B.

There are several common themes that emerge from these roadmaps and can inform the transition in Ireland.

There is a general trend towards electrification in all roadmaps

While energy efficiency improvements are delivered across all sectors reducing overall energy use, electricity consumption rises to double its share of this reduced final energy demand. This is, in general, due to the increased use of electricity in the heat and transport sectors.

Electrification of heat and transport occurs alongside decarbonisation of the power sector

While the move to a carbon neutral power sector is essential to the strategy of electrification as a pathway to low carbon, electrification proceeds alongside the continued decarbonisation of the power sector rather than after its completion. This is because the efficiency benefits of electric solutions over their fossil fuel equivalents bring significant emissions savings even with the current carbon content of electricity.

There is a consistent pattern towards the deployment of heat networks

Many roadmaps see a growing role for heat networks as a cost-effective way of providing a low carbon pathway for future heat demand, especially in urban and mixed industrial/ residential settings. Even in markets like the UK where currently heat networks supply only around 2% of heat demand, they are seen as a core part of the future energy system. A key reason for this is the ability of heat networks to capture and use waste heat (e.g. from thermal power generation) for space heating thus reducing overall use of fossil fuels.

Heat pumps provide up to 60% of households with their heating requirements

Heat pumps play a significant role in space and water heating for homes, especially in rural areas. The precise contribution of heat pumps varies across roadmaps, with higher shares occurring where biomass-based heat is constrained.

The passenger vehicle stock shifts towards electric vehicles, with there being general agreement that around 60% of new car sales would need to be electric-drive by 2030

Emission reductions in the transport sector are driven more by improvements in the efficiency of conventional vehicles than by the adoption of alternative technologies in the period to 2025. This delays the shift towards electric vehicles but gives some time to develop charging infrastructure and for market development and consumer acceptance. However, the switch to EVs is necessary in the medium to longer-term. Most roadmaps find that EVs should form the majority of new car sales from 2030 for sufficient penetration to meet 2050 mitigation targets.

Reducing emissions beyond 80% - Deep decarbonisation - is still dependent on the development of new technologies

Innovations and technology development are required. In particular, there is a strong presumption in most roadmaps that CCS technology will be deployed commercially and at scale in the longer-term. There are also potential roles for hydrogen and methanol as alternative fuels in segments that are especially hard to decarbonise. Activities in these areas will become increasingly important as we move from 80% decarbonisation to 95% or fully decarbonised.

Ongoing concerns around sustainability limit bioenergy to around 10% of final energy demand

Though bio-based solutions are generally considered cost competitive across the sectors, it is likely that there will be limits to the supply of each type of sustainable bioenergy. In the case of biogas, this has potential

TABLE 14 – ROADMAP STUDIES REVIEWED DURING THE PROJECT

Author	Title	Geography	Sector(s)
Committee on Climate Change	Fifth Carbon Budget (Committee on Climate Change, 2015)	UK	Power Gen, Transport, Heat
SEAI	Bioenergy Roadmap (Sustainable Energy Authority of Ireland, 2012a)	Ireland	Power Gen, Transport, Heat
SEAI	Residential Energy Roadmap (Sustainable Energy Authority of Ireland, 2010b)	Ireland	Heat
SEAI	Electric Vehicle Roadmap (Sustainable Energy Authority of Ireland, 2011)	Ireland	Transport
SEAI	Smart Grid Roadmap (Sustainable Energy Authority of Ireland, 2011)	Ireland	Power Gen, Transport, Heat
Aurora Energy Research	Electrification of Heating and Transport in GB (Aurora Energy Research, 2016)	GB	Heat, Transport
Carbon Connect	Pathways for Heat	GB	Heat
ETI	Options, Choices, Actions (Energy Technologies Institute, 2015)	GB	Power Gen, Transport, Heat
DEA	Our Future Energy (The Danish Government, 2011)	Denmark	Power Gen, Transport, Heat
David Connolly (Aalborg University)	Smart Energy Europe (Connolly, et al., 2016)	EU	Power Gen, Transport, Heat
David Connolly (Aalborg University)	Heat Roadmap Europe (Connolly, et al., 2015)	EU	Heat
European Commission	EC Energy Roadmap (European Commission, 2011)	EU	Power Gen, Transport, Heat
UCC	Low Carbon Energy Roadmap for Ireland	Ireland	Power Gen, Transport, Heat
KPMG	2050 energy scenarios the UK Gas Networks role in a 2050 whole energy system (KPMG, 2016)	GB	Gas Networks
DCENR	Offshore Renewable Energy Development Plan (Department of Communications, Climate Action and Environment, 2014)	Ireland	Power Gen
DCENR	Ireland's Transition to a Low Carbon Energy Future National Mitigation Plan (Department of Communications, Climate Action and Environment, 2015)	Ireland	Power Gen, Transport, Heat
Deloitte	A Sustainable Energy Model for Spain (Monitor Deloitte, 2016)	Spain	Power Gen, Transport, Heat
ESRI, E4sma, UCC	Technical support on developing low carbon sector roadmaps for Ireland: Low Carbon Energy Roadmap for Ireland (Deane, et al., 2013)	Ireland	Power Gen, Transport, Heat
E4Tech	Scenarios for the deployment of hydrogen (E4Tech, et al., 2015)	GB	Power Gen, Transport, Heat
Gas Networks Ireland	Network Development Plan (Gas Networks Ireland, 2016)	Ireland	Power Gen, Transport, Heat
Element Energy	Pathways to high penetration of EVs (Element Energy, 2013)	GB	Transport
EPA	Ireland's Greenhouse gas emissions projections (Environmental Protection Agency, 2017)	Ireland	Power Gen, Transport, Heat
Greenpeace	Energy [r]evolution (Greenpeace International, 2015)	Europe	Power Gen, Transport, Heat
ICCT	Transition to a global zero-emission vehicle fleet (International Council on Clean Transportation, 2015)	International	Transport
IDDRI	Pathways to deep decarbonisation (Deep Decarbonisation Pathways Project, 2015)	International	Power Gen, Transport, Heat

implications for the fixed gas distribution network. The likely limits to economic biogas supply were explained in Chapter 5. If beyond 2050, the supply of biogas at economic prices does prove to be significantly below gas demand, this may imply a limit to the life of the general gas distribution network. The large volume gas transmission network is likely to be needed for electricity generation with CCS. In this event, the available economic supply of biogas will need to be directed to the sectors where the feasible alternatives are more limited and so its value is greatest. In most cases, this would result in bio-energy supporting emissions reduction in aviation and heavy goods vehicles.

6.3 QUANTIFYING THE 80% HEADLINE TARGET AND TRAJECTORY

The first step in constructing a roadmap using the insights gained from other roadmaps and the earlier chapters is to quantify the Irish Government's 80% target in terms of the permitted emissions in 2050. We have referred to this as the First Constraint.

Next we derive an emissions trajectory to 2050 for heat and transport, the main sectors outside the EU Emissions Trading Scheme. This is because these, non-ETS, emissions will be the subject of member state targets rather than an EU-wide target and actions to meet these targets will be part of national climate and energy plans. These targets will be an important comparison point for our projected roadmap. We refer to this trajectory as the Second Constraint.

The emission reduction trajectory in our roadmap aims to keep Non-ETS emissions below both constraints. In practice, this means staying within the second, Non-ETS, constraint provided it is lower than the first 2050 constraint.To validate the resulting estimated emissions targets, we have compared them with those implied in the UCC 80% decarbonisation scenario and have found them to be broadly consistent. The constraints and the comparison are described in more detail below.

6.3.1 THE FIRST CONSTRAINT IS THE 2050 ENERGY DECARBONISATION TARGET

The Irish Government has committed to delivering a reduction in energy emissions (i.e. net of agriculture, waste and industrial processes) of 80% over 1990 levels by 2050. Using data contained in the National Greenhouse Gas Emissions Inventory, (Environmental Protection Agency, April 2017) table 15 shows the split of emissions by sector in 1990 and 2015 (for comparison). Using this definition, energy sector emissions must be no more than 6,060 $ktCO_2e$ in 2050 to meet the Government's long-term commitment. Assuming non-energy emissions remain constant at 2015 levels, this 80% reduction in energy sector emissions leads to a decrease of around 51% in total emissions over 1990 levels by 2050. This is an average annual reduction of around 5% in emissions from energy from 2015 to 2050.

To put this reduction in perspective (see Figure 33), the total energy sector emissions in 2050 could only support around:

- 54% of current emissions of the electricity sector; OR
- 51% of current emissions of the transport sector; OR
- 90% of current emissions of the industry and commercial sector; OR
- the current emissions of the residential sector.

This is illustrated in fig. 33 below.

Even setting aside expected growth in activity levels in all these sectors, achieving this target will require a fundamental transformation from business as usual across all key energy sectors, meaning no sector will be unaffected. **This is transformative rather than evolutionary change.**

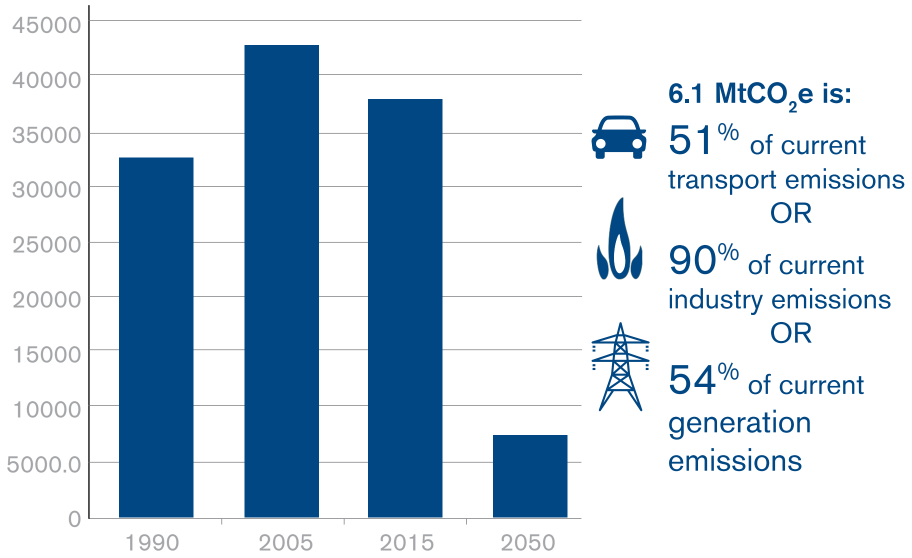
TABLE 15 – EMISSION LEVELS BY SECTOR ($ktCO_2e$)

Sector	1990	2005	2015	2050 target est.
Power generation	11,435	15,858	11,328	
Residential	7,524	7,272	6,041	
Industry and Commercial	6,206	8,299	6,766	
Transport	5,135	13,121	11,827	
Total Energy	**30,300**	**44,550**	**35,962**	**6,060[1]**
Industrial Processes	3,237	2,749	1,993	
Agriculture	20,963	20,347	19,807	
Waste	1,567	1,315	974	
F-gases	35	1,020	1,142	
Total	**56, 103**	**69,982**	**59,878**	**26,689[2]**

Notes: 1 20% of the reported 1990 figure; 2 based on no further reduction of agriculture emissions beyond the 2015 level and an 80% reduction in industrial processes, waste and F-gas emissions.

Source: EPA

FIGURE 33 – THE TOTAL ENERGY SECTOR EMISSIONS TARGET IN PERSPECTIVE ($ktCO_2e$)



6.3.2

THE SECOND CONSTRAINT: THE EU NON-ETS EMISSION TARGETS

Since emissions outside the EU Emissions Trading Scheme will be the subject of member state targets and national climate and energy plans, it is useful to separate out the trajectory of these emissions as implied by our roadmap so this can be compared with the 2020 and 2030 proposed effort sharing targets. For 2050, as there is no proposed EU non-ETS emission target, we have assumed an 80% reduction, consistent with the first constraint, the Government's 2050 energy sector reduction target. Our analysis is based on three key assumptions:

- Non-ETS reduction requirements will become increasingly tight over the period to 2050. Our assumed trajectory is based on the following:
  - 20% reduction over 2005 by 2020; (existing EU target);
  - 30% reduction over 2005 by 2030; (consistent with the trend implied by the proposed EU target).
  - An 80% reduction in Non-ETS energy over 2005 by 2050 (consistent with the first constraint of an 80% reduction for the energy sector as a whole).

- There will be limited scope for emission reductions in the agriculture and waste sectors up to 2030, reflecting market views that decarbonisation actions in the non-energy sectors will only be able to stabilise absolute emissions in the face of anticipated sector output growth.

In benchmarking these assumptions, we note that:

- The 2030 reduction limit proposed above is close to the target proposed by the EU Commission for Ireland net of the proposed ETS flexibility (Environmental Protection Agency, 2017) This is a measure of the total mitigation action required on the ground (including afforestation under the land use credit) to meet the target ; and
- While the 2050 limit implies an increase in the speed of reduction post-2030, at 1.8% per annum compounded it is still below the levels being recommended in other markets – for example, the UK Committee on Climate Change in its fifth carbon budget (CCC, 2015) assumes annual reductions of 2% in non-ETS emissions.

TABLE 16 – ASSUMED TRAJECTORY FOR NON-ETS EMISSIONS (ktCO_2e)

Assumed trajectory for non-ETS emissions (ktCO_2e)					
Non-ETS Emissions	2005 (actual)	2015 (actual)	2020 (est.)	2030 (est.)	2050 (est.)
Energy emissions Agriculture, waste, F-gases		21,124 [1] 21,923	17,052 21,923	14,700 20,865	4,129
Total Non-ETS emissions	48,718	43,037	38,975	35,565	

Note: 1 ETS energy sector emissions in 2015 were 16,831 ktCO_2e.

Source: Analysis based on EPA data. (Environmental Protection Agency, 2017), estimates: Pöyry/ESB

The projected trajectory of Non-ETS emissions to 2050 is shown in Figure 34 below.

Implications of the 2050 target

The implication of these assumptions is an estimated non-ETS energy emissions limit of 4,129 ktCO_2 for 2050 (Constraint 2). As shown in Figure 34, this is equivalent to:
- 35% of current transport emissions;
- 61% of current industrial emissions;
- 68% of current residential emissions.

The level of emission reduction activity in the non-ETS energy sector over the period to 2020, 2030 and 2050, against current levels implied in our assessment, is shown in Figure 35. The cumulative reduction between now and 2050 is 17 MtCO_2, an average emission reduction of 4.5% per year.

FIGURE 34 – THE NON-ETS ENERGY TARGET IN PERSPECTIVE (ktCO_2e)

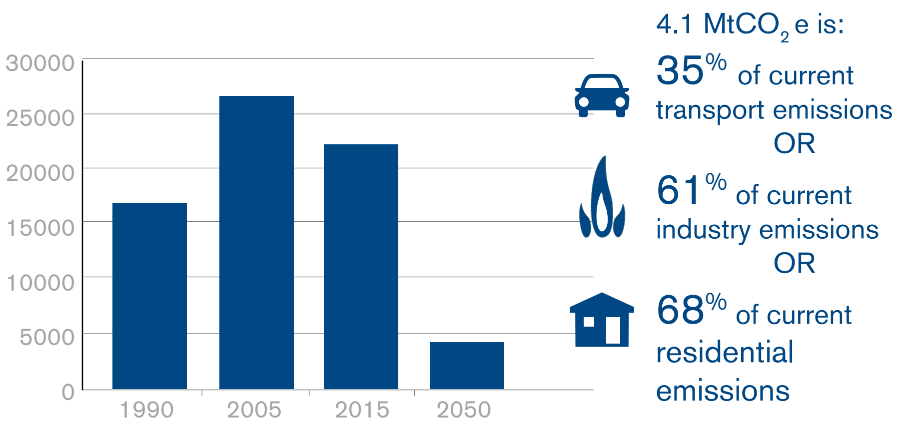
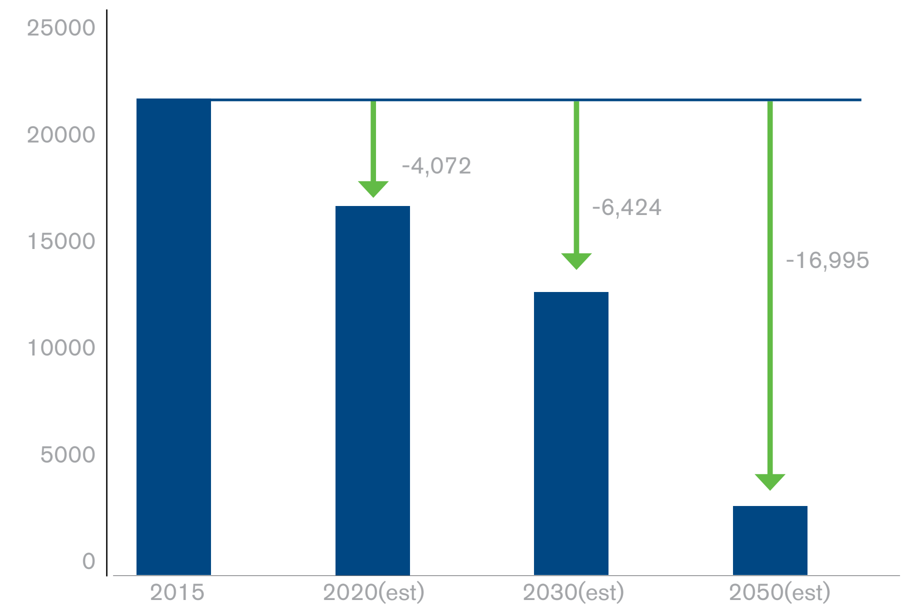


FIGURE 35 – THE SCALE OF EMISSION REDUCTION ACTIVITY IN THE NON-ETS ENERGY SECTOR (ktCO_2e)



6.3.3

COMPARISON WITH THE UCC 80% DECARBONISATION SCENARIO

We have compared our projected trajectory for Non-ETS emissions with the figures underpinning the UCC 80% decarbonisation scenario from 2013 in Table 17. The long-term reduction expectations are closely aligned – by 2050 the non-ETS energy sector will not be able to emit more than around 4,129 ktCO_2. There is some difference in the 2030 position due to the UCC projections not having explicit intermediate targets for the non-ETS sector. However, overall the two perspectives are in good agreement.

TABLE 17 – COMPARISON OF PROJECTIONS - UCC 80% DECARBONISATION AND ESB/PÖYRY

	Non-ETS energy emissions ($ktCO_2e$)		Non-ETS Emissions reduction (2015 base) ($ktCO_2e$)	
	2030	2050	2030	2050
ESB/Pöyry projection	14,700	4,129	6,424	16,995
UCC 80% reduction scenario	16,537	4,500	4,731	16,768

6.4

DELIVERING THE EMISSION REDUCTIONS FROM ELECTRICITY SECTOR

In this section, we describe the level of emissions from plant in the ETS in Ireland in 2050 as part of the 80% reduction. Then we recap on the findings from the electricity generation technologies described in Chapter 3. We then use these to infer what the generation mix will need to look like at the milestone dates of 2030 and 2050.

The technology options for electricity generation were outlined in Chapter 3: Electricity of this report. Each of these technologies presents significant challenges. Based on current information, it is very likely that gas generation with CCS will form a significant part of the low carbon generation mix along with variable renewable generation and possibly biomass.

Target emissions level for 2050

We saw in the preceding section that the goal of an 80% reduction in emissions from the energy system by 2050 leads to a limit of 6,060 kt CO_2 on total energy emissions and the trend line of EU Non-ETS emission targets, implies a limit of 4,129 kt CO_2 for Non-ETS emissions in 2050. This implies a ceiling for ETS emissions in Ireland of around 2,000 kt CO_2.

Technologies

The technology options for low carbon electricity generation were outlined in Chapter 3. We recap here on the findings from the Chapter:

- it is very likely that:
- variable renewable generation
- gas generation with CCS and
- possibly biomass
will form the low carbon generation mix.

- In order to safeguard system stability, operators set an upper limit on the amount of variable generation and interconnection flow that can be running at any one time as a proportion of locally running generating plant. This limits the role of interconnection in integrating renewable generation while these technical barriers remain.

- Storage has many uses over short time scales but current storage technologies cannot economically provide the scale of capacity to operate an electricity system on variable renewable generation and storage alone.

The above means that, for the foreseeable future, we need a mix of variable renewables and low carbon conventional plant in order to maintain system stability. Accordingly we propose to chart out a rough mix for 2050 based on variable renewables – a mix of onshore and offshore wind and solar – combined cycle gas turbines with CCS and some biomass. We will assume that biomass is limited because of the proposed restriction in generation from biomass in the draft revision of the EU Renewable Energy Directive. This specifies that generation from biomass must in future be in combined heat and power configuration. Ireland has a 'chicken and egg' problem because we are currently lacking the heat networks to make use of the heat from CHP plant.

Further Constraints

As we saw earlier, electricity generation must meet the following parameters in 2050, partly arising from the transition requirements of other parts of the energy sector:

- To achieve the policy goal of an 80% decarbonisation by 2050, UCC modelling projects that generation carbon intensity will need to fall from 437 gCO_2/kWh in 2015, to 38 gCO_2/kWh in 2050.

- The roadmap calls for, among other measures, the further adoption of electric solutions to mitigate CO_2 in both the heat and transport sectors. This will impact on electricity demand. On a broad estimate, this could lead to an additional 10 TWh of electricity demand by 2050, equivalent to around a 40% increase on current electricity consumption levels. This is broadly in line with the projections in the UCC (2013) analysis, which projects a 38% increase in electricity consumption between 2010 and 2050 in an 80% carbon reduction scenario.

As electricity demand in 2015 was about 25TWh, this implies a demand in 2050 of 35 TWh, not counting any extra data centres that may be connected. Finally there are the constraints arising from the time it takes to plan and build or re-build conventional generation plant, the unpredictability surrounding plant closures because of market conditions and the time to develop a regulatory framework for CCS. Based on all of the foregoing, the following table sets out a high level outline of what the transition to a low carbon electricity system might look like.

Outline of Electricity Transition to Low Carbon			
	2015	2030	2050
System Demand (TWh)	25	29	35
Target emissions ($MtCO_2$)	11.435		2.0
Variable renewables (%)	12.6	55	60
Biomass (%)		5	5
Gas CCGT and peakers (%)	42.2	26	5
Gas CCGT with CCS (%)		10	26
Coal (%)	25.0		
Peat (%)	12.3		
Others	6.4	4	4
Interconnection Capacity	1.3	0	0

Conclusion

The particular circumstances of Ireland's electricity system and resources makes a system with a high level of variable renewables and a high level of gas generation with CCS likely. The transition will be unpredictable over short time scales and will not be linear in nature and changes will arise from a small number of large impact decisions given the size of thermal power stations. Individual decisions with respect to plant closures and new generation investment will be driven by market conditions and factors outside the electricity market e.g. the regulatory framework for CCS. Work on this framework should start next year to enable CCS to be used by the mid 2020s.

6.5

DELIVERING THE NON-ETS ENERGY EMISSION REDUCTIONS

Having derived a trajectory for non-ETS emissions, in this section we set out headline reductions for each segment and the proposed mitigation measures likely to form part of a cost-effective pathway, based on the technologies in Chapters 4 and 5 and the patterns emerging from other roadmaps earlier in this chapter. Note that, in the absence of detailed modelling, this is not a comprehensive road mapping exercise. In arriving at this roadmap, we have made the following assumptions:

- We have based our analysis on a fixed energy system – that is, we have taken the emissions and scale of activity in 2015 as a fixed point and looked at transformation of that system and the emission implications. We have not projected the effect of changes in population or economic activity (e.g. numbers of households, vehicle use, etc.). The implication is that action will need to be more rapid to mitigate potential growth in emissions that may occur between now and 2050;
- We have focused on residential and commercial heating and road vehicle transport. In reality these segments form the majority of the emissions in each sector as discussed in sections 2.2.5 and 2.2.6. The internal workshops accordingly focused on these areas;
- We have used existing, practical technologies but have not costed the actions. Therefore this is one potential combination of changes that deliver the required level of emission reductions over this period rather than a modelled, optimised least-cost pathway to decarbonisation. In practice, the consistency with other roadmaps means that the actions in our roadmap are likely to be close to those included in any cost-effective pathway;
- As in most national roadmaps, we have not accounted for emission reduction activities associated with international aviation which will be subject to international agreement.

The savings targeted for each sector are shown in Table 18 below.

The table shows gaps between savings and target, both positive and negative. For 2020, emissions projections in recent years have been consistently indicating a breach of Non-ETS target around 2017 and an increasing trend thereafter (Environmental Protection Agency, 2017). Realistically, at this point, the target reduction of over 4 $MtCO_2$ by 2020 across the sectors may not be achievable within three years, even if new policy measures (e.g., the renewable heat incentive) are implemented. The roadmap has tried to be realistic.

However, these policies should be pursued as they will be necessary to promote the longer-term change that is required. Action will help to kick-start the new technologies and consumer acceptance, as is the trend with electric vehicles. An overachievement is shown in 2030 because of the necessity of ramping up towards 2050. Any overachievement will assist with any undershoot in later years. There is a small shortfall shown in 2050. This indicates uncertainty as some savings that can be made in 2050 will not be apparent to us now.

The key decarbonisation actions modelled in each sector are summarised in Table 19, with further detail provided in the following sections.

TABLE 18 – SUMMARY OF ANNUAL EMISSION REDUCTION ACTIVITY

	Emissions savings ($MtCO_2$ per annum)		
	2020	2030	2050
Target	4,072	6,424	16,995
Modelled savings from:			
Residential	829	3,638	5,965
Industrial and Commercial	199	993	2,747
Transport	1,044	2,611	7,800
Total	2,072	7,242	16,512
Gap to target	2,000	-818	483

TABLE 19 – SUMMARY OF DECARBONISATION ACTIONS BY SECTOR

Sector	Action	Reduction delivered by 2050 ($ktCO_2$)		Magnitude of change (approximate) 2020	2030	2050
Residential	Heat pumps replacing oil boilers	no.	2,079	50,000	300,000	500,000
	Biomass boilers replacing oil	no.	2,079	50,000	300,000	500,000
	Energy efficiency retrofit of gas homes	no.	1,121	168,000	450,000	560,000
	Partial Decarbonisation of gas heating	no.	686	31,000	156,000	565,000
Industrial and Commercial	Heat pumps replacing oil boilers	no.	215	145	725	1,450
	Biomass boilers replacing oil	no.	501	335	1675	3,350
	Decarbonisation of non-oil energy use	no.	2,030	-	-	-
Transport	EV deployment	no.	4,832	150,000	800,000	2.8m
	Liquid Biofuel	(L)	2,608	60,000	110,000	0.9m
	Electrification of public transport		360			

6.5.1

RESIDENTIAL SECTOR

Our analysis of the residential heat market is based on the household decomposition and thermal demand presented in the SEAI Renewable Heat to 2020 analysis (Sustainable Energy Authority of Ireland, 2015a). In this analysis, there are almost a million households with oil as their primary fuel source and over 620,000 households with gas as their primary fuel. [24]

An average oil household emits 5.2 tCO_2 per annum, with an average gas household emitting 3.7 tCO_2 per annum for heating purposes. In addition, there is a wide variation in emissions across the housing stock driven both by the size of the household and the thermal efficiency of the building stock. A large domestic dwelling with low thermal efficiency has almost four times the average annual energy demand, and hence almost four times the emissions, as a similar house with a high thermal efficiency (26.3 MWh/yr. compared to 7.1 MWh/yr.).

Reductions in residential emissions are achieved through a combination of major improvements in the thermal efficiency of the building fabric and the replacement of the heat source with a low carbon alternative. Most decarbonisation roadmaps assume that replacement of heat sources takes place at the end of their natural lives (typically around 15 to 20 years for oil boilers).

The main low-carbon technology choices are heat pumps and biomass boilers. The balance between these two options is itself driven by a combination of factors including cost, availability of biomass resource and feasibility e.g., restrictions on air quality or issues in use of heat pumps for particular building types and availability of space for fuel storage.

of heat pumps for particular building types and availability of space for fuel storage.

SEAI's residential energy roadmap focuses initially on activities to improve energy efficiency of the housing stock, projecting the retrofit up to 1 million households by 2020. Only after 2020 is there an acceleration in the deployment of renewable technologies, with up to 95% of the housing stock being converted to low carbon heat sources by 2050. However, SEAI offers two alternative pathways – a high electrification pathway (with contributions from heat pumps, solar PV/thermal and electric storage heating) and a high 'chemically fuelled' pathway (including liquid biofuels, biogas and biomass).

By comparison, the UCC 80% scenario has biomass and biogas each meeting the heat requirements of around 15% of the housing stock in 2050, with electric heating through heat pumps supplying 32% of households. The remaining 37% is still provided by gas.

Therefore, in any residential decarbonisation, three parallel trends should be anticipated:

- The substitution of oil-fired heating with low-carbon alternatives such as renewable energy or electric heat pumps;
- The improvement in the energy efficiency of the building stock and;
- The partial decarbonisation of gas-based heating systems.

Replacement of oil boilers

Assuming that an oil boiler has a lifetime of 20 years, then, given a strong policy environment towards decarbonisation, it is reasonable to expect around 5% of households to convert from oil each year, so that, by 2040, there should be no oil-fired heating in the domestic sector. The balance between heat pumps and bio-based heating options implied by this trajectory is less certain. The mix in the UCC scenarios suggests equal shares which is broadly consistent with that implied by the review of international roadmaps, where heat pump penetration may get as high as 60%.

The roadmap assumptions are therefore:
- Replace half of domestic oil boilers with heat pumps or equivalent electric-based solutions;
- Replace half of domestic oil boilers with biomass or biogas solutions; [25]
- Full replacement of the stock should be completed by 2050, with an assumed limited replacement prior to 2020 (10%) and 60% by 2030.

This implies:

- Around 500,000 heat pumps to be deployed in the current housing stock by 2040, with 300,000 installed by 2030 (or 20,000 installations per annum from now to 2030);
- An increase in electricity demand for domestic heating in the order of 1.2TWh per annum by 2040; and
- Realised cumulative emission savings of 0.4 $MtCO_2$ by 2020, 2.5 $MtCO_2$ by 2030 and 4.1 $MtCO_2$ by 2050.

The focus of the roadmap is in addressing the emissions of the housing stock that will be in place by 2020 (given the reliance on the SEAI study (2015a). Building regulations will need to specify zero local emissions from new homes to avoid further growth in the housing stock placing upward pressure on total emissions from the residential sector and avoiding the requirement for further action and disruption to homeowners.

[24] Note that this analysis implies a higher level of emissions from the residential sector than is reported by the EPA for 2015. SEAI projects annual emissions at 7453 $ktCO_2$, which we believe reflects an assumed growth in the number of households to 2020 of around 25,000 per year and also is basing analysis on average weather conditions whereas 2014 was a warm year.

Energy efficiency retrofit

As has already been mentioned, the energy efficiency of the existing housing stock is variable. SEAI analysis shows that the current average dwelling is equivalent to a D rating on the Building Energy Rating (BER) scale. Part of the improvement in this will need to come from deep energy retrofit of the fabric of the housing stock.

In our roadmap, we have based our emission saving calculations on the assumption that the replacement of oil boilers described above will be accompanied by a deep retrofit of the building fabric in each case. We have also assumed that all homes with gas-fired heating undertake a deep retrofit of the building fabric. If all existing gas households were to have the 'low' thermal demand level of the most energy efficient household categories in the SEAI analysis (Sustainable Energy Authority of Ireland, 2015a)[26] , then emissions would be 0.9 $MtCO_2$ lower per annum. This would more than halve the average emissions from a gas-fired household – to 1.5 tCO_2 from 3.7 tCO_2.

However, it should be noted that, this deep retrofit of building fabric while retaining the gas boiler will still mean gas heating is contributing to non-ETS emissions until the boiler is replaced with a low carbon heat source. For the purpose of this roadmap, no assessment has been done of the relative cost effectiveness of investing in such retrofits around individual heating solutions or considering more community-based heating solutions (such as district heating). The latter would enable further transitions to zero-carbon solutions in the future (whether bio-based, commercial scale heat pumps or even geothermal heat) and would be consistent with the 'chemically based' SEAI pathway that enables access to non-electrically powered renewable heat technologies.

The roadmap assumptions are therefore:
- 30% of current gas households have deep retrofits by 2020, 80% by 2030 and 100% by 2050.

This implies:

- Around 170,000 households to have a deep retrofit by 2020, 450,000 by 2030 and 560,000 by 2050; resulting in;
- Emission reductions of 0.34 $MtCO_2$ by 2020, 0.9 $MtCO_2$ by 2030 and 1.1 $MtCO_2$ by 2050.

Partial Decarbonisation of gas-based heating systems

Further emission reductions can be realised through the decarbonisation of the heat demand of the housing stock remaining on natural gas. This may be achieved through a combination of options including conversion to electric or biomass-based heating solutions, as proposed for oil or injection of green gas (biomethane) to the grid. For the purposes of this study we have not identified a specific solution, but emphasise the main message that additional action beyond energy efficiency improvements will be required from households currently heating with natural gas.

The roadmap assumptions are:
- 5% of household gas demand is 'decarbonised' by 2020, 25% by 2030 and 90% by 2050.

Overall contribution

The overall contribution of modelled actions in the residential sector to the reduction in non ETS emissions is shown in Table 20.

TABLE 20 – RESIDENTIAL SECTOR EMISSION REDUCTION CONTRIBUTION ($ktCO_2$)

		2020	2030	2050
Total non-ETS energy emission reduction requirement		4,072	6,424	16,995
Residential sector contribution		**829**	**3,638**	**5,965**
of which:	Oil to electric heating	208	1,247	2,079
	Oil to bio-based heating	208	1,247	2,079
	Energy efficiency retrofit of gas homes	336	897	1,124
	Decarbonisation of gas heating	77	247	686

6.5.2

INDUSTRIAL AND COMMERCIAL SECTOR

The non-domestic energy demand is split between industrial applications and commercial heating needs. We have assumed that around half of energy consumption in the commercial sector is electricity for non-heating needs. Heat demand in the commercial sector is derived from SEAI data. At present, around two-thirds of fossil-fuel heat demand is by gas and one-third oil. Oil boilers currently contribute 0.72 $MtCO_2$ to non-ETS emissions in the sector.

The replacement of these with lower-carbon solutions is again assumed to be a core element of delivering lower emissions. However, the balance of heating technologies is different, with a higher proportion of biomass and biogas solutions relative to electric-based solutions. This is in line with the projections in the UCC analysis where natural gas remains in the mix and the majority of the substitution is from oil. The roadmap assumptions therefore are:

- 10% of oil boilers replaced by 2020, 50% by 2030 and 100% by 2050;
- 70% of this replacement is assumed to be with biomass-based solutions and 30% with electric thermal or larger heat pump solutions.

This implies:

- Converting around 1,450 commercial properties to electric heating solutions by 2050, leading to an increase in electricity demand of around 0.7TWh.

Remaining, non-oil, energy demand in the industrial and commercial sector will also need to be addressed. This includes around 1.2 $MtCO_2$ of commercial heat demand from gas and another 1.3$MtCO_2$ from industry that we have not analysed as part of this study. As in the residential sector, we would anticipate the decarbonisation may achieved through a combination of technology and energy vector choices including biomethane, electrification, biomass, CCS and hydrogen.

The roadmap assumptions for this are:
- 5% decarbonisation by 2020, 25% by 2030 and 80% by 2050.

The overall contribution is outlined in table 21.

TABLE 21 – COMMERCIAL SECTOR EMISSION REDUCTION CONTRIBUTION ($ktCO_2$)

		2020	2030	2050
Total non-ETS energy emission reduction requirement		4,072	6,424	16,995
Commercial sector contribution		**199**	**993**	**2,747**
of which:	Oil to electric heating	22	107	215
	Oil to bio-based heating	50	251	501
	Decarbonisation of non-oil energy use	127	635	2,030

[25] Note that the options here may include installation of stand-alone biomass boilers or access to biogas through grid injection.

[26] The low demand level for a small, medium and large domestic dwelling is reported in the SEAI study as 3.5, 4.6 and 7.1 MWh/yr respectively, these are broadly half the emissions of a 'moderate' household and a quarter of those of a 'large' household.

6.5.3

TRANSPORT

Current transport sector emissions are more than double what they were in 1990, the base year against which the 80% energy emission reduction target is set. This is a consequence of the rapid growth in transport activity, particularly in vehicle ownership, which has led to a more than doubling of final energy demand in the sector for oil, a highly carbon-intensive energy carrier. An average car emits around 2.8tCO_2 per annum. This is more than a medium-sized, moderately efficient, gas-heated household.

The options for reducing emissions in transport vary across the different modes. While all modes are assumed to be able to benefit from improvements in the fuel efficiency of current engine technology, available electrification options are currently focussed on lighter road vehicles and rail because of considerations of battery capacity. For larger vehicles, from heavy goods vehicles to buses and trains, bioliquids are the predominant fuels in many roadmaps, with a lesser role for biogas. In addition, most roadmaps focus attention in the earlier stages of decarbonisation on improving fuel efficiency only in the later years showing conversion to alternative, lower carbon fuels.

Cars and light commercial vehicles

In the roadmaps analysed, electric vehicles (either battery EVs or plug-in hybrids) form upwards of 60% of the vehicle stock by 2050. The SEAI roadmap projects EVs being 60% to 70% of the vehicle stock by 2050, with their central scenario also having 18% of hydrogen fuel cell cars. The UCC 80% decarbonisation scenario has the whole private car fleet electrified by 2050, though the transformation in the car stock does not really start until 2030. A comprehensive study of transport by the International Council for Clean Transportation (International Council on Clean Transportation, 2015) projects a wide range of EV penetration rates for 2025-2030 in advanced market, from 20% to 50%. They assume that leading markets like the EU reach 20-25% electric-drive market shares by 2030

Consideration of both the ICCT and UCC trajectories on electrification of the passenger vehicle fleet, together with the need to meet the constraints on emissions, has led to the following assumptions in our roadmap:

- 5% of the passenger vehicle fleet being electric by 2020;
- 25% of the passenger vehicle fleet being electric by 2030; and
- 90% of the passenger vehicle fleet being electric by 2050.

This implies:

- A major growth in EV penetration by 2020 from around 500 vehicles to 90,000 vehicles;
- Around 2.8 million EVs by 2050 assuming growth in the fleet to 3 million private vehicles by that time; and
- An increase in electricity demand from transport in the order of 8TWh per annum by 2050.

Energy efficiency improvements in the internal combustion engine will further reduce emissions from this sector in the near-term. They will have limited impact in the longer-term as ICE numbers decline with increasing EV penetration. The assumption is that:

- New ICE passenger vehicle efficiency will reach 95 gCO_2/km by 2020 (in line with tightening EU regulations); and 85 gCO_2/km by 2030 (drawing on work by ICCT).

Heavy goods vehicles, rail and public transport

The road freight and public transportation (rail and bus) sectors together account for over 24% of emissions. The core changes in these segments of the sector are in line with those presented in the UCC scenario. By 2050, freight transport is around 10% gasoline and 90% biofuels. The biofuel mix is around two-thirds liquid biofuels and one-third biogas.

Following the transition to biofuels that is reported in the UCC analysis, we have assumed that the biofuel consumption in the heavy goods vehicles sector is:

- 5% by 2020, 10% by 2030 and 90% by 2050.

This implies:

- A large increase in imported biofuels to replace the oil imports that currently occur – the expectation is that existing distribution infrastructure will be able to deal with this increase.

Public transport contributes only 0.4MtCO_2 in 2015. As part of the roadmap, we have assumed this is electrified. The roadmap assumption is:

- 5% electrification by 2020, 25% by 2030 and 90% by 2050.

The car, light and heavy goods vehicle contribution under these roadmap assumptions is shown in Table 22.

TABLE 22 – TRANSPORT SECTOR EMISSION REDUCTION CONTRIBUTION (ktCO_2)

		2020	2030	2050
Total non-ETS energy emission reduction requirement		4,072	6,424	16,995
Transport sector contribution		**1,044**	**2,611**	**7,800**
of which:	EV vehicles	268	1342	4,832
	ICE efficiency improvement	593	843	0
	Bioliquid substitution	163	326	2,608
	Public transport electrification	20	100	360

6.6

OTHER ACTIONS

The actions outlined above deliver 16.5 MtCO_2 non-ETS energy sector emission reductions in total. This is broadly in line with the required savings to meet our modelled target as shown in Table 18.

Impacts on the electricity sector

The roadmap calls for, among other measures, the further adoption of electric solutions to mitigate CO_2 in both the heat and transport sectors. This will impact on electricity demand. On a broad estimate, this could lead to an additional 10 TWh of electricity demand by 2050, equivalent to around a 40% increase on current electricity consumption levels. This is broadly in line with the projections in the UCC (2013) analysis, which projects a 38% increase in electricity consumption between 2010 and 2050 in an 80% carbon reduction scenario.

It will also shift the profile of demand, creating additional pressures in balancing the system to deal with seasonal heat demand patterns.

As already outlined in 6.4, UCC projects that alongside this increase in electricity demand, the power generation sector will see a major transformation, with average carbon intensity falling to 38gCO_2/kWh in 2050 from 437gCO_2/kWh in 2015. To achieve this change, a fundamental change in the future generation mix is anticipated, with UCC seeing this being composed primarily of gas CCS and wind generation. The future generation mix has not been investigated in detail during this review, but, in line with UCC, we would anticipate a much greater penetration of low-carbon generation to deliver reductions in carbon intensity, with deployment of new technologies including energy storage and increased use of demand-side flexibility.

6.7

ROADMAP CONCLUSIONS

We summarise the evolution of the sectors through the roadmap below:

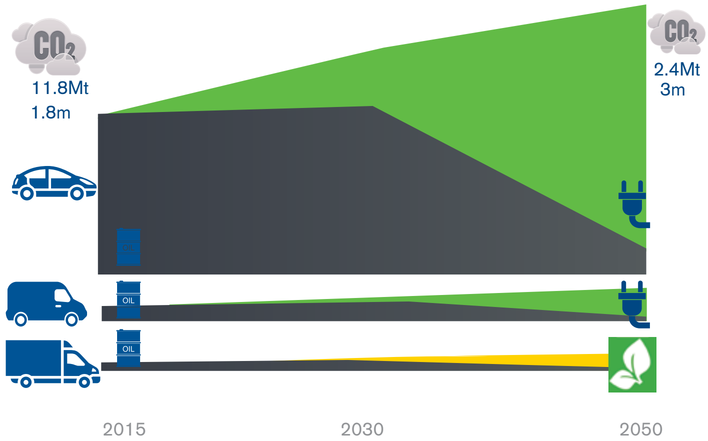
- The transport sector sees a transition to a passenger vehicle fleet that is 90% electric vehicles in 2050, alongside a larger role for biofuels in meeting residual transport fuel demand.
- Industry will be sourcing the majority of its energy requirements from renewable sources or from fossil fuels with CCS technology
- Oil will be removed from heating with biomass and electric heating options (primarily heat pumps) replacing oil
- The electricity sector, driven by the ETS, will be significantly decarbonised by 2050, with emissions expected to be around 2 $MtCO_2$.

The main insights from the roadmap exercise are:

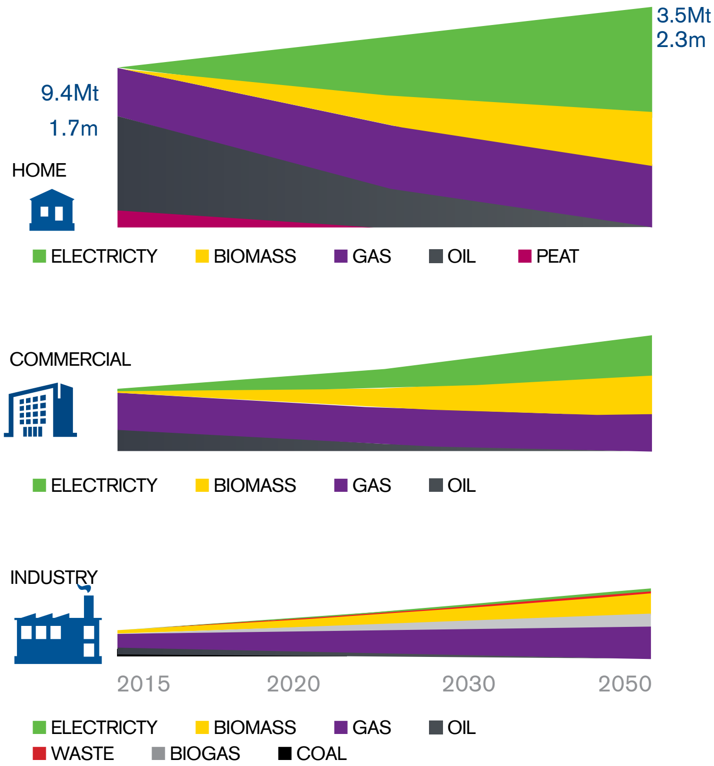
- To achieve 80% energy emission reductions requires action across the economy – activity cannot focus on a single sector because the scale of change is too large;
- The share of oil, the most carbon intensive fuel, in the country's energy mix must be drastically cut by 2050, falling from around 55% today to 5% by 2050 – this places emphasis on developing and delivering lower carbon alternatives in the transport and heating sectors;
- Electrification will have to be at the heart of the transformation in the core heating and road vehicle sectors;
- Biomass will play a role in low carbon heating
- Heat networks are likely to play a significant role especially in city centres where the building stock may be difficult to retrofit
- Deployment of new technologies such as heat pumps and electric vehicles will need to accelerate in the coming decade if there is to be any chance of meeting targets; and
- Opportunities for decarbonisation in segments of the market not investigated in this report will need to be exploited to meet the target.
- The development of CCS will be critical to Ireland's electricity system.

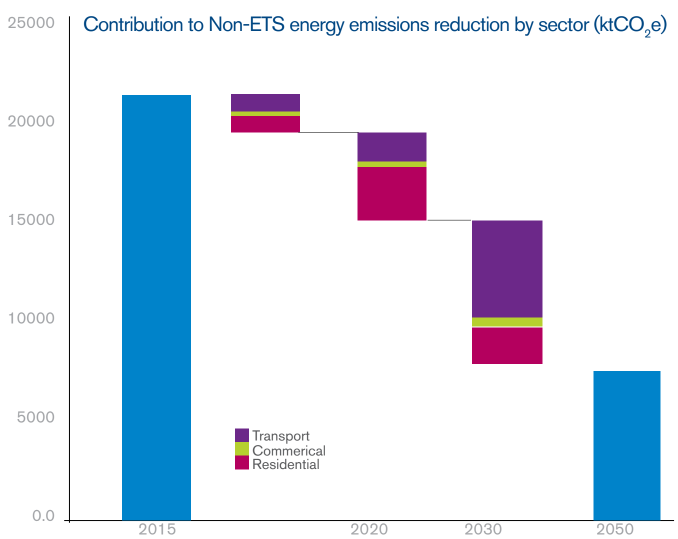
This transformation will not happen without a change in the commercial and policy landscape. What steps might be needed to facilitate the decarbonisation are discussed in Chapter 9.

TRANSPORT ROADMAP BY FUEL



HEAT ROADMAP BY FUEL





7

The Empowered Customer And Low Carbon Choices

- Customers already determine much of the nature of our energy system. The total amount of energy required is significantly influenced by the big and small choices customers make in their everyday lives. Decisions such as where they live, how they move about and decisions regarding the appliances they buy and use, all have an impact. Reducing emissions in heat and transport is a priority for Ireland. The move to a low carbon energy system requires the customer to make low carbon choices where they exist and therefore places the customer at the centre of the energy system and, directly or through a trusted agent or supplier, into the electricity market. A number of developments are facilitating this:
  - New housing standards are improving the efficiency of building fabrics to minimise losses.
  - Electric transportation options are becoming increasingly available.
  - Renewable generation is central to the removal of greenhouse gas emissions from electricity. Customers are increasingly installing micro electricity generation in their premises, becoming prosumers.
  - The general increase in variable generation raises the market value of responsive demand that can adjust to match available generation.
  - Low carbon technologies such as electric vehicles and heat pumps have inherent storage properties. They, in turn can facilitate demand response.
  - Technology, in the form of widely available broadband, smart controls, mobile phone applications and the phased introduction of smart meters, facilitates energy reduction, by making usage information more transparent and by enabling the automation of demand response in ways that maintain customer comfort and convenience.
- How the benefits of these changes are conveyed to the customers and how they are supported through the transition will determine how quickly these choices can be made.
- Experience to date shows that a number of customer-centred services will be crucial to facilitate the transition:
  - Availability of clear, relevant information.
  - Availability of independent trusted and highly qualified advisors.
  - Accessible finance.
  - A supportive policy framework.
  - Friendly, easy-to-use installation and connection processes.

7.1

INTRODUCTION

The preceding chapters have outlined the scale of emission reduction implied by Ireland's international responsibilities and climate policy and also the range of technologies that can be used to reduce emissions in electricity generation, heat and transport while maintaining or improving levels of service and comfort.

In heat and transport especially, mobilising a switch to low carbon technologies involves customer choice. With 2.6m vehicles on Irish roads (Department of Transport Tourism and Sport, 2017) and 1.7m occupied homes (Central Statistics Office, 2017) plus commercial and industrial buildings, a low carbon transformation amounts to a very large number of individual customer decisions. How can these decisions be influenced and facilitated to effect change while both avoiding undue hardship in the transition and providing increased utility for the customer? This chapter firstly looks at the patterns of customer energy use, some of the determinants of that energy use and some of the implications for customers and the energy system of low carbon and digital technologies. Finally we look at the considerations for achieving the transition through customers.

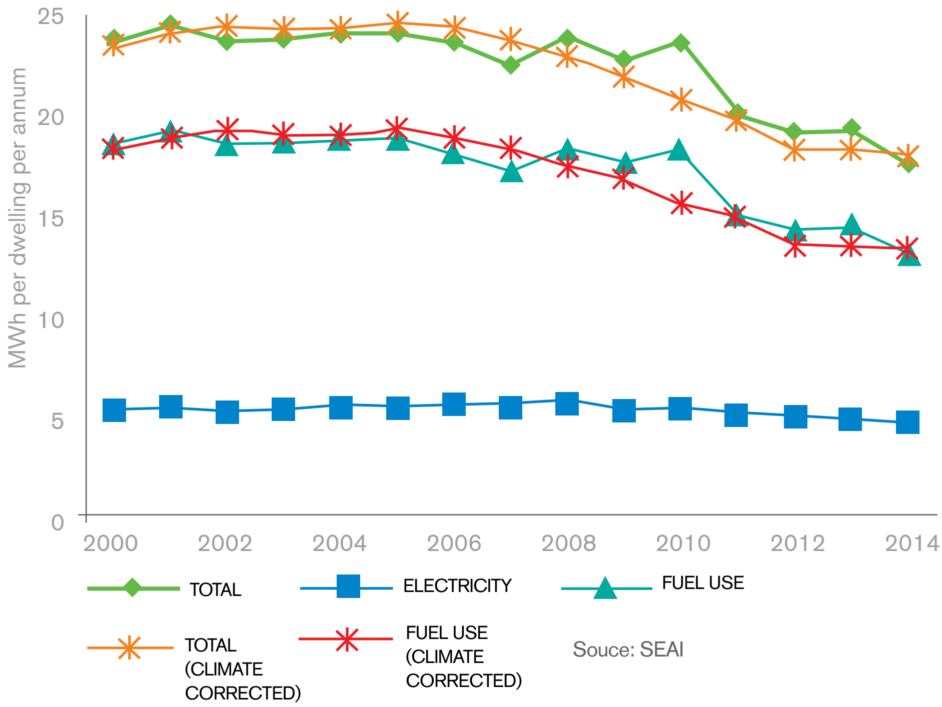
In looking at the factors influencing customer decisions, the chapter focuses on customers in the residential and commercial or services sectors. The home is where most recent technological change has been seen to date and broadly the same range of low carbon technologies applies to both sectors.

7.2

TRENDS AND DETERMINANTS OF CUSTOMER ENERGY USE

In 2015 the residential and commercial/public sectors accounted for 9.56 Mt of CO_2e and 4.85 Mt CO_2e respectively (Sustainable Energy Authority Ireland, 2016). In total this is about a quarter of greenhouse gas emissions. Buildings account for 35% of total final energy consumption in Ireland which means that the built environment is the second largest sector within energy after transport.

FIGURE 37 - FINAL ENERGY DEMAND PER DWELLING

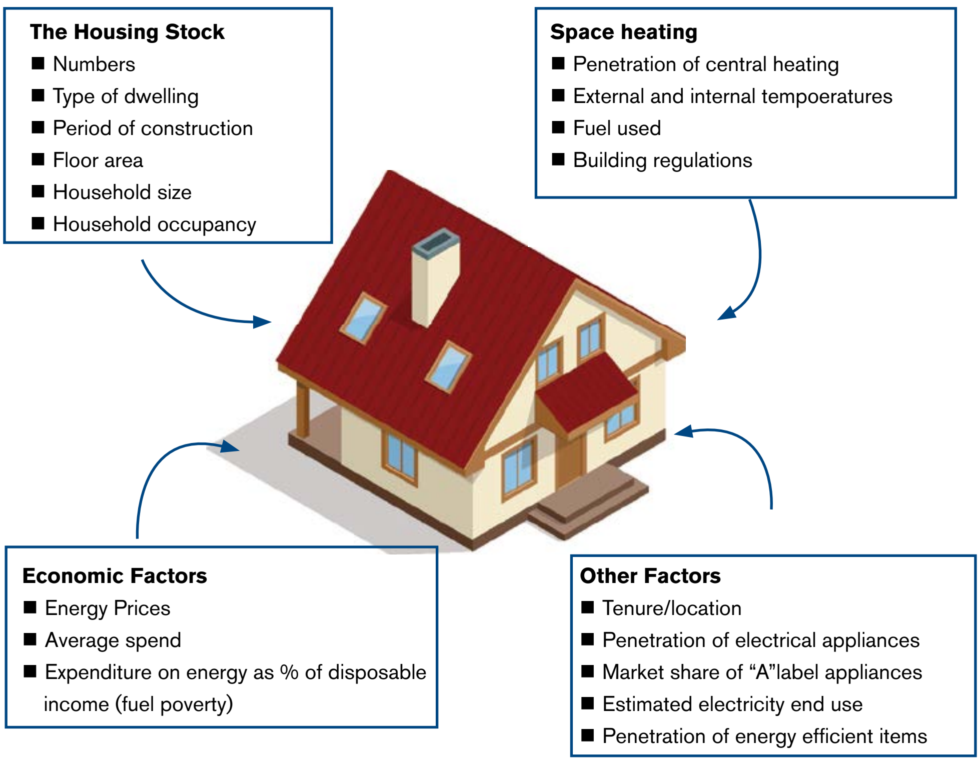


Souce: SEAI

In 2014, the average energy use of a dwelling in Ireland was about 18,000 kWh a year. Of this, use of fossil fuels – mainly for space and water heating - was about 12,000 kWh per year.

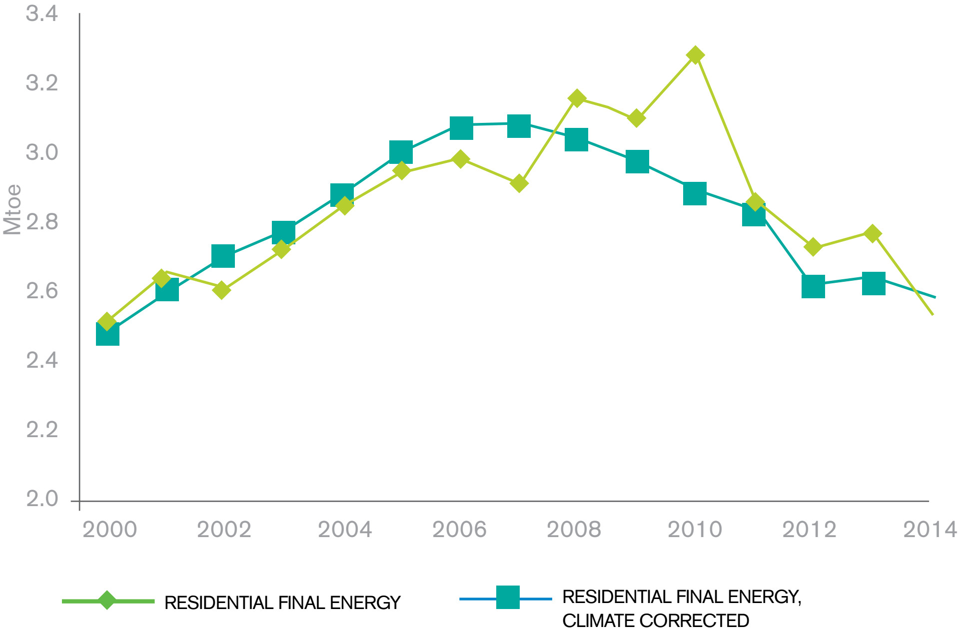
Residential energy use is driven by a range of factors. These are illustrated in the figure below.

FIGURE 38 - DRIVERS OF ENERGY USAGE AND CO_2 EMISSIONS



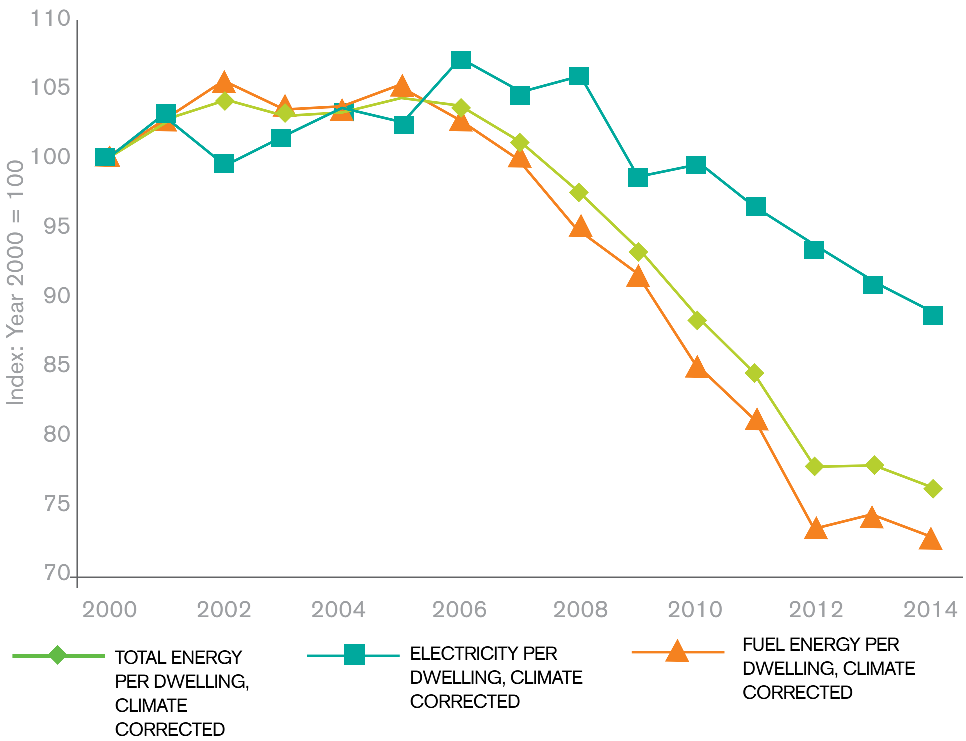
Souce: SEAI

FIGURE 39 RESIDENTIAL FINAL ENERGY DEMAND WITH CLIMATE CORRECTION



Souce: SEAI

FIGURE 40 INDEX OF ENERGY PER DWELLING CLIMATE CORRECTED, TOTAL, FUEL AND ELECTRIC



Souce: SEAI

Some of the principal factors are:

- Household size and occupancy level
- Choice of heating
- Choice of appliance i.e. whether they are 'A' rated or of lower efficiency
- How efficiently the appliances and heating are used
- Choice of transport

(Sustainable Energy Authority of Ireland, 2008)

Analysis by SEAI shows that energy efficiency has been improving in buildings, especially in homes. Figures 39 and 40 show this trend in energy use in homes in Ireland.

Energy use per dwelling decreased between 2000 and 2014 due to an estimated 34.7% improvement in energy efficiency. The SEAI study attributed this mainly to an improvement in the efficiency of heating, estimated at 39.3%, deriving from a shift from open fires to more efficient central heating, combined with improved insulation levels and the increase in buildings built to more recent, improved building standards (Sustainable Energy Authority of Ireland, 2016)(SEAI Energy Efficiency in the residential sector).

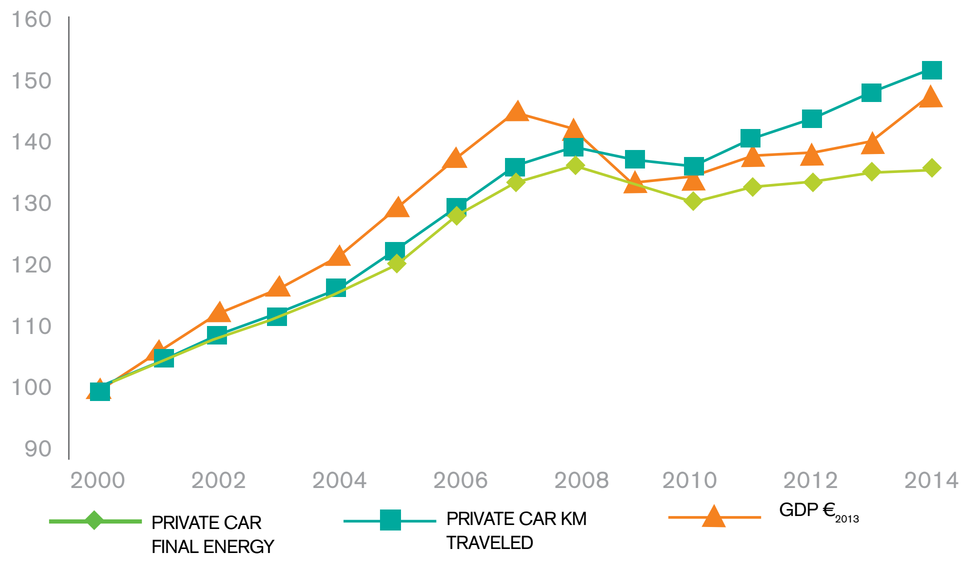
About a third of energy use in homes is electricity. Fossil fuels make up the balance. Ireland is unusual in having a large proportion of oil heating primarily due to large areas being remote from the gas network.

Information on energy use in the services sector is much more limited in Ireland. However energy use in the sector has been relatively flat even as the turnover of the sector and the number of employees has risen. Of the energy use in the sector, electricity's share is about 42%.
Within the transport sector, there have also been gains in the efficiency of private cars purchased by customers. While energy use in transport has increased, it has lagged behind the increase in total km travelled each year due to greater car numbers. However this improvement is significantly less marked than that in buildings.

FIGURE 41 SERVICES SECTOR FINAL ENERGY DEMAND

Souce: SEAI

FIGURE 42 CAR FINAL ENERGY AND UNDERLYING DRIVERS



Souce: CSO and SEAI

7.3 STEPS IN MAKING THE TRANSITION TO LOW CARBON

Assuming that the EU guidelines on energy efficient appliances will continue to improve the efficiency of electricity use, there are a number of significant steps that customers can take to reduce greenhouse gas emissions.

As we saw in Chapter 4, a customer can move to low carbon transport by:

- Selecting a battery electric or plug-in hybrid private car
- Using public transport that is low carbon, once it becomes available
- Walking or cycling where feasible.

Chapter 5 outlined the three key steps to transitioning the heating of a building to low carbon:

- Reduce energy use through increased efficiency of the heating system
- Shift the remaining energy use to low carbon sources such as electricity or biomass
- Reduce energy through improvements in the building fabric: insulation and airtightness.

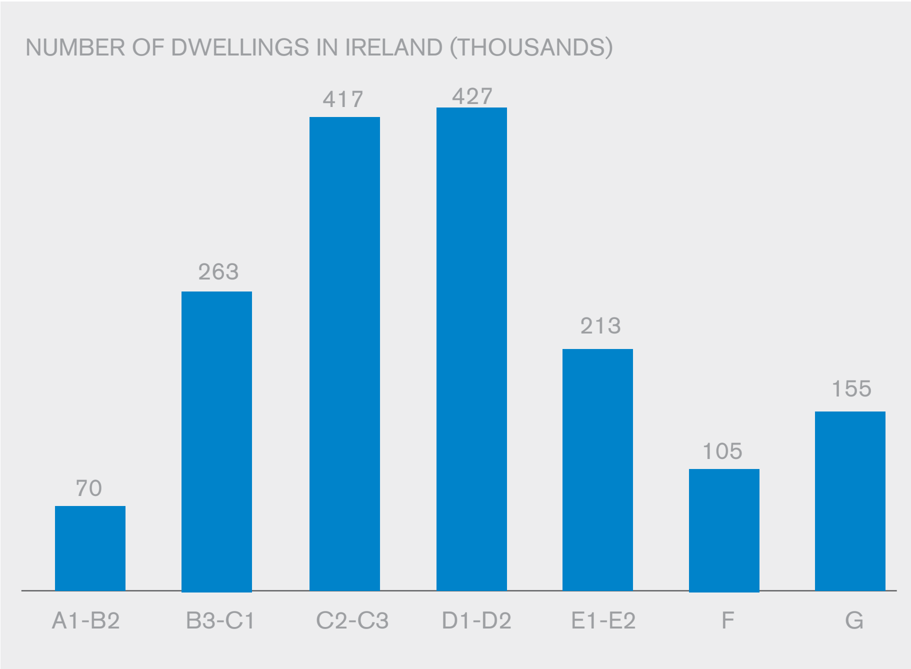
There is an additional option for those purchasing a new home:

- Selecting a new home that has no fossil fuel burning

In conjunction with low carbon heating, there are further steps that can assist the wider transition of the energy system to low carbon:

- Allow their electric vehicle charging or electric heating to be remotely turned up or down to provide system services to the electricity grid.
- Supplement their low carbon heating by installing microgeneration of renewable energy such as photovoltaic or solar thermal heating, although this is not currently cost-effective.

FIGURE 43 NUMBER OF DWELLINGS IN IRELAND BY BER CATEGORY (ESTIMATED)



Souce: SEAI (n.d)

These steps to low carbon have practical implications for customers. An understanding of these can illuminate the later discussion of the central role of the customer and the kind of policy environment that is conducive to these actions. The key practical implications are discussed below.

7.3.1 TRANSPORT OPTIONS

Selecting a battery electric or plug-in hybrid electric vehicle

The principal practical implication of operating an electric car is a means of charging. This means having a home charger fitted and having access to public charging infrastructure or workplace charging. The cost of fitting home charging depends on whether the home has a driveway and the length of the wiring route from there to the electrical distribution board in the home. This cost of this wiring (subject to a cost ceiling) is currently subsidised for the first number of electric vehicles.

Ireland has a relatively advanced and pervasive EV charging infrastructure. This forms a good basis to build on. Workplace charging exists in Ireland but is still in its early stages.

All of this means that using battery electric vehicles or driving plug-in hybrid electric vehicles in electric-only mode is feasible for the average daily commute. Workplace charging further facilitates this.

Low carbon public transport

At the time of writing, electric trains along the DART line in Dublin are the existing option. Electric buses are in operation in many cities in Europe and the US although capital costs tend to be higher. The National Transport Authority is currently running a market enquiry into the purchase of 'alternative fuel' buses (National Transport Authority, 2017).

7.3.2 REDUCING ENERGY USE

The majority of existing housing in Ireland has low energy performance. The mean BER rating is C to D (Sustainable Energy Authority of Ireland, n.d.).

In practice, to become low carbon, an existing home will need to make efficiency improvement to:

- Roof insulation
- Wall insulation
- windows and external doors
- airtightness

It will also require the replacement of the heating source with a low carbon heating source. This is known as a deep retrofit for the purposes of greenhouse gas reduction (Engineers Journal, 2017).

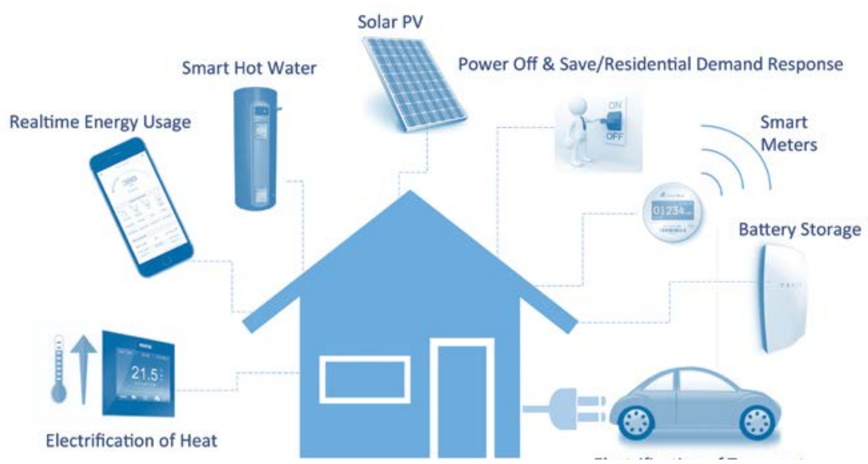
Moving to a low carbon heat source

There are limits to efficiency improvement. Firstly, there is the law of diminishing returns. The early efficiency measures taken by a homeowner will make the biggest impact on emissions. Once the overall usage has been reduced, there is less remaining energy - and emissions - to save and to fund the investment. After a certain point, the gains of further efficiency improvement measures become marginal. For example, it is in practice impractical to improve the efficiency of the fabric of an existing building to the point where a boiler is never switched on. Once a certain number of measures have been put in place, it is more practical to replace the boiler with an electric heat pump or biomass boiler, possibly with thermal solar panels. A low level of energy will still be used but it will be low carbon energy or using a mode of energy – electricity – that is reducing its carbon intensity in line with an EU agenda to reach low carbon.

As explained in chapter 5, the methods of achieving low carbon that are available to households in the EU are electricity, district heating, where it is available, biomass and biogas, where available. Electricity and district heating providers are both required to reduce greenhouse gas emissions over time without any obligation from customers. Biomass and biogas are regarded as low carbon although the potential future extent of their supply is unclear.

Heat pumps operate by maintaining a building at an even temperature – with small variations - all of the time. It turns out that a building that has had the efficiency of its fabric upgraded is ideally suited for this form of heating.

FIGURE 44 ILLUSTRATION OF THE CONCEPT OF THE SMART HOME



Selecting a new home that has no fossil fuel burning

Because the Paris Agreement effectively sets a finite budget for greenhouse gas emissions, fossil fuel heating will ultimately have to be removed from buildings. From this perspective, it is sensible to purchase a new home that doesn't use fossil fuels. The current building regulations are relatively progressive and mean that homes that emit zero carbon dioxide cost the same or less than emitting homes. However they still facilitate compliance for heating designs that burn fossil fuels provided photovoltaic electricity generation is installed.

Renewable electricity generation in a building helps Ireland increase its renewable electricity generation. However it does not in itself 'cancel out' or offset in any way the emissions from a fossil fuel boiler in the same building. On-site heat needs to be provided from a local source of renewable heat or else via an external source of energy such as electricity or district heating which itself has a viable pathway to low carbon. Otherwise the new fossil based heating systems in these new homes will have to be removed and replaced in time. In addition, open fireplaces and stoves, unless externally aspirated, promote draughts, increasing energy bills and compromising comfort.[27] In this way, a continuation of the current building regulations will lead to future carbon costs for Government and retrofitting costs for customers with new mortgages.

7.3.3 FLEXIBILITY AND DEMAND RESPONSE

Allowing electrical equipment in the home to provide flexibility, or demand response

As we have seen in Chapter 3 of this report, the principal sources of renewable electricity in Ireland are variable. In order to maintain supply at all times, electricity generation must always be matched with electricity demand. With variable generation, this means having a combination of dispatchable generation and demand reduction to maintain balance when the wind drops or sunshine dims. Electrical equipment with thermal storage is ideally suited to help in this task.

In the commercial sector cold stores are used in this way. Once the store has got down to temperature and the doors on the cold store remain closed, the cold store can tolerate the cooling equipment being switched off for a period without ill effect. In the same way, hot water cylinders in a home or a building with an efficient fabric heated by a heat pump have thermal storage. The heat pump or water heater can be interrupted for a period without noticeably affecting the room or water temperature.

Because they have a battery, electric cars can work in a similar way. An EV being charged at home can be interrupted for a period and reconnected to catch up later, provided there is sufficient charge by the morning. This interruption can be equivalent to an increase in generation to balance the system.

Electric heat pumps and electrical vehicles are part of the answer to reducing greenhouse gas emissions in the heating and transport sectors. Fortunately, as described above, it turns out that they can in principle assist with the decarbonisation of electricity as well.

7.3.4 MICROPRODUCTION OF RENEWABLE ENERGY

The capture of renewable energy on site can reduce the carbon footprint of a building. Some ways of achieving this are:

- Solar photovoltaic (PV) panels that generate electricity from the sun.
- Solar thermal panels. These heat water from the sun. The hot water can be used for water heating or for space heating. It can also be used as the heat source for a heat pump.
- Electric heat pumps. While electric heat pumps consume electrical energy, they use this to capture a greater quantity of renewable energy from the environment via the air, ground or a water body. The environmental heat obtained is around three times the electrical energy used.

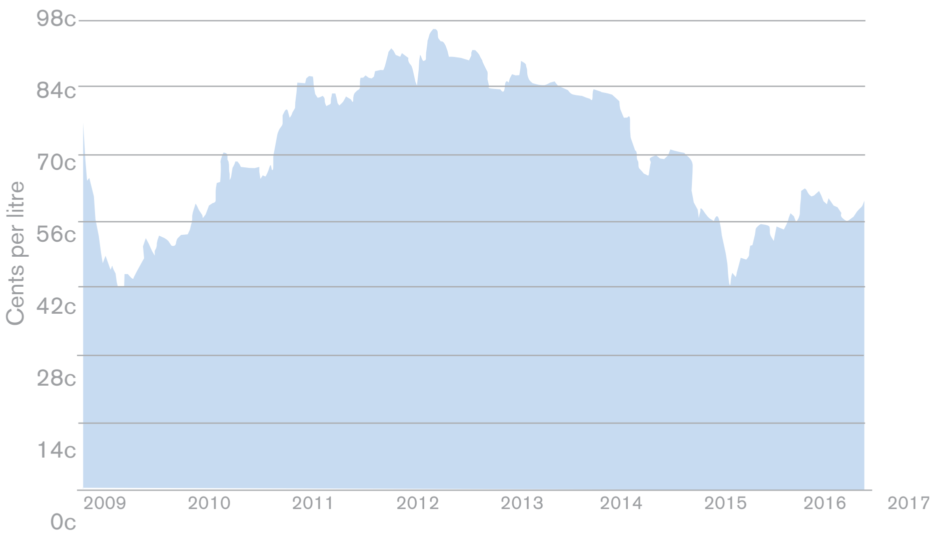
7.4 THE CUSTOMER AT THE CENTRE OF THE TRANSITION

A number of technologies and services have emerged with the potential to make it easier for the customer to play this more active role. They are briefly described under the following headings:

- Smarter home

[27] To avoid carbon monoxide poisoning, closed stoves require an open vent to be placed in an external wall, effectively puncturing the airtightness barrier. A hearth that has its own air supply obviates this requirement. However at the time of writing, these do not appear to be widely available or used as the building regulations allow these openings to be temporarily blocked for the purposes of airtightness certificationw

FIGURE 45 IRISH HEATING OIL PRICE TRENDS IN IRELAND



Souce: CheapestOil.ie

- Smart metering
- Mobile Applications
- Mediators
- Advisors

7.4.1 SMARTER HOME

The increasing capability for automation within the home is well documented. The widespread availability of wireless broadband within homes together with the increase in built-in intelligence in household appliances and devices has increased the possibilities for sophisticated control at low cost. Remote monitoring of CCTV cameras and control of heating or lighting are examples. Smart assistants such as Amazon's Alexa, Google's home or Apple's Homekit translate voice commands into instructions directed at control-enabled devices, appliances or socket outlets.

These capabilities bring closer the adaptation of energy use in real time in response to market signals, provided it can be seamless and advantageous to the customer.

7.4.2 SMART METERING

The Commission for Regulation of Utilities has recently announced the decision to install smart meters in every customer premises on a phased basis (Commission of Regulation of Utilities, 2017). Smart meters provide consumption data much closer to real time than normal meters, for example every half hour. This information will be available to customers through their electricity supplier and by interfacing with the meter's wireless home area network. This information can then be used by the customer in applications to manage energy use and devices in the home.

The availability of half-hourly consumption information will ultimately make it possible to settle all electricity costs in the wholesale electricity market on an actual basis every half hour. This, in turn, will incentivise electricity suppliers to respond to the price signals in the market in response to the availability or scarcity of intermittent renewable generation. Smart meters also facilitate recording of exported as well as imported energy which may facilitate the trading of excess electricity generated by a customer's microgeneration and provide for remuneration for the provision of system balancing services.

Finally, it will be possible to provide services that are already becoming popular, such as pay as you go electricity, without the need for additional hardware and without delay, much as it is possible to switch from contract to pay as you go in mobile phone services.

7.4.3

Mediators and platforms aggregators

Aggregators are third parties who trade in the electricity market on behalf of a large number of small generators or demand response customers. Energy suppliers can also act as aggregators. The commands to switch on or off in response to market requirements may issue to large numbers of separate installations at the same time. The speed with which switching instructions can be transmitted and effected is critical when providing system services.

Peer to peer electricity trading

Platforms are emerging that facilitate customers to sell or donate their exported renewable generation to other customers.

7.4.4 MOBILE APPLICATIONS

Applications on mobile phones and tablets place powerful software, supported by online databases, in customers' hands at low cost. Applications with well-designed interfaces make it easy for customers to make choices, change their preferences and to monitor costs and comfort levels in their home. They can use these applications to remotely switch appliances or devices or to change temperatures without having to be physically in the home.

Smart thermostats and electric heat pumps are now supported by free mobile applications that make temperature and other information held in a heating system visible to the customer and allow conditions and heating schedules to be adjusted to suit preferences and to control costs.

In transport, the eCar connect application gives the location of every EV charging point and real-time information on which charging points are in use and which are available in each location. The Real Time and Journey Plan applications from the National Transport Authority Ireland provide real time information on public transport services.

Mobile applications also offer new ways to engage with customers and communities by providing targeted tips and hints and advice based on what has been achieved by other customers in the area. Interfaces based on those used in games can be more engaging and effective than traditional interfaces.

7.4.5

Independent Advisors

Given the complexity and potential risks of a home retrofit project, the availability of independent advisors with proven expertise who can audit a home, recommend improvement measures and contractors and manage the subsequent project have been shown to be crucial to customers' decisions to proceed with low carbon measures and to the ultimate success of the project (Sustainable Energy Authority of Ireland, n.d.).

These advisors can use case history information and actual energy information from completed retrofits to gain more learning and expertise which can be used to improve the effectiveness for customers of future projects.

7.4.6 THE COMMERCIAL AND SERVICE CUSTOMER

The foregoing has focused on residential customers and the home because the potential for remote control has only recently emerged in the residential sector. The same opportunities – for low carbon transport and heating retrofit and demand response – and the same barriers exist for larger customers in the commercial and services sector (Sustainable Energy Authority of Ireland, 2015).

7.5 UNCERTAINTIES

The customer has a clear role in the low carbon transition. Technological advances mean that many tools are in place to enable switches to low carbon and the development of ecosystems that support demand response. As in any emerging field, uncertainties and potential barriers exist. It is useful to examine these as areas where effort and policy can make a substantial difference.

AWARENESS

As clarity is only just emerging on the likely lowest regret pathways towards the low carbon transition, there are major gaps in awareness among customers as to future direction. Awareness of the benefits of low carbon retrofit and of opportunities to arrange this are important considerations for take-up (Sustainable Energy Authority of Ireland, n.d.). In home retrofit, the presence of independent, trusted advisors can assist in overcoming this.
It is also important that customers have access to information when buying a new house or car on which choices are compatible with the low carbon future and with better resale values. This could perhaps be promoted by ensuring that building energy ratings and vehicle rating bands correctly indicate which choices are required for the transition to low carbon.

Where the Customer is not the Decision Maker

The selection of heating system for a new home is often in the hands of a developer rather than the future home-owner. Customer preferences may not be influential in a seller's market or, at least, there may be a lag before they have an influence on construction choices. In a similar way, the decision on whether or not to retrofit a rented premises for low carbon and improved comfort is in the hands of the landlord. In these cases, incentives may be 'split': the benefits flow to the tenant but the landlord would pay any extra costs to get these benefits.

FINANCE

SEAI has estimated the average cost of a low carbon home energy retrofit as €20,000 meaning that retrofitting housing nationally will cost in the region of €35bn (Engineers Journal, 2017). Case histories have documented the improvement in comfort and life quality that results for customers. However payback periods based on running cost savings alone are long. Customers tend to find it difficult to obtain finance for these investments. SEAI has found that most retrofits have been carried out by customers who were able to pay for them from savings.
With a total cost in the billions, it will be important that low cost finance can be secured to help fund the work. A financing vehicle using European Investment Bank or other low cost funds to provide this would be worth exploring.

DISRUPTION

Concern with disruption doesn't feature in the survey of customer attitudes carried out by SEAI, although anecdotal evidence suggests this can be a barrier (Sustainable Energy Authority of Ireland, n.d.). However concern with how easily the project can be put together and organised is identified as the second most important factor after improved comfort.

FOSSIL FUEL PRICES

Home heating oil prices are approximately 30% lower today than they were in 2015. This significantly lengthens the payback period for low carbon retrofits. In addition, the uncertainty around future heating oil prices is likely to create doubt in the minds of customers who wish to improve their homes. The task of persuading customers to invest would be significantly easier even at the level of oil price seen only 4 years ago (Cheapest Oil, n.d.).

HEAT NETWORKS

To the factors considered above can be added the consideration that a framework for heat networks is only in the earliest stages or forming in Ireland. Customers are not familiar with relying on a utility for their hot water and there are no trusted providers as yet with a track record in this area who would attract trust from customers.

While research doesn't exist at this early stage, this is likely to prove a barrier. Given the lead time in establishing trust, it will be important to support the development of successful projects and the dissemination of their case histories in order to overcome this. The Heat Networks Development fund in the UK or a similar method should be explored.

7.6 CONCLUSION

With two million cars in Ireland and just under that number of occupied homes, the low carbon transition will require a large number of individual decisions by customers. Technologies are emerging that can empower customers to play a more active role in the energy system and market without undue time or difficulty. Making it all happen is still a challenge. Promotion of awareness and a supportive and coherent policy framework that promotes low carbon options in both transport and heating will be important. The role of communities in spreading awareness and facilitating initiatives will be important. We make recommendations in Chapter 9 to this end.

Once customers move in this direction, the role of an adaptive smart network and of related customer-facing processes will have a key role to play.

8

SMART DISTRIBUTION NETWORKS – TYING IT ALL TOGETHER

- EVs and electric heat pumps present a new kind of usage pattern to the distribution network. Before this, because of short running times and the natural variation in usage, the total loading for a group of houses has generally been much less than the sum of the peak loads in each home. This is known as a high level of 'diversity'. Network connections for housing are designed to be least cost and therefore make use of this fact. In contrast, EVs and heat pumps run at a constant level for long periods and at similar times and so have the potential to almost fully add to the peak with very little diversity unless actively managed.
- In new developments of 'all electric' homes and offices with EV charging and electric heat pumps, the distribution network can be designed at the outset to accommodate them economically.
- ESB Networks' studies indicate that the existing network connecting rural homes and housing schemes can accommodate retrofits of EVs and/or electric heat pumps up to a penetration level of approximately 20% at a reasonable cost, assuming an additional load of 3kW per EV and/or electric heat pump per customer.
- For existing customers/industrial buildings, the current procedures for an increase in capacity at a connection point can be used by customers to accommodate an 'all electric' retrofit.
- While studies will be required for penetration levels above 20%, ESB Networks is developing innovative technical methods to efficiently provide the necessary increases in capacity. As a result, ESB Group believes that the increased electrical demand should enable the impact on electricity prices to be minimised.
- ESB Networks is proactively engaging in trials and field studies with other industry players to identify emerging trends, evaluate the impacts and find the most economic and 'smart' ways to manage these new technologies.

8.1
INTRODUCTION

The roadmap in Chapter 6 of this report – as well as most others - sees electrification of heat and transport as a critical element of achieving a low carbon energy system. The impacts of electrification on the customer and the increasingly smart, internet enabled home were explored in the last chapter. Obviously these devices will also interact with the distribution network, which is itself evolving into a smart network.

A key question is how the existing distribution network can accommodate relatively new, high load factor loads such as electric heat pumps and electric vehicle chargers within quality of supply standards at a reasonable cost. Another question is how new or upgraded networks can be designed with the flexibility to permit increased capacity where and when it is needed in response to electrification. This chapter draws on published documents describing ESB Networks' work on these issues (PlanGridEV, 2015). In addition, descriptions by ESB Networks of their work on new concepts relating to smart networks are included in boxed sections (marked 'ESB Networks') below.

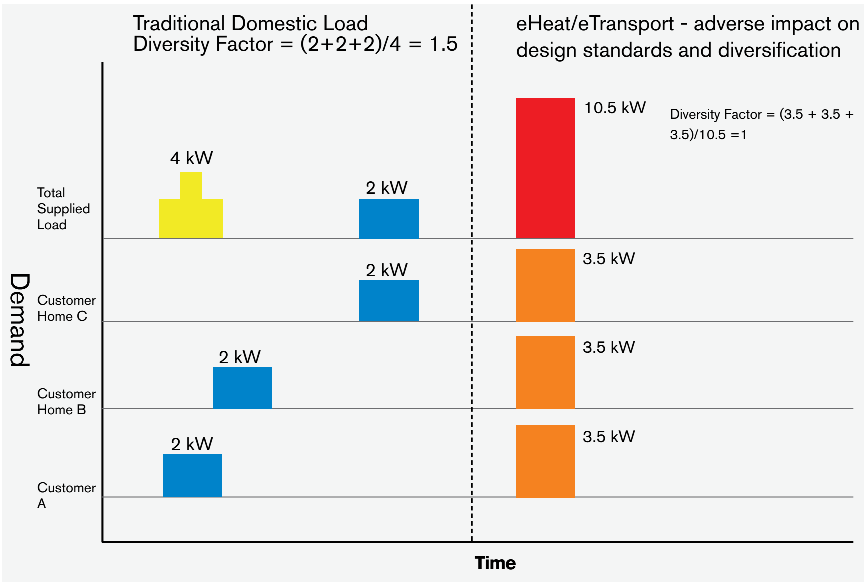
8.2
ELECTRICITY NETWORK DESIGN & DIVERSITY

In order to understand the implications of heat pumps and electric vehicles for existing electricity distribution networks, it is useful to appreciate the approach to their design. This is described briefly in the following section.

8.2.1
HOW NETWORKS HAVE BEEN HISTORICALLY DESIGNED

The planning of utility networks to meet customer demand follows the same fundamental economic principles as it did in the 1950's, albeit updated gradually over time in response to gradual societal development.

FIGURE 46 DIVERSITY FACTORS EXAMPLE

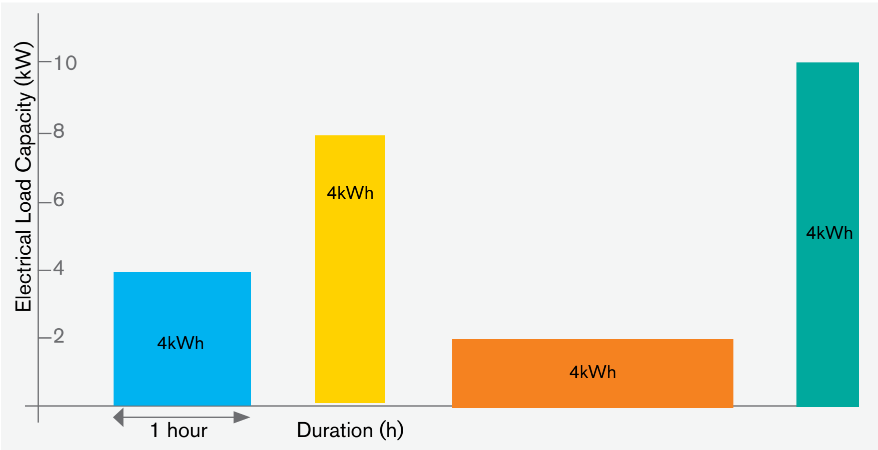


These principles rely on traditional, user-driven, stable and predictable models of customer load and were used to provide contracted capacity to customers at the minimum reasonable cost. Similar to other utilities, the distribution network in Ireland was designed on the principle of diversification. After diversity maximum demand (ADMD) is the coincident peak load per customer a shared network component is likely to experience over its lifetime. It is calculated based on measurements which show that human activity is diverse and thus so is the corresponding energy use.

An example of this principle in practice is that the dedicated cable ('service') connecting a single customer to the shared network in a housing estate must be able to cope with the maximum import capacity (MIC) of that customer, usually 12kW. On the other hand, the peak demand on the upstream network shared by many customers will generally be much less than the sum of the individual MICs of the customers connected to it (generally 2kW per household, subject to a 12kW minimum). Designing networks based on the load patterns of individual customers not coinciding has historically proven a very reliable way of meeting customers needs at the minimum reasonable cost.

The principle is illustrated in Figure 46 above of a simple network supplying 3 customers. The top profile (labelled 'Supplied Load') is that of the shared network. The three profiles below it are those of the individual customers (labelled 'A', B' and 'C') connected to it. On the left hand side of the chart, the individual demands from customers, A, B and C rarely coincide. This leads to moderate demand in the common network serving them. Later in the day, to the right hand side of the chart, where the demands of all three customers coincide, we see a system peak in the shared network (marked in red). This is illustrative of the potential impact of electric vehicles and heat pumps. EVs and heat pumps both tend to be on for long periods with a constant demand. They are much more likely to coincide and add to peak demand on the shared network, with little diversity.

FIGURE 47 IMPACT OF LOAD DURATION ON PEAK



An EV may charge for 6 hours at 3kW, so that the average maximum demand seen on the shared network supplying such houses could now increase from 2kW to 5kW. In practice, other factors will also have a bearing. For example, the driving behaviour of the EV owner, may mean that the average charge requirement per household may be substantially less than this. Similarly, with respect to electrified heat loads the increased efficiency of our housing stock will reduce the electrical energy requirements for technologies such as heat pumps.

8.3 THE EMERGING SMART NETWORK OF THE FUTURE

Similar to the customer's premises and the move to the 'connected home', electricity networks are evolving towards smarter networks. These may have implications in future for how electrification loads are managed. An overview of these developments is provided below.

8.3.1 OVERVIEW OF THE TECHNOLOGIES

The concept of smart grids arises from the linking of information technology to electricity networks for more intelligent control in response to conditions and events on the network. It is partly driven by the increase in generation on distribution networks, ranging from large sites such as utility scale wind farms or solar parks, to small scale generation based in homes or workplaces. This can change the traditional flow of electricity on distribution networks. Traditionally the flow was from large central generation stations into the transmission network, from there into the distribution network and finally to the customer's home or business premises. Now the flow can happen in both directions from distributed generation sites through the distribution system to nearby customers or into the transmission system.

An additional and significant part of this picture is the active consumer or 'prosumer'. As well as the trend for customers to have generation and in some circumstances storage on their premises that can export as well as import, customers can have 'smart' electrical loads that can be remotely controlled, usually by an intermediary, to provide system services in the electricity market and to the System Operator. Now, given the need to fully decarbonise heat and transport, a home with an electric vehicle charger and a heat pump is anticipated to be a more frequent configuration. Both EV chargers and heat pumps, once connected, have the potential to be controlled to provide demand reduction. Thermal storage, in the form of the building fabric of the home and a hot water tank is cheaper than electrical storage and could be used to facilitate a heat pump in demand management activities. In this way, EV chargers and heat pumps are likely to join remote network monitoring and control and distributed generation in the extended ecosystem facilitated by the smart network of the future.

These complex flows and events are occurring increasingly often on a network that was designed for unidirectional flow and for human and random switching of customer loads rather than automated and concerted switching. This creates the need for the active management of the network for operational reasons, to maintain supply standards for customers and also to minimise the extra investment required to accommodate these unaccustomed flows and events. (See box on 'ESB Networks and Servo' below)

Some of the technologies that form part of the emerging smart network are described in more detail below:

Distribution Automation

Distribution automation is the remote or automated control of switching points on the distribution network. It may be used to carry out normal switching operations or to reconfigure the network, isolating failed plant and restoring supply to customers after a fault on the network. Distribution automation technology also usually provides information from sensors in these remote devices back to a control centre to facilitate operations and for analysis.

Self-healing networks

The concept of a self-healing network is a development of coordinated distribution automation schemes where a network can remotely reconfigure itself without any operator intervention in the event of a fault, isolating the faulty section and restoring supply.

Distributed Generation

Distributed generation refers to electrical generation capacity connected to the distribution system. This ranges from large sites such as utility scale wind farms or solar parks to micro generation based in homes or workplaces across the distribution system.

Demand Response

Demand response is the remote control of electrical loads in customer premises, sometimes by an intermediary, to benefit from lower electricity prices at certain times of day, or to provide services in the market or to the system operator. At present in Ireland these services are offered to the transmission system operator and wholesale market, but in principle services could provide customers with a means of reducing their electricity costs, reducing the investment required to connect them to the network or providing services to the distribution system operator.

ESB Networks and 'Servo'- Real time facilitation of demand response

The advent of demand response and aggregators - who in principle could initiate the coordinated switching of large numbers of customer loads - leads to the need for the additional technical capability for distribution system operators (DSOs) to selectively intervene in those few cases where a particular switching instruction at a particular site would lead to a breach of the mandatory standards of supply. It will be necessary for DSOs to maintain power quality and reliability for all customers while facilitating third party demand response. This will require far greater real time monitoring and modelling of local system conditions. In Ireland a technical implementation of this emerging concept is known as 'Servo' (ESB Networks, 2017).

The Producer/Consumer ('Prosumer') or active consumer

A prosumer is a customer who has generation as well as demand and/or whose electrical loads than can be controlled in response to price signals or other means of control.

The group of active technologies forming the smart grid and interacting with it are illustrated in figure 48.

8.4 ELECTRIFICATION OF HEAT AND TRANSPORT AND THE DISTRIBUTION SYSTEM

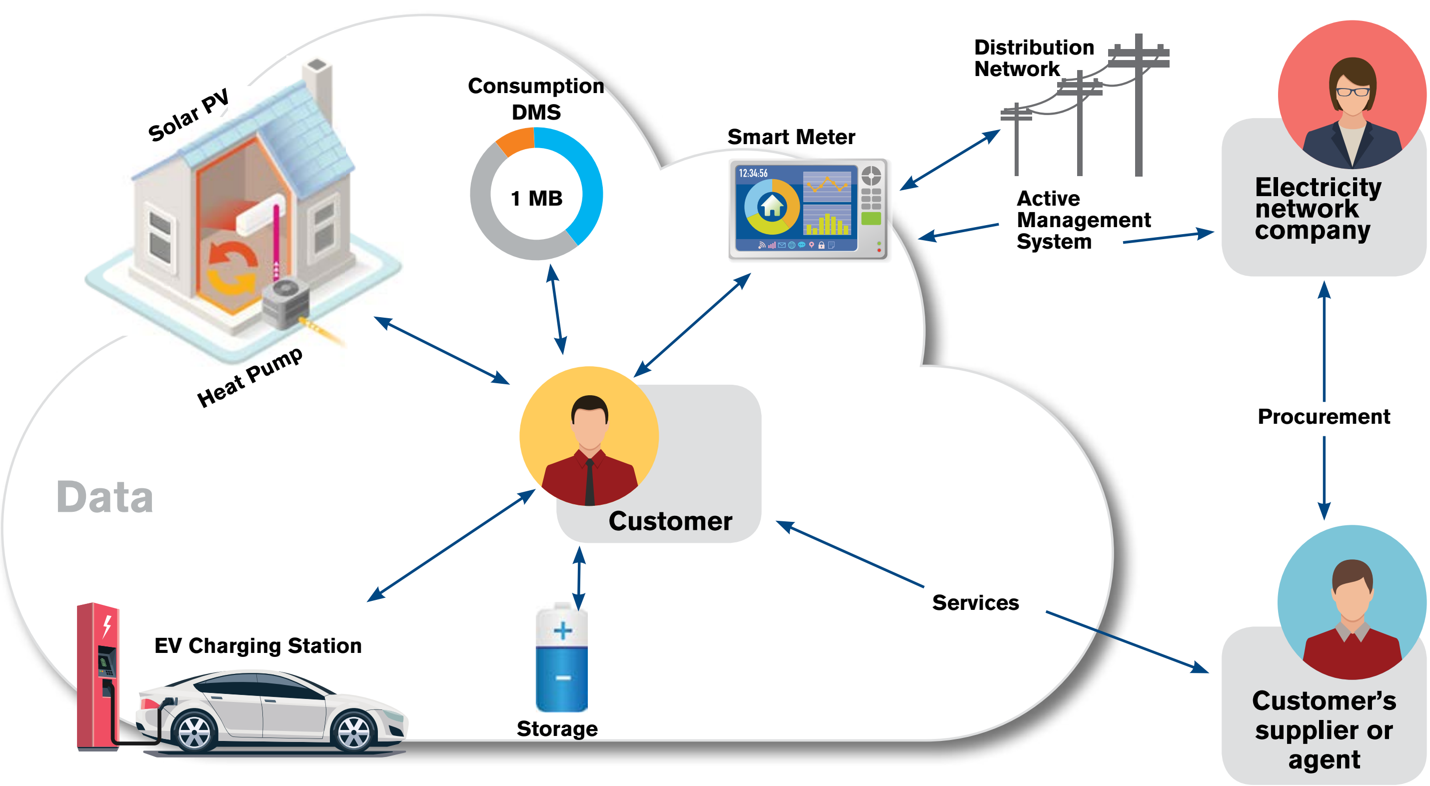
8.4.1 APPROACH TO ACCOMMODATING ELECTRIC VEHICLES AND HEAT PUMPS ON THE DISTRIBUTION SYSTEM

The low carbon roadmap in chapter 6 predicts the large scale proliferation of EVs and HPs on distribution networks. Based on experience to date and from the results of trials and studies, ESB believes that these changes can be managed at a reasonable cost with intelligent strategic planning and design of the network. This will include the efficient reinforcement of the low voltage network in existing housing schemes, updated design approaches for new developments to build the necessary flexibility in a the start, and may involve exploiting technological developments in 'smart' heating and EV charging. These approaches are further explained below.

8.4.2 WHAT THE ROADMAP WILL MEAN FOR NUMBERS OF EV CHARGERS AND HPS:

The Department of Tourism Transport and Sport projects that Ireland will have 25,000 Electric Cars by 2020, 260,000 by 2025 and 820,000 by 2030. (Alternative Fuels Framework Consultation Document Oct 2016). ESB Networks has studied the implications of a penetration of electric vehicle chargers into 20% of homes (ESB, 2016). An electric vehicle or electric heat

FIGURE 48 ILLUSTRATION OF THE COMPONENTS OF THE SMART NETWORK



pump imposes a similar load on the network so, the same design principles can be used to ensure the network can facilitate either of these technologies, or a mixture or both.

Existing housing

In older housing estates which have been designed for 2kW coincident load per household, increases may be more difficult to accommodate. It is expected that, in reality, such increases will mainly occur when car owners decide to change their cars, or as existing heating systems come to the end of their lives or when a house is being renovated. This is consistent with about 5% of homes installing either an EV charger or electric heat pump per year.

If this is correct, the impact will be gradual until EV adoption increases and a national building refurbishment programme achieves scale. This means that, in the early stages of the low carbon transition, problems are most likely to arise in 'clusters' or locations where a concentration of customers all adopt the new technology in a short period. Where these clusters occur, early reinforcement may be required. Accordingly ESB Networks have identified specific solutions that can be quickly deployed in such locations to solve the problem at an efficient cost (ESB, 2016).

Outside of these clusters, where the rate of electrification will be more uniform and diffuse, the additional anticipated capacity requirements could potentially be designed into routine renewal and reinforcement works so as to minimise cost implications. For example, when a transformer is due for replacement it could be replaced, where appropriate, with a larger unit at a low marginal cost where appropriate, so as to provide for the anticipated additional demand.

Later, as electrification increases, the same technical solutions can be used, albeit in response to demand growth rates which require intervention outside of the maintenance cycle.

For rural housing, because there are smaller numbers of customers sharing any LV network, designs cannot be as finely tuned and repeatable. Some networks will have adequate spare capacity already; others will require reinforcement. In the cases where reinforcement is required, it is generally technically straightforward but will cost relatively more than in the case of a housing scheme because of the reduced economies of scale.

Overall impact of 275,000 EVs and/or heat pumps on network serving existing housing
In the case of networks serving existing housing, ESB Networks has estimated that the existing capacity headroom on the network, together with some reinforcement where EVs are concentrated ('clustered'), will allow a further 275,000 EVs/HPs (3kW) to be connected at an estimated cost of approximately €300m (ESB, 2016).

Existing non-domestic customers
Connections to business customers are individually designed and processes exist for responding to requests for increases in connection capacity (ESB Networks, 2017).

Designing for Electrification in New Housing
Accommodating EV chargers or electric heat pump heating in new housing is relatively inexpensive if the demand is accounted for when the network is being designed in the first place. The low voltage network serving it can be designed so the required capacity can be provided on an incremental basis as the load develops.

8.5 WORK ON SMART DISTRIBUTION NETWORKS IN IRELAND

Ireland has a high penetration of wind generation connected to the distribution system and demand response has been accommodated for a number of years. The distribution system is relatively modern having been the subject of extensive refurbishment and capacity upgrade (by means of voltage conversion) in the last decade. It is also relatively extensive with the length of network per customer considerably above the EU average. For these reasons, ESB Networks was early in bringing smart elements to the network and has been recognised for this.

Partly supported by a provision for innovation approved by the utility regulator, ESB Networks has been active in research and trials in this area. Please refer to the box for trials and research projects that ESB Networks is participating in.

ESB Networks collaboration in research and trials on future networks solutions

Partly supported by a provision for innovation approved by the energy regulator, ESB Networks has been active in research and trials and is active in engaging with other utilities, the industry internationally and with expert groups sponsored by the European Commission to identify the challenges of changing networks use and to propose solutions. Extensive innovation trials have been undertaken by ESB Networks since 2009, involving customers, technology suppliers, academia and international experts including the Electric Power Research Institute (EPRI). These include: -

European FP7/H2020

- PlanGridEV – distribution grid planning and operational principles for EV mass roll-out while enabling distributed energy resources integration
- RealValue – demonstrate how local small-scale and distributed energy storage (thermal) could benefit all market participants, assess revenue streams and impact on the distribution network

National Research Projects

- Heat Pump trials and MV/LV unit substation monitoring – increased visibility of the low voltage distribution network
- Energy efficiency and loss management – conservation voltage reduction and network voltage conversion, low loss transformer trials and assessment;
- Continuity improvement – self healing networks, intelligent fault passage indicators;
- Network analysis – data analytics integrating smart metering and network data to assess loading patterns and predictive techniques;
- Reactive power and voltage management – innovative applications of distributed generation operational modes and network technologies to deliver more efficient connection solutions
- EV integration – field trials of clustered EV deployment on existing network to assess the voltage headroom and power quality impacts
- Demand side response (DSR) – developing active networks management solutions with prospective demand response R&D projects and customers

The projects specified above all involve physical trial locations on the distribution network. This evidence-based approach enables the appraisal of the distribution network in facilitating a higher penetration of eHeat and eTransport technologies and allows key research questions to be answered. The outcomes will identify a set of rules, standards, platforms and principles which will set the foundation for the active distributed networks of the future.

Overall this work and collaboration will assist the distribution system operator to identify the impacts early and establish practical solutions based on the evidence gained.

– ESB Networks

8.6 CONCLUSION

The electrification of heat and transport can be economically, efficiently and effectively accommodated in business connections and in domestic new build. Retrofitting in homes will require reinforcement of the network in some cases. For penetration levels of up to 20% of total EVs plus heat pumps (3kW), the costs are moderate.

Beyond this level, an increased requirement for reinforcement is expected. A programme for this work and the means of cost recovery will be subject to regulatory decision. Based on the load patterns of EVs and heat pumps and on studies to date, ESB Group believes that the cost of system development to support ever higher penetrations may be balanced by increased consumption, limiting any impact on the per unit price of electricity.

With the research and innovation currently underway into smart networks and smart homes, ESB Networks is well placed to efficiently manage this transition.

9

Recommendations

- This report has highlighted the urgency of climate action globally and for Ireland.
- We have looked at 5 elements of making this happen:
  - Customers and Communities
  - Low Carbon Electricity
  - Low Carbon Transport
  - Low Carbon Heat
  - Enabling Networks
- Each of these key dimensions requires a vision with recommendations to bring it about
- This section puts forward our proposals for this. It is our intention that they will stimulate the debate and lead to – hopefully – improved – visions and actions being brought into reality. We look forward to playing our part.

9.1

INTRODUCTION

This report has explored the implications for Ireland's energy system of its commitment to a low carbon future, has examined the technology options in each sector and has compiled an outline roadmap based on these findings. This section of the report considers potential actions to place each part of the energy sector on a pathway to low carbon that is least-cost and low regrets. For each sector, the vision is outlined and a set of recommendations is presented.

9.2

CUSTOMERS AND COMMUNITY

It will be important to clearly communicate with citizens on the implications of Ireland's commitment to low carbon and to raise awareness on the direction of travel of Ireland's mitigation plan. A holistic and sustained approach with a role for communities will be needed to enable the transition. In addition, the understanding of the long term vision set out in the Mitigation Plan will be fundamental to an informed debate on future infrastructure choices to move towards a consensus.

Vision

A public who are well informed on what a low carbon energy system means and are empowered to involve themselves and their communities in sustainable projects would be an asset in achieving the necessary changes. There is a developing consensus among representative politicians and parties on the long term vision for a low carbon Ireland in the National Mitigation Plan enabling it to become a reality.

Recommendations

- Inform the public of the specific sources of Ireland's emissions– the facts of the present – and debate proposed actions in terms of emissions impacts
- Build on the present Dialogue on Climate Action to further engage communities around the country
- Obtain national political consensus on the long-term low carbon vision in the National Mitigation Plan
- Maintain awareness-raising campaigns throughout the transition

9.3

ELECTRICITY

Ireland and Europe will need an electricity market that is designed to address this new range of technologies and economics to provide the necessary confidence for these investments.

Vision

A new market design to allow renewable solar and wind generation and low carbon generation to be developed and advanced. The policy and regulatory frameworks are in place for investment in key transition technologies such as carbon capture and storage.

Recommendations

- Promote Ireland's leading status on a global level as a developer and integrator of wind. Engage with the European Commission to influence the development of a 'Target Model 2.0'
- Secure potential storage sites for CCS and establish the legal and regulatory frameworks at an early date
- Promote investor confidence by clarifying the EU's direction of travel in the sustainability criteria for biomass

9.4

TRANSPORT

Emissions in transport have been strongly rising in recent years. International trends are moving towards the adoption of electric vehicles. This provides an opportunity to promote early adoption to halt the rising emissions trend and conserve Ireland's carbon budget.

Vision

Ireland has a private car fleet where all new additions are at the high efficiency end of the market, reducing emissions and avoiding loss of value for car owners. Zero emission vehicles are visible in our public fleet. Lower emission options for heavy goods vehicles including compressed natural gas have been developed. Experimentation is underway with new shared models of transport that may afford an opportunity to deliver step changes in emission and cost performance.

Recommendations

Government has identified key actions in the National Mitigation Plan. We suggest the following enabling steps:

- Make an early announcement of direction on the Government review of VRT and motor tax
- Provide confidence around the charging infrastructure into the medium term
- Introduce time-limited non-financial incentives for zero emission vehicles
- EVs in Government fleets and bus fleets
- Mandate EVs in Government fleets and bus fleets
- Following the current study by the International Transport Forum into a shared transport model for Dublin, commence a pilot. Set the goal of being an early adopter.

9.5

HEAT

The building stock in Ireland – as in other countries – needs to be effectively refurbished to zero emissions or provided with zero emission heat sources. Much has been learned about how to do this from the current pilot schemes for housing retrofit. In addition, Ireland is about to recommence house building in volume to serve a rising population. It is estimated that 30% of the homes we will have in 2050 have yet to be built.

Given the national goal of progressively reducing emissions, it appears intuitive that new housing and workplaces must not burn fossil fuels. This avoids adding to the scale of the GHG challenge and also improves air quality. In addition and, as signalled in the White Paper, a heat strategy is required to map the optimal low carbon approaches to specific geographical areas for the long term.

Vision

Ireland has a building industry where all new buildings have zero emissions, avoiding the need for retrofit for new homeowners and maximising air quality. An ecosystem of trained tradespeople exists, supporting a retrofit industry. Trusted advisors and financing options are widely available to building owners in low carbon retrofits. Comprehensive geographic data exists on heating demand and sources and clarity exists on which solutions are best suited to each area. This dovetails with the National Spatial Strategy to facilitate heat planning. Top class local academic expertise in heat solutions exists and is supporting a developing heat network industry.

Recommendations

- Move to building regulations that prescribe zero local emissions for all new buildings.
- Widen the availability of trusted advisors for low carbon retrofits.
- Establish standards and support upskilling
- Establish the enabling legislative and policy framework to facilitate those developing heat networks.
- Make attractive finance available for low carbon retrofits
- Establish a national heat study to gather detailed heat mapping data and to form a heat strategy to match solutions to specific areas for the least cost pathway to zero carbon. Consider including a local academic institution and an international one with expertise in heating at the centre of the project. Draw on this data and expertise to form a concrete low carbon plan for the sector.

9.6

ELECTRICITY NETWORKS

Ireland has a recently refurbished medium voltage network and has carried out early studies into the implications of electrification. In general, Ireland is well-placed to support national actions for low carbon heat and transport.

Vision

Smart, flexible networks support the low carbon vision in the National Mitigation Plan at optimal cost and with high quality of supply. The networks interact with aggregators of generation, heat and EV charging loads to facilitate renewable integration. Connection processes and commercial policies are seamless and easy to use and provide for the low carbon transition.

Recommendations

- Provide a clear policy direction on facilitating the actions in Government's National Mitigation Plan
- Embed this perspective in the planning of networks into the future
- Provide confidence around the availability of network capacity for electrification of heat and transport
- Operate processes that facilitate customers making the transition

We provide a brief summary of these recommendations in the next section.

9.7 SUMMARY OF RECOMMENDATIONS

Customers/Energy Citizens	Electricity	Transport
Inform the debate using accessible information on emission causes and their scale. Also on emissions solutions and their impact	Promote Ireland's status as a pioneer in integrating wind	Communicate the direction of travel following the Government review of VRT and motor tax
Build on the Climate Action Dialogue to engage communities	Engage with the European Commission to influence the development of a 'Target Model 2.0'	Provide confidence in the EV charging network
Obtain a cross-party position on the National Mitigation Plan	Secure potential storage sites for CCS and establish the legal and regulatory frameworks at an early date.	Non-financial incentives for early EV owners
Awareness-raising campaigns	Clarify the regulatory framework for biomass	EVs in Government fleets and bus fleets
		An early shared transport pilot in Dublin and other cities

Heat	Networks
Move to zero emissions in all new buildings	Policy guidance on facilitating the National Mitigation Plan
Trusted advisors for low carbon retrofit Set standards and support upskilling.	Facilitating low carbon heat and transport is a consideration in planning the networks
Low interest finance for home retrofit	Provide confidence in the capability of networks to support these goals
Enabling framework for heat network development	Adopt policies that facilitate customers making the transition
National heat study leading to a Heat Strategy	Review the networks tariff structure to ensure it supports the cost-effective transition to low carbon

ANNEX A - REFERENCES

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ANNEX B - ROADMAPS

The key aspects of each of the roadmaps reviewed are summarised in the following sections.

B.1

UK COMMITTEE ON CLIMATE CHANGE 5TH CARBON BUDGET (2015)

The UK Committee on Climate Change (CCC) is an independent statutory body responsible for advising UK government on setting and meeting its carbon budgets. In its report on recommendations for the 5th carbon budget (for the period 2028 to 2032) the UK Committee on Climate Change (CCC) outlined scenarios for the extent and timing of decarbonisation by 2032 to enable longer-term transformation to meet the UK government's 80% greenhouse gas reduction target by 2050.

On this pathway, emissions are projected to be 57% below 1990 levels by 2032 (compared with 36% below in 2014), requiring significant action across the economy. In the short-term (i.e. to 2020), the majority of reductions are expected to be delivered through the power sector and vehicle emission improvements, but beyond this, while there will continue to be downward pressure on the carbon intensity of generation, with a target to reduce this to below 100gCO2/kWh by 2030, there is also recognition that the emphasis will need to shift beyond power generation.

The non-ETS sectors are anticipated to deliver a 2% per annum reduction in emissions out to 2032, through a combination of energy efficiency improvements and electrification.

Key elements of this include:
- a 15% reduction in agricultural emissions, including expansion of anaerobic digestion (AD) technology for manure management;
- a target of 1 in 7 homes to be converted to low-carbon heat (mainly heat pumps and networks) by 2030; and
- a requirement for the majority (60%) of new cars to be electric vehicles by 2030.

The longer-term picture is one where not only the power sector is fully decarbonised by 2050, but almost complete decarbonisation of buildings and surface transport is also envisaged. To deliver this transformation, the CCC acknowledges a need to both promote new technologies – in particular, CCS – and to invest in infrastructure – primarily around the heat networks and EV charging infrastructure.

Bioenergy is expected to play a larger role in a decarbonised energy system, but the pathway reflects a constraint on available biomass (domestic and imports) due to sustainability concerns. Bioenergy is assumed to be able to meet 10% of primary energy demand by 2050, with a large proportion of this being diverted for use through CCS and in aviation and heavy transport, where alternative low-carbon solutions are not available.

B.2

DENMARK – OUR ENERGY FUTURE (2011)

The Danish energy system has a long-term target to deliver 100% renewable energy by 2050. In this roadmap, the government set out a coordinated long-term plan with intermediate goals to achieve this. Importantly, current decisions on technologies incorporate views on future technology choices to avoid lock-in to higher cost and/or carbon pathways.

Electrification is seen as an efficiency improvement in energy consumption and is promoted in both the heat and transport sectors, through heat pumps and EVs respectively. One of the critical factors in the early phase of the transition is a shift away from more carbon-intensive technologies. This is demonstrated in the target to phase out the use of oil boilers in heating by 2030.

Again, there is a focus on where best to use limited biomass resource to ensure sustainability. In addition to the emphasis on second generation biofuels for heavy transport there is specific reference to the use of biogas as a means of addressing emissions from livestock.

B.3

B.3 SMART ENERGY EUROPE (2015)

Smart Energy Europe is a roadmap for the EU28 developed by researchers at the University of Aalborg, Denmark, with funding from the Innovation Fund Denmark and from the EC via the Intelligent Energy Europe Programme. The roadmap analyses ways of delivering a 100% renewable energy system. The development of the system is based on the deployment of new sources of flexibility in the heat and transport sectors to accommodate higher levels of intermittent electricity production.

The analysis starts from the premise that current, large scale centralised production facilities in electricity and heat can only accommodate up to

20-25% of wind and solar power and that biomass resource is insufficient to deliver the remaining low carbon energy production. Higher shares of intermittent renewables are assumed to be accessible from utilising further flexibility. In particular:

- heat pumps are assumed to enable 30-40% penetration of intermittent generation through utilising thermal heat storage capability;
- electric vehicles in addition to heat pumps enable 50-60% intermittent generation to be accommodated; and
- by utilising 'electrofuels' (i.e. methanol and dimethyl ether (DME)) greater than 80% intermittent generation can be accommodated.

In developing heating solutions, the authors note that, at present, thermal storage is between 50 and 200 times cheaper than electricity storage. Much of the discussion of the value flexibility appears to be around larger-scale thermal stores linked to district heating systems, and the Heat Roadmap Europe study scenarios projected up to 500GWh of thermal storage capacity across Europe when 50% of heat demand was met by district heating (compared to average electricity consumption of 400GWh/hour).

However, a comparison of individual heating technologies concludes that oil and direct electric heating are not sustainable – the former due to carbon emissions and the latter due to the lower efficiency of conversion than with other options such as heat pumps, solar thermal and biomass boilers. The study concludes that, especially given the higher value of biomass in other sectors, heat pumps will be the most attractive technology option in the longer-term.

The shift in heating technology is assumed to take place alongside improvements in energy efficiency of the building stock, with the study projecting that an average of between 30% and 50% heat reduction in buildings would be cost effective between now and 2050.

Within the transport sector, the focus is on the deployment of electric vehicles to make use of the storage capacity associated with the technology. The scenario assumes conversion of 80% of the passenger vehicle fleet (of 250 million cars) by 2050, though it notes that at present there are two main barriers that will need to be overcome to ensure large-scale take up:

- a reduction in the commercial cost of vehicles; and
- a roll out of charging infrastructure.

B.4

B.4 DEEP DECARBONISATION PATHWAYS PROJECT (2015)

The Deep Decarbonisation Pathways Project (DDPP) report is prepared by independent research teams from across 16 countries that represent 74% of current global CO2 emissions. It is not a single energy system solution but an aggregation of analysis from each national market. The report emphasises some important common trends across a diverse range of economies:

- the transition in the energy mix is generally from coal to gas and then to lower or zero-carbon energy carriers;
- the transition will see a substantial increase in the role of electricity in the energy mix – on average, electricity's share of final energy demand doubles by 2050;
- there is a need to avoid investment in technologies that provide short-run incremental emissions reductions but are not compatible with deep decarbonisation as this increases overall cost of the transition through stranding of assets;
- in the earlier phases of transition energy intensity improvements occur more quickly than carbon intensity improvements as the shorter lifetimes of appliances and vehicles mean that new standards can be introduced and take effect more quickly.

These overarching messages are supplemented by more detailed analysis for individual countries. We have briefly reviewed the detailed roadmap for the UK (produced by University College London) to illustrate the actions required in a market similar to that of Ireland.

B.4.1

UK ROADMAP

The UK roadmap looks at ways of achieving 80% emission reductions by 2050. One of the key findings is that to deliver this overarching target, energy sector emission reduction will need to be more stringent (between 90% and 95%) to offset the lower or more costly activity in other areas. By 2050, 70% of residual emissions will be in non-CO2 greenhouse gases and CO2 emissions from international aviation.

The general trend in the energy system is similar to that in other markets:

- electricity doubles its share of the energy mix to be about 30-40% by 2050;
- low-cost trajectories rely on the development of specific low-carbon technologies, especially carbon capture and storage;
- there is an increasing role seen for district heating in any solution for the built environment;
- passenger vehicles are largely transitioned to electric-drive solutions; and

- hydrogen becomes a major energy carrier in the period post-2030.

The power sector is considered the most cost effective sector to decarbonise early, with a reduction in carbon intensity over today's levels of 85-90% by 2030 (i.e. around 75gCO2/kWh). However, this is dependent on the development of CCS and the report emphasises that further investment in fossil-fuel solutions (i.e. gas fired power generation) should not be taken unless there is confidence over the feasibility of CCS to mitigate emissions in the longer-term.

The passenger vehicle market sees a transformation towards electric vehicles (battery powered EVs, hybrid EVs and hydrogen fuel cell cars) over the period, though the assumption is that these emerge through natural stock turnover. As such, by 2030, EVs account for around 40% of new vehicle sales by 2030 and 90% by 2040. Freight traffic (HGV and LGV) follows a different pattern. HGVs are assumed to transition to a largely hydrogen-based solution via compressed natural gas, whereas LGVs are anticipated to be around two-thirds EV and one-third hydrogen-based by 2050.

The heat market sees a growing contribution from non-gas sources, though the high penetration of gas in the current system means this transition is relatively slow. By 2030 heat pumps and district heating account for around 15% of residential heat demand with the majority of the market still supplied by gas. By 2050, the gas contribution is less than 20% in all scenarios (replaced by a combination of heat pumps, solar thermal and district heating). However, the study notes that there is a residual role for the gas system to provide peak demand back-up (winter evening peaks are 2 to 4 times daily demand and this is most cost-effectively delivered by back-up gas boilers).

The role for district heating in urban areas is a large shift from current practice, though the study accepts that the ability to expand this is constrained by challenges on delivering new infrastructure and accessing sufficient volumes of low- or zero-carbon heat sources.

B.5

ENERGY TECHNOLOGIES INSTITUTE (2015)

The Energy Technologies Institute has developed two long-term scenarios for UK energy system decarbonisation – Clockwork and Patchwork – that present two different visions for a coordinated, centralised evolution or a more decentralised, localised adoption of low-carbon technologies. In both scenarios there is a drive towards energy efficiency and a material growth in the use of heat networks.

The electricity sector is largely decarbonised by 2050 in both scenarios, though the total capacity differs and the Clockwork scenario envisages biomass in association with CCS.

B.5.1

CLOCKWORK

The Clockwork scenario focuses on CCS and nuclear as long-term technologies. An earlier drive towards decarbonisation in the heat sector due to a lower cost of abatement enables a more phased development in transport. The earlier transport reductions come from improvements in the efficiency of ICEs and substitution with bio-based liquid fuels. To deliver reductions in the heat sector, a two-pronged approach is assumed, with upfront investment in heat networks to supply urban areas and a switch to heat pumps and biomass in boilers in rural areas. One of the implications of the change is a phase out of local gas distribution networks during the 2040s.

In applying CCS to biomass generation, the Clockwork scenario enables 'negative emissions' technology to be deployed (i.e. where the combined effect of using biomass as a fuel source and capturing the carbon emissions from combustion leads to a net removal of carbon from the atmosphere).

B.5.2

PATCHWORK

The patchwork scenario represents a less coordinated approach to decarbonisation and relies less on the deployment of CCS technology, which means more action across other sectors because there is no additional benefit from the carbon capture technology that would deliver negative emissions from power generation.

The immediate focus is again on the heat sector where there is an immediate need for oil boiler substitution for heat pumps and local heat networks being developed. In the transport sector there is a more pronounced shift to alternative fuels (electric and hydrogen and gas) to realise the transition. An interesting result of this pathway is a declining level of industrial activity.

B.6

EU ENERGY ROADMAP 2050 (2011)

The EU Energy Roadmap to 2050 looks at the decarbonisation options for the whole of the EU28. The pathway leads to a significant reduction in the role of oil and solid fuels in the primary energy mix, replaced by a growth in renewables and a doubling of the share of electricity in final energy consumption to around 40%. This electrification is anticipated to play a major contribution in the decarbonisation of the transport sector (65% of passenger and light vehicles are assumed to be electric by 2050) and heating.

The power sector is almost completely decarbonised by 2050 and there remains a critical role for CCS in the power sector.
Biomass is seen as the main option for aviation and long distance transport, though it is again limited by sustainability concerns.

B.7

LOW CARBON ENERGY ROADMAP FOR IRELAND (UCC, 2013)

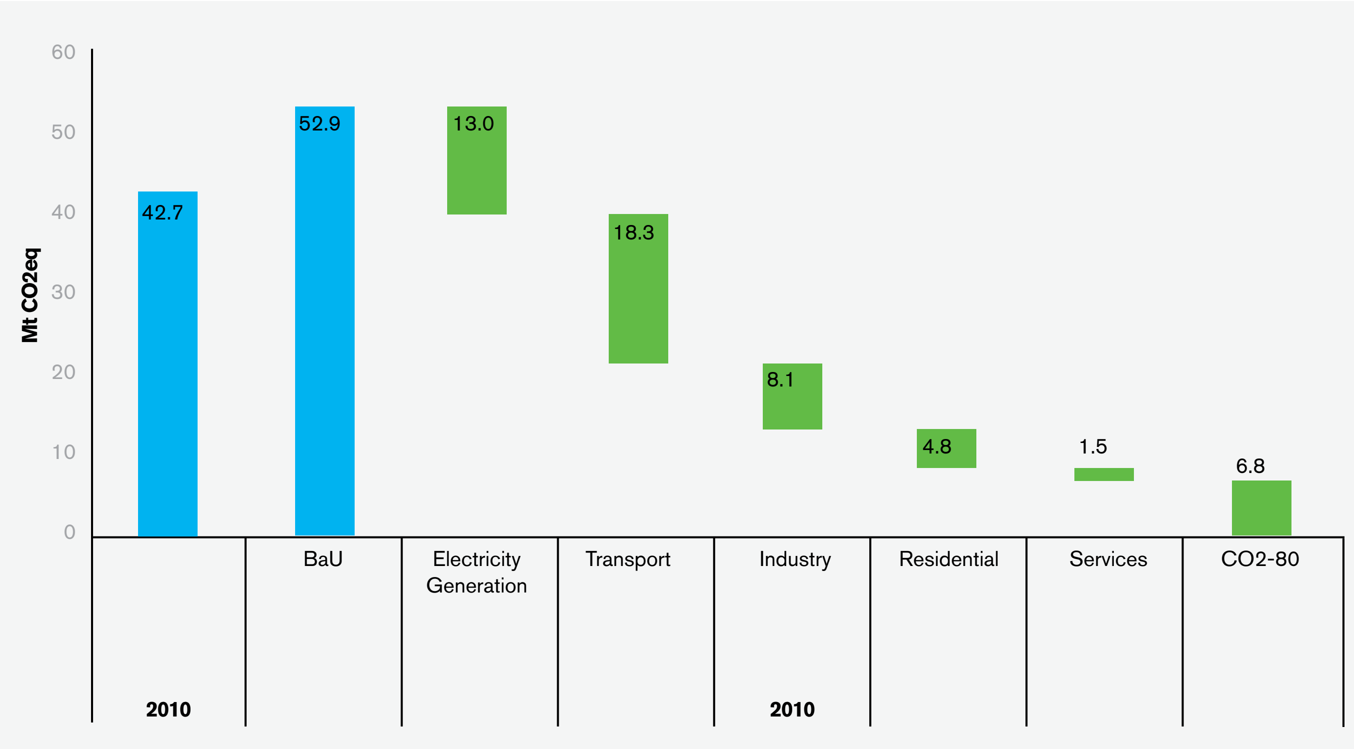
Table 23 below shows the sectoral GHG emission reductions that will be required to meet an 80-95% reduction in Irish greenhouse gas emissions in 2050 compared to 1990 levels[22]. It implies an interim 2030 target of a 30% reduction, with the backdrop that without strong climate policies, GHG emissions could increase 50% by 2030 under a BAU-scenario. We focus on the CO2-80 scenario (i.e. achieving the 80% reduction target) and Figure 32 shows the largest emissions savings (relative to BAU scenario) are required in the Transport sector (18.3Mt) with significant savings also made in electricity generation (13.0Mt).

TABLE 24 – LOW CARBON ENERGY ROADMAP TO 2050 GHG EMISSIONS

Sector	2030 relative to 1990		2050 relative to 1990	
	BAU	Low Carbon	BAU	Low Carbon
Electricity	45%	-56% to -58%	31%	-84% to -94%
Building	-11%	-53%	-11%	-75% to -99%
Services	5%	-33%	-6%	-70% to -99%
Residential	-16%	-59%	-13%	-77% to -92%
Transport	226%	104% to 122%	285%	-72% to -92%
Total	**50%**	**-29% to -31%**	**55%**	**-80% to -95%**

22. Technical support on developing the low carbon roadmaps for Ireland. Gallachóir et al., December 2013.

FIGURE 41 – CHANGE IN CO2 EMISSIONS BY SECTOR TO REACH AN 80% REDUCTION BY 2050



Source: Technical support on developing the low carbon roadmaps for Ireland. Gallachóir et al., December 2013.

The CO2-80 scenario implies a dramatic drop in reliance on oil, whereas bioenergy expands. Liquid biofuels are extensively used in transport, with solid biomass in industry. There is a significant expansion in wind energy and electricity used both in transport and heating for the residential sector.

By 2050, the power sector is largely decarbonised. Compared to a current carbon intensity of generation of around 500 gCO2/kWh, the CO2-80 scenario has a carbon intensity of 38gCO2\kWh. Demand is largely met through onshore wind resource with the remaining requirement for energy provided by gas CCS and conventional Gas CCGT's.

Renewable Transport in the form of bioenergy and renewable generated electricity grows to a penetration of 92% of transport energy use. Total final consumption for the sector is approximately 45% lower in 2050 (compared to the BAU scenario) due to technology switching, efficiency improvements and a reduction in demand due to demand response. Bioliquids are used in freight and public transport while electricity is used in private transport and small amounts in public transport.

Renewable heat supplied by bioenergy grows to a penetration level of 62% of total thermal energy use for the CO2-80 scenario. 84% of renewable heat is supplied by solid biomass with 14% coming from biogas. Biomass is used predominantly in industry for heating and industrial processes with lower volumes used in the residential and services sector for space and water heating.

Renewable heat is also supplied by electric heat pumps. Electric heating supplies approximately 725,000 average dwellings in the residential sector. The decarbonisation of the electricity sector and high efficiencies of the technology enable the technology to appear in the cost optimal solution. The model does not consider district heating systems in Ireland, so no potential for development is identified.

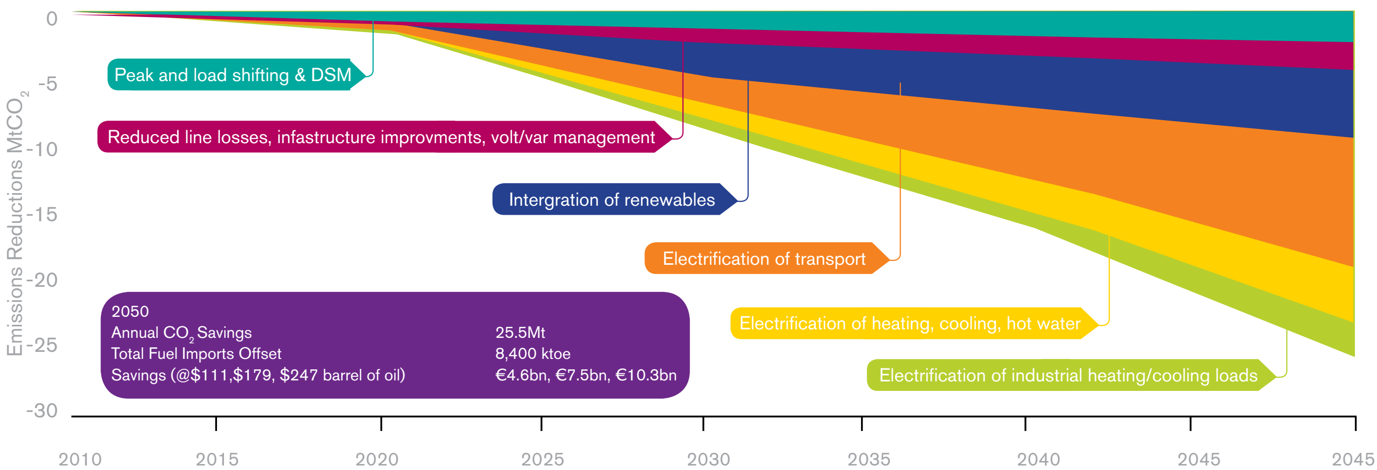
B.8

SEAI ROADMAPS

The general trends in energy sector roadmaps are also present in a series of roadmaps constructed by SEAI. There are a series of roadmaps looking at individual sectors – wind energy, electric vehicles, residential heating and bioenergy – as well as a more holistic roadmap (drawing on some of the findings of the sector level roadmaps) that focusses on the development of a smart grid.

Figure 42 illustrates the SEAI Ambitious scenario, and how it can deliver savings of up to 25 MtCO2 per annum by 2050 through integrating the behaviour and actions of all users connected to the electricity system – generators, consumers and those that do both. What is important to note is

FIGURE 42 – POTENTIAL REDUCTION IN ELECTRICITY RELATED EMISSIONS UNDER THE AMBITIOUS SCENARIO (MT CO2/YEAR)

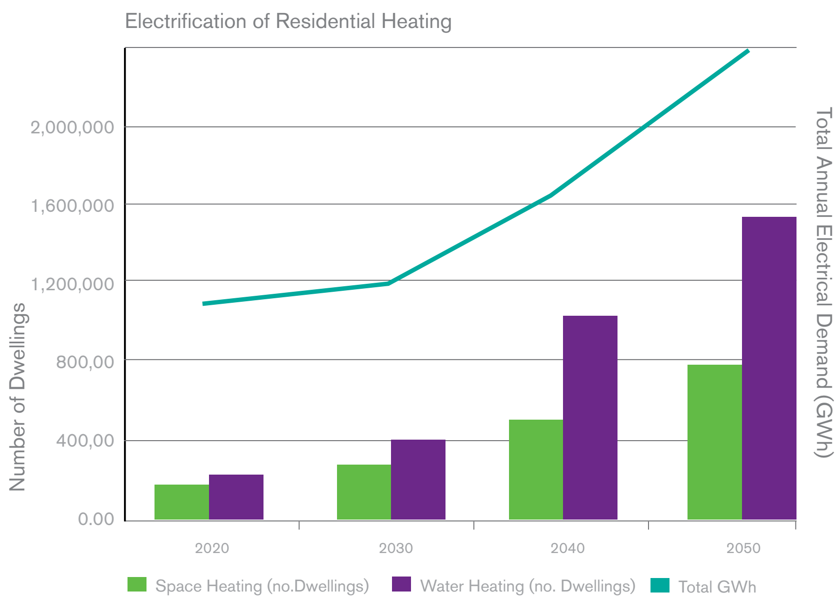


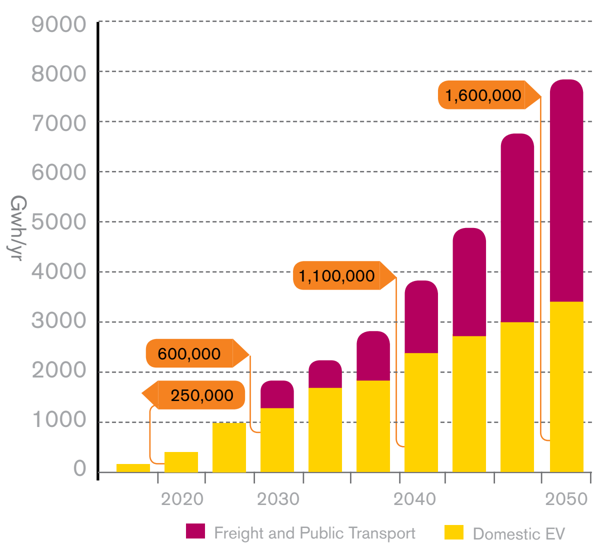
that transport and heat electrification account for around 60% of the total savings realised and the flexibility that is inherent in the technologies also enables integration of much higher volumes of wind generation onto the system, allowing further reductions in the carbon intensity of generation.

The core SEAI roadmap demonstrates similar characteristics to those of other roadmaps.

- Total electricity consumption grows by around 50% from 2010 levels – industrial and residential heat demand rises to around 12 TWh (or 33% of current electricity consumption) with another 8TWh of annual demand from electrification of the passenger vehicle fleet. See Figure 34 below.
- By 2020 the EV contribution to the passenger car segment is 10%, growing to 60% by 2050. Given expected growth in the passenger fleet, this is around 1.6m cars (or around 85% of the current car fleet).
- Close to 800,000 households have electric space and water heating by 2050 and an additional 700,000 have electric water heating (direct or solar thermal)
- Residential CO2 emissions are reduced by 90% through a sustained programme of dwelling retrofits and regulation improvements.

FIGURE 43 – ASSUMED ELECTRIFICATION OF RESIDENTIAL HEATING AND TRANSPORT





ACRONYMS

AD (Digester)	Anaerobic digestion. The production of biogas (Methane and CO2) from organic materials using microbes.
ADMD	After Diversity Maximum Demand
AEA	Annual Emissions Allocation (in respect of national Non-ETS emission targets)
AR5	Fifth Assessment report of the Intergovernmental Panel on Climate Change
ASHP	Air Source Heat Pump
BER	Building Energy Rating
BEV	Battery Electric Vehicle
BOS	Biofuels Obligation Scheme
c/kWh	euro cent per kilowatt hour
CBA	Cost Benefit Analysis
CCC	(UK) Committee on Climate Change
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Sequestration
CH_4	Methane
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COP	Conference of the Parties
CoP	Coefficient of Performance (the ratio of heat output for electricity input of a heat pump)
CSP	Concentrated Solar Power
DCCAE	Department of Climate Action, Communications and Environment
DCENR	Department of Communications, Energy and Natural Resources (now DCCAE)
DCMNR	Department of Communications, Marine and Natural Resources (now DCCAE)
DEA	Danish Energy Agency
DECC	Department of Energy and Climate Change (in UK)
DECLG	Department of Housing, Planning, Community and Local Government (Environment is now part of DCCAE and Housing is part of the Department of Housing, Planning and Local Government)
DfT	Department for Transport (in UK)
DH	District Heating
DNI	Direct Normal Irradiance (Levels)
DPER	Department of Public Expenditure and Reform
DS3	Delivering a Secure, Sustainable Electricity System', an EirGirid programme to facilitate the running of high levels of variable renewable generation while maintaining the stability of the electricity system
DSO	Distribution System Operator
DSR	Demand Side Response
E4SMA	Energy consultancy (Energy, Engineering, Economic, Environmental Systems Modelling and Analysis)
EAI	Electricity Association of Ireland
EEA	European Environment Agency

EMEA	Europe, the Middle East and Africa
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ESB	Electricity Supply Board
ESBI	ESB International
ESD	[EU] Effort Sharing Decision. Allocated national carbon targets outside the ETS sector
ESRI	Economic and Social Research Institute
ETI	Energy Technologies Institute
ETS	[EU] Emission Trading Scheme
EU	European Union
EU15	The 15 Member States of the EU in 2003 (Before a Large Expansion)
EU-28	28 Member States of the European Union
EUA	Emission Unit Allowance (within EU ETS)
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
F-Gases	Fluorinated Gases
GB	Great Britain
GHG	Greenhouse gas
GNI	Gas Networks Ireland
GSHP	Ground Source Heat Pump
GWh	Giga Watt Hours
GWP	Global Warming Potential
H_2	Hydrogen
HGV	Heavy Goods Vehicle
ICCT	International Council for Clean Transportation
ICE	Internal Combustion Engine
IDDRI	Institute for Sustainable Development and International Relations
IEA	International Energy Agency
IPCC	Intergovernmental Plan on Climate Change
IRENA	International Renewable Energy Agency
ISEA	Irish Solar Energy Association
KPMG	An investing/accountancy firm
$ktCO_2e$	Thousand Tonnes of Carbon Dioxide Equivalent
ktoe	Thousand Tonnes of Oil Equivalent
kW_{th}	kilowatt (thermal)
LCOE	Levelised Cost of Electricity
LCVP	Low Carbon Vehicle Partnership
LGV	Light Goods Vehicle
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LULUCF	Land Use, Land-use Change and Forestry
LV	low voltage
MIC	Maximum Import Capacity
MS	Member State (of the European Union)
Mt	Megatonne

$MtCO_2e$	Megatonnes of Carbon Dioxide Equivalent
MV	Megavolt
MW	Megawatt
MWh	Megawatt hour
N_2O	Nitrous Oxide
NCC	National Control Centre
NG	Natural Gas
NOx	Nitrogen Oxides
OCGT	Open Cycle Gas Turbine
OFMSW	Organic Fraction Municipal Solid Waste
P2G	Power-to-Gas. Usually denotes the generation of hydrogen gas through the electrolysis of water by electricity
PHEV	Plug-in Hybrid Electric Vehicle
POST	[UK] Parliamentary Office of Science and Technology
PV	Photovoltaic
R&D	Research and Development
REEV	Range Extender Electric Vehicle. An EV fitted with an engine and fuel tank that is used to provide power beyond the range of the battery
REFIT	Renewable electricity feed-in tariff
RES	Renewable Energy Sources
RES-E	Renewable Energy Sources - Electricity
RES-H	Renewable Energy Sources - Heat
RES-T	Renewable Energy Sources - Transport
SEAI	Sustainable Energy Authority of Ireland
SEM	Single Electricity Market in Ireland and Northern Ireland.
SEMO	Single Electricity Market Operator
SERVO	Term in Ireland describing real time monitoring and modelling of local conditions on the distribution system to facilitate remote switching of customer loads and generators while maintaining supply standards
SMMT	Society of Motor Manufacturers and Traders
SMR	Small Modular Reactor
SNSP	System Non-Synchronous Penetration. The percentage of system electricity generation at any moment that comes from non-synchronous sources such as wind and high voltage direct current interconnector imports
SOx	Sulphur Oxides
tCO_2	Tonnes of Carbon Dioxide
TV	Television
TWh	Terawatt hour
UCC	University College Cork
UCL	University College Limerick
UK	United Kingdom
UN	United Nations
UNFCCC	UN Framework Convention on Climate Change
US	United States
VRT	Vehicle Registration Tax

NOTES:

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