Our Climate Neutral Future

Zero by 50

MARCH 2021

Green Tech Skillnet

MaREI

WIND ENERGY IRELAND

Foreword

Ireland must have **an energy sector with net-zero carbon emissions by 2050** if we are to play our part in preventing irreparable damage to our planet. This study outlines how this can be done for Ireland's energy system across all key sectors: electricity, heating and transport. MaREI have created one answer to this question which is not only about technology, politics and economics, but at its core it is about our future. More importantly it is about our children's future and our deep responsibility to leave the generations that follow with the hope of the prosperity that we have enjoyed from the past. A **sincere thanks to MaREI for providing us with the knowledge of how to do this**, we must all now deliver on it.

It is clear from the analysis here that **we have now entered the Age of Electricity**. We must electrify huge proportions of our heating and transport needs in the coming decades, which will mean **our electricity demand will grow by 3-4 times**, from 29 TWh today to 84-122 TWh by 2050. This is not about evolution, this is a revolution in how we provide our energy.

Supplying this enormous electricity demand in the future will require a rapid increase in the volumes of renewable electricity we produce in Ireland. MaREI forecast here that **we will need approximately 25 GW of renewable electricity capacity by 2050** compared to the 4.5 GW of capacity we have today, which has taken us ~15 years of concentrated effort to deliver. The exact mix across onshore wind, fixed offshore wind, floating offshore wind and solar is not critical here, but what is critical is that we need to scale up our efforts across all of these technologies.

Luckily in Ireland we are in the enviable position that we have an abundant wind resource available which is more than capable of meeting our future needs. Moving to our own indigenous wind energy means that Climate Action will not only improve our environment, it will also improve our Energy Security. As renewable electricity becomes the backbone of our energy needs, **Ireland's energy security across all sectors will increase as our dependency on imported fuels drops from ~70% today to 5% in 2050**. Beyond that we even have the potential to become a net energy exporter for the first time in our history, something which could truly transform the Irish economy. MaREI have estimated that **a net-zero carbon energy system could create at least 50,000 jobs in Ireland** and they have identified three specific sectors which Ireland needs to start expanding our supply chain capability in to unlock this: building retrofits, wind energy development and the hydrogen economy.

The investment required to realise this clean, low-carbon and energy independent future is also very modest compared to the huge benefits it delivers. The analysis quantifies that for an increase in ambition from an 80% reduction in CO_2 to Net-Zero CO_2, the energy system will need an additional investment equivalent to 1.4% of GDP in 2050. For context, Ireland and the EU currently spend 8.5% and 11.2% of GDP respectively on energy annually. Put simply, **the cost of doing something is marginal**, **the cost of doing nothing is likely fatal**. This marginal extra investment will result in a sustainable, habitable and secure future for the generations that follow, which will not be the case by continuing to rely on fossil fuels.

Finally, **it is now time to deliver**. Central to the analysis here is Ireland's carbon budget, which MaREI have demonstrated very clearly is not only about the end point, but about the journey towards that end point. Moving from the current ambition of 80% reduction in CO_2 to an ambition of Net-Zero CO_2 by 2050 will reduce Ireland's carbon footprint by approximately half over the coming 30 years, due to the cumulative emissions that we save along the way. The longer we take to act, the bigger the challenge becomes.

MaREI concluded here that **all of the technologies, concepts and interventions required to reach Net Zero exist today in some form**. With electricity becoming the backbone of our energy system in 2050, we can **start by getting to a zero carbon power system by 2035** at the latest, so we then leverage our clean electricity for zero-carbon heat and transport also. We now have the knowledge of what is required, so for our planet, our economy, and our future, now it is time to deliver it.

Dr. David Connolly
CEO, Wind Energy Ireland

Sponsors

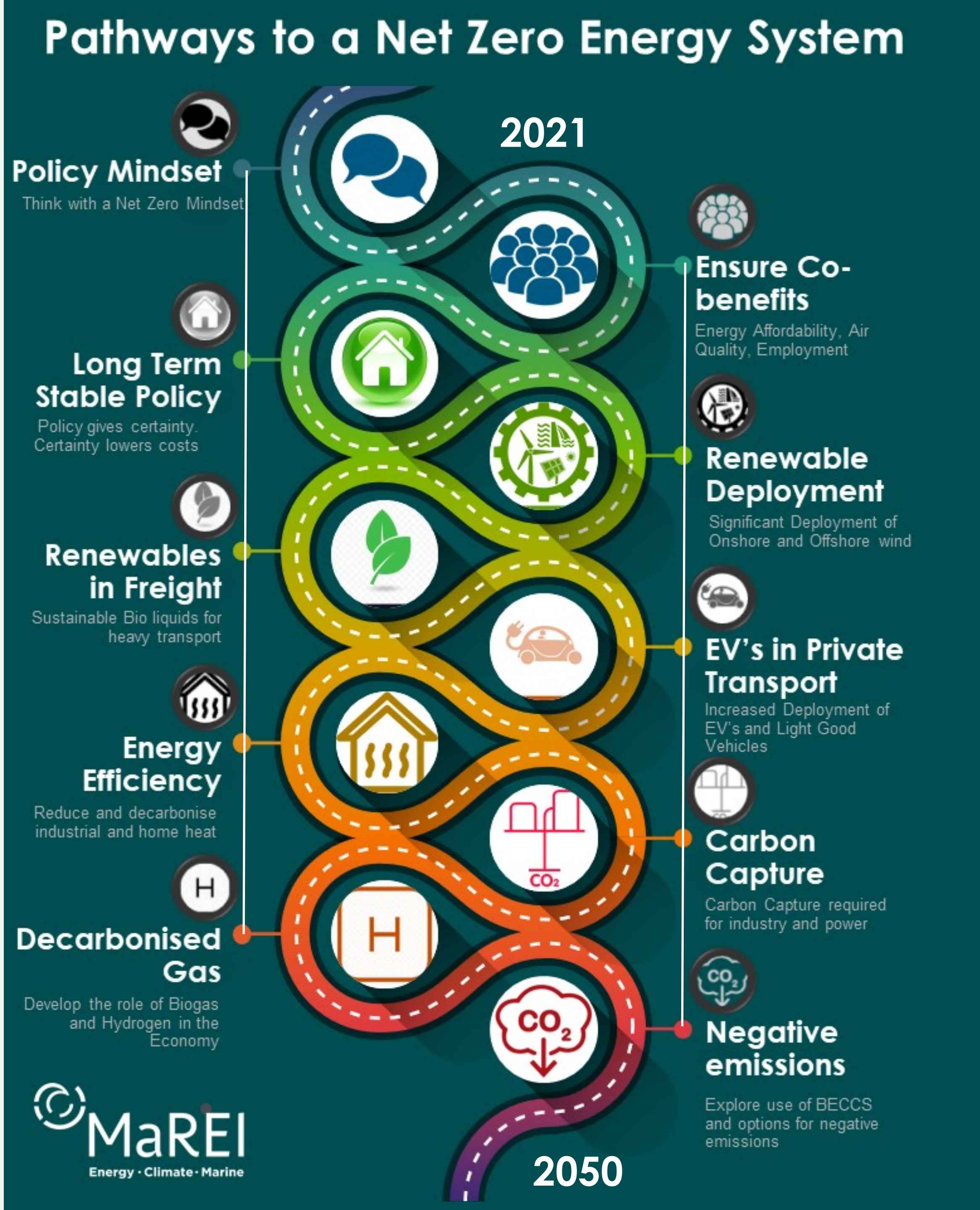
The Journey to a Climate Neutral Future

Zero by 50

In March 2021, the Irish government published a new climate law committing Ireland to Net-Zero carbon emissions by 2050. This is an increase on the previous level of ambition which was an 80% reduction in carbon dioxide emissions by 2050 compared to 1990 levels for the energy system and a separate ambition for carbon neutrality in agriculture and land-use. This study commissioned by Wind Energy Ireland and supported by Green Tech Skillnet looks at what a Net-Zero carbon energy system for Ireland entails and elaborates on the role of Ireland's wind energy sector in this future. In this report we detail one pathway to a climate neutral future by 2050 where carbon dioxide emissions are effectively reduced to zero thus limiting Ireland's contribution to global warming from domestic energy consumption. This is known as a 'Net Zero' energy system because there is a balance between emissions sources and removals. There are many possible pathways to a Net Zero energy system, but they share several common features. International science tells us that there are important **No Regret Options** that must happen now, and these can get us most of the way, these are:

- Energy efficiency
- Electrification
- Deployment of market ready renewables

Beyond that, there are **Future Energy Choices** relating to the scale and magnitude of technologies that will help the hardest to decarbonise areas. These are hydrogen production, carbon capture and storage and electrofuels. While the scale and mix of these specific technologies is currently unclear, it should not be, and is not a barrier to action. A mutual outcome of a Net Zero energy system is a dramatic reduction in the importation of fuels into Ireland to meet our energy needs from 70% today to less than 5% in the future. Considering that Ireland is one of the most fossil fuel dependent economies in Europe today, this outcome in conjunction with a Net Zero energy system would be a remarkable achievement. This study explains the choices, outcomes and what is required to get there.



Key Messages

A Net Zero Energy System is technically feasible and can be achieved at a manageable investment:

All the technologies, concepts and interventions required to reach Net Zero exist today in some form, however they must be radically scaled up across the economy. Significant investment must be made to achieve this and as these investments are paid back over decades the investments as a % of GDP for a Net Zero energy system is relatively low. We calculate that the additional incremental investment in 2050 over the current level of climate ambition of an 80% reduction in CO_2 is approximately 1.4% of GDP.

Ireland must harness its vast renewable resources and increase energy efficiency. These are no regret options:

Energy efficiency is the foundation of all Net Zero visions with renewable energy as its supporting structure. Both energy efficiency and increased renewable deployment are robust policy choices that reduce carbon emissions, save money, improve air quality, and reduce our dependence on imported fuels.

Net Zero is technically possible but not easy:

The journey to a Net Zero energy system is very hard. There will be difficult choices ahead and some headwinds. Infrastructure such as grid must be built, large investment must be sought, renewable fuels required, and homes and businesses transformed. Without these changes and societal and political support, a Net Zero energy system cannot be achieved. Engagement and transparency at an early stage with the public is key.

Energy independence radically increases:

As we move away from fossil fuels and harness renewable indigenous resources, we enhance our energy security position. Today Ireland is one of the most dependent countries in Europe on imported fossil fuels, however, by 2050 this dependence could reduce to less than 5%. However, this requires a resilient electricity system with adequate flexibility, underpinned by grid development, flexible loads, sufficient capacity, interconnection and storage.

Over 50,000 jobs could be created in critical sectors, requiring new skills and supply chains to be established:

Using the analysis here, we have identified specific sectors which while will need additional jobs in the coming decades to support Ireland's journey to a zero-carbon energy sector. These are retrofitting buildings, wind energy development and the hydrogen economy. Combined we expect these sectors will create over 50,000 jobs. However, it will take time to train and upskill people in these areas, so planning for these supply chains needs to start now. To do so, we have proposed that a centre of excellence is established to coordinate our efforts in each of these areas.

The time to act in now:

As communities rise and the economy recovers from the COVID pandemic, international financial analysis points to the convergence of climate action and green recovery. Now is the time to act. Now is the time to build a Net Zero future.

Why we must act

Climate Change is happening now

2020 was one of the warmest years on record. Evidence for warming of our climate system is beyond dispute and observations show that global average temperatures have now increased by more than 1 degree Celsius since pre-industrial times. The projections of future global and regional climate change indicate that continued emissions of greenhouse gases will cause further warming and changes to our climate. Governments around the world have agreed to strive to limit this warming to 2.0 degrees Celsius and pursue efforts to limit the temperature increase to 1.5 degrees Celsius.

...and climate action brings overlapping benefits

Climate Action isn't just about the planet, it is about people. By increasing the production of clean renewable energy, saving energy in homes by making them better insulated and promoting electric transport we can deliver benefits in terms of cleaner air, wellbeing and health. In Ireland, the EPA estimate that poor air quality from the burning of solid fuels causes 1300 premature deaths per year and organizations such as the Irish Heart Foundation have called for action in this area. In Northern Ireland, air pollution is recognized as a health risk and UK Government statistics estimate that air pollution reduces the life expectancy of every person by an average of 7-8 months. Upgrading homes to use less energy helps address energy poverty which impacts an estimated 400,000 families in Ireland. Energy poverty or the inability to maintain a warm, thermally comfortable home is a serious overlapping issue with low incomes, high energy costs and energy inefficient dwellings are contributing causes of household energy poverty. Targeted policies can promote energy efficiency and help those in need of assistance while also delivering climate action.

This requires us to target Net Zero...

A Net Zero vision is important as it's the best way we can tackle climate change by reducing global warming. Because we can't reduce all emissions to zero, its means achieving a balance between the emissions put into the atmosphere and those taken out. This is also sometime referred to a carbon neutral economy.

Emissions in Ireland's Energy System Today

Greenhouse Gas Emissions are 60 Million tonnes today and this must reduce as close to zero as possible by 2050

Energy Emissions account for approximately 62% of all GHG emissions and is at the heart of the solution

Our climate challenge is a shared global challenge – and it is largely an energy challenge. Energy accounts for almost two-thirds of global greenhouse gas emissions. This means energy must be at the heart of any solution.

Ireland's GHG emissions are dominated by Energy (62%) but Agriculture is also very significant. The overall reduction in 2020 was 6% due to COVID19 but this comprised a 9% reduction in energy related emissions and no change in agriculture. Official data from 2019 from the Environmental Protection Agency showed that national greenhouse gas emissions declined by 4.5% on 2018 levels to 60 million tonnes carbon dioxide equivalent despite the economy continuing to grow. This reduction in total emissions, driven by the Electricity, Agriculture and Transport sectors, is a step in the right direction that must be sustained and enhanced over the next decade. Emissions in the electricity show a decrease of 11% or 1.2 Mt CO2eq in 2019, which is attributable to a 69% decrease in coal and an 8% decrease in peat used in electricity generation. Electricity generated from wind increased by 16% in 2019. However, despite some progress Ireland will miss its mandatory emission reduction targets and renewable energy targets for 2020 and must purchase compliance and statistical transfers of credit at a cost of 50m€ from other countries. This is due to a shortfall in renewable energy for heat and transport.

In this report we examine energy system emissions only reflecting a distinction in between energy and agricultural emissions.

Ireland's previous national policy position was to reduce CO2 emissions in 2050 by 80% on 1990 levels across the Electricity Generation, Built Environment and Transport sectors, with a goal of Climate neutrality in the Agriculture and Land-Use sector. Also, as per Ireland's national accounting inventory, International Aviation and Shipping are not included but discussed as part of a Future Ambition. Therefore, this study focuses explicitly on the energy-related greenhouse gas emissions accounted for domestically in Ireland, which means international aviation and marine fuel is excluded (although **Further Ambition** is discussed briefly for these at the end of this study).

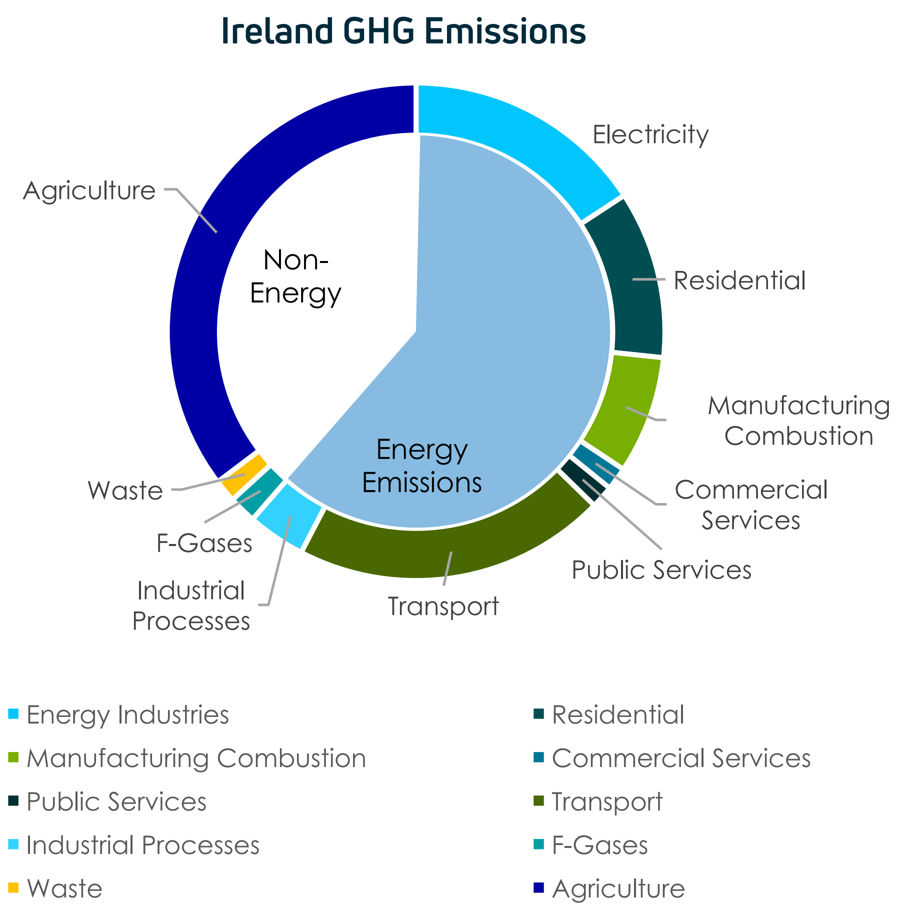


Figure 1: Ireland's GHG emissions (EPA 2019)

Today, Ireland's Energy System is dominated by Oil

Our system is dominated by fossil fuels, in particular oil with an estimated annual import bill of €5 billion

Like most modern economies, oil is the dominant fuel in Ireland accounting for just under half of primary energy (please see glossary for technical definition) requirement in 2018. While most oil is used for transport, there is also significant oil use in residential heating and in the industrial sector. Ireland has moved away from oil use in the electricity sector although it plays a role as a secondary fuel for gas-fired electricity generation. Transport continues to dominate as the largest energy-consuming sector, with a 42% share of final energy consumption. Historically, Ireland sourced most of its oil and refined products from countries such as the UK, Norway and to a lesser extent West African countries.

Natural gas is the second fuel of dominance in Ireland where it is used electricity generation, industry, services and residential heating. From the mid-1990s import dependency grew significantly due to the increase in energy use, together with the decline in indigenous production. Ireland's overall import dependency reached 90% in 2006. It varied between 85% and 90% until 2016 when it fell following the opening of the Corrib gas field. In 2019 import dependency was 69% and this is projected to increase over the coming years as Corrib production declines. Ireland imports gas through the UK which itself has indigenous resources and pipeline imports from Norway, Europe and LNG imports from a variety of countries such as Qatar and more recently the USA.

Renewable energy avoids emissions and reduces fossil fuel imports

Renewables, including wind, hydro and bioenergy made up 12% of gross final consumption in 2019 and this avoided 5.8 million tonnes of CO2 emissions and over €500 million of fossil fuel imports. In 2019 the use of renewables in electricity generation in 2019 reduced CO2 emissions by 4.8 million tonnes and avoided an estimated €297 million in fossil fuel imports.

The electricity sector is at the forefront of decarbonisation in Ireland

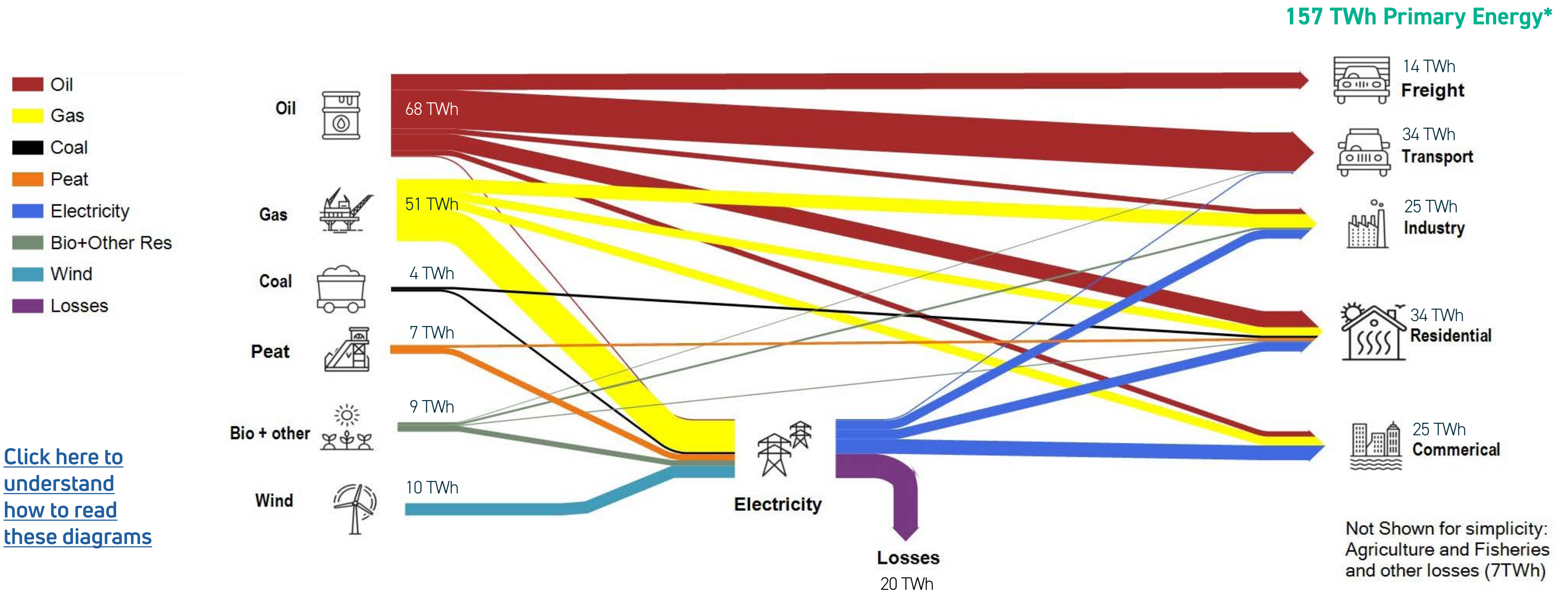
The carbon intensity of electricity fell by 14% in 2019 to 324 gCO2/kWh. This was the lowest level recorded in over 70 years. In the past three years coal use in electricity generation fell by 86% while renewables' contribution to the electricity inputs increased by 13% in 2019. Renewables accounted for 26% of the inputs to electricity generation in 2019 but they were responsible for 38% of the electricity generated. This is because non-combustible renewables such as wind, hydro and solar are considered 100% efficient, and so no energy is lost in generating electricity, unlike traditional thermal generation such as coal, gas or peat which typically lose 35-60% of the energy they consume.

Gina Krog Platform in North Sea. Ireland sources significant volumes of oil and gas from the North Sea region | Credit Ole_Jørgen_Bratland

Oil has by far the largest share of final energy use at 57% in 2019, more than all other fuel types combined.

Transport and home heating account for 86% of oil use-SEAI Energy in Ireland-2020

Ireland's Energy System 2019



[Click here to understand how to read these diagrams]

Our Energy system is dominated by imported fossil fuels with strong end use demand from Transport

Primary Energy*
32 MWh/capita

Energy Emissions
37 Million tonnes

Renewable Energy
12%

Renewable Electricity
37%

Import Dependence
70%

Figure 2: Ireland's energy system in 2019 * Excludes international aviation and shipping

Towards a Net Zero Future

" Real success can only come if there is a change in our societies and in our economics and in our politics"
Sir David Attenborough

The Energy System in a Net Zero Future

The future is uncertain but pathways to Net Zero share common features

There are many paths to achieving climate neutrality by 2050. International science reviewed by the Intergovernmental Panel on Climate Change (IPCC) details 78 different global pathways to meet ambitious emissions reductions. In this report, we outline and explore one pathway that is technically feasible and cost-optimal in aggregate, based on assumptions agreed with Wind Energy Ireland members.

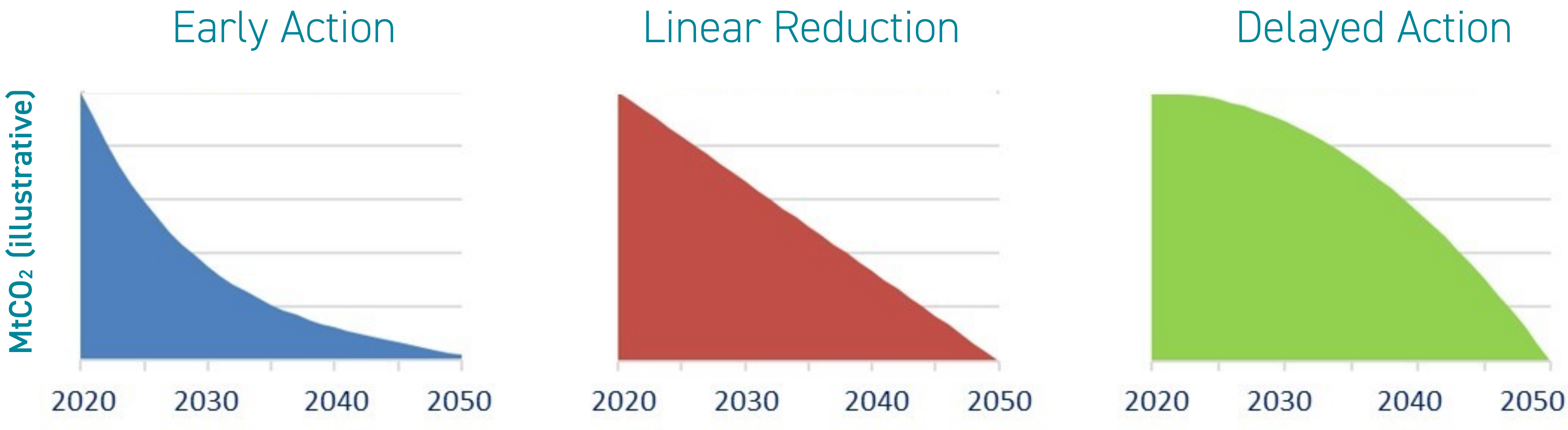
To arrive at this pathway, we accessed more than 1,000 decarbonization technologies using the **Irish TIMES** Integrated Energy System model both on the supply, transformation and demand side, and explored a decarbonisation trajectory that would meet the defined carbon budget for Ireland with the end point of Net Zero in 2050. We test power system results with PLEXOS, an industry grade power system software. We did not constrain economic growth nor consumption, and we assumed that industry locations will not shift to areas outside of Ireland (i.e., cement production etc.). It is important to note that this is not a forecast or prediction but is a helpful tool to explore the magnitude of the challenge and the resulting energy system implications. Results are by their very nature uncertain and the roadmap is based on current best understanding. However, our collective expectations about the future have an enormous impact on the economy and markets, and we highlight no regret actions that appear in this roadmap and previous other academic studies that MaREI has published.

'No Regret' Options represent resilient policy choices

These **No Regret Options** can be seen as **robust policy choices** that are resilient to uncertain futures and offer wider social, environmental and economic benefits beyond emissions reduction. We also highlight and outline **Future Energy Choices** for technologies and options that are more influenced by technology development, societal support and political ambitions. Finally, we look to **Further Ambition** and discuss the impact of including international aviation and shipping as part of our climate ambition. These areas currently fall under separate international agreements, but future ambition could allow us to consider them as part of our national obligations.

There are naturally many options that feature in Net Zero analysis across the scientific and policy literature that are not considered in this report due to brevity and scope. We do not examine low demand growth scenarios, significant societal transformations, steam methane reforming for hydrogen production, widespread adoption of district heating, increased use of carbon capture and storage, or nuclear energy. Any of these options could play a role in the future energy mix and their role will become clearer over the next decade, however, the **No Regret Options** highlighted in this report would nevertheless be resilient across these choices.

The road to Net Zero should be determined by a Carbon Budget: CO2 can vary even with the same end point



Getting to Net Zero by 2050 is not adequate: it is the cumulative emissions along the way that matters.

The three illustrative emission reduction pathways above all achieve net-zero emissions in 2050, but the 'Delayed Action' pathway has cumulative emissions that are double the 'Early Action' cumulative emissions and therefore double the global warming impact. A carbon budget is the cumulative amount of carbon dioxide emissions permitted over a period to keep within a certain temperature threshold. Like a household budget, climate science sets a carbon budget for greenhouse gases that can be 'spent' (emitted) for a given level of global warming. If we exceed this budget, global temperatures will become higher. In this study we apply a cumulative carbon budget of 376 MtCO2 from 2020. This figure is derived from the scientific publication **(Glynn et al)** who looked at the Irish population, historic emissions and future ambition for reduced warming. This constraint is consistent with a 33%-50% probability of meeting a 1.5°C target with mitigation action commencing in 2020. Ireland's previous ambition of an 80% reduction in CO2 by 2050 equates to a carbon budget of over 800 Mt.

While a Net Zero energy system target in 2050 constitutes an additional 20% increase in end ambition, it translates into to a 50% increase in ambition when carbon budgets are considered.

This is an important point and is frequently under appreciated. It means early and sustained action is required.

Drivers of change: Economy | Population | Technology

Our energy needs, economy and population and will be different in the future

People do not want energy itself, but rather the services like mobility, heating, cooking that energy provides and the products that rely on these services. The three most basic drivers of these services and resulting energy requirement are economic activity, population, and technology. In developing future energy scenarios, it is important to include these projections. Ireland's energy requirement has grown over 50% in the past 30 years while population increased by 40%.

For example, population growth impacts the number of homes we need, which has a rolling impact on heating, cooking, lighting demand while it also influences the number of kilometers we move and travel each year which feeds into transport demand. Energy efficiency measures such as retrofitting buildings with better building fabric and shifting of mobility preference from personal transport to public transport are also included.

One of the most significant changes in the future will be electricity demand as this is impacted by all three core drivers (population, economy and technology) and climate ambition. The results of this analysis are tied to these macroeconomic assumptions and results of the macro-economic model, which by themselves are inherently uncertain. While we don't present a detailed sensitivity analysis, lower economic growth leads to a lower demand in energy for the same level of decarbonisation. The same applies to population numbers. Note that in Figure 4 the value hydrogen production is net of recirculated hydrogen in the power sector (8 TWh) to avoid double counting.

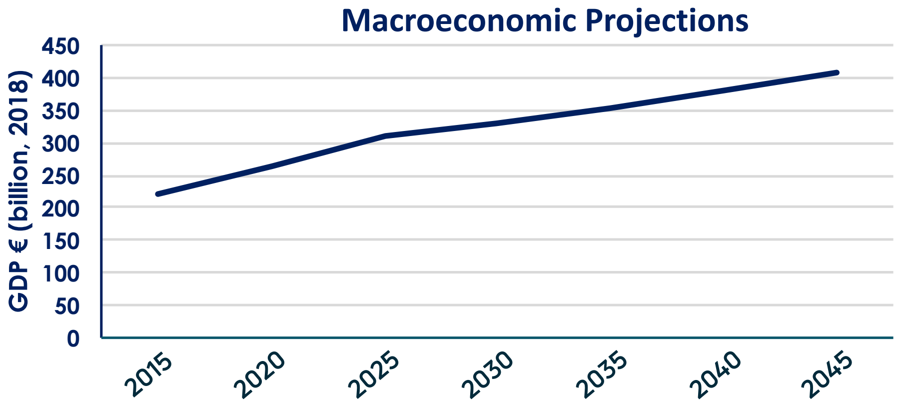


Figure 3: Macroeconomic projection GDP (model input) -See glossary

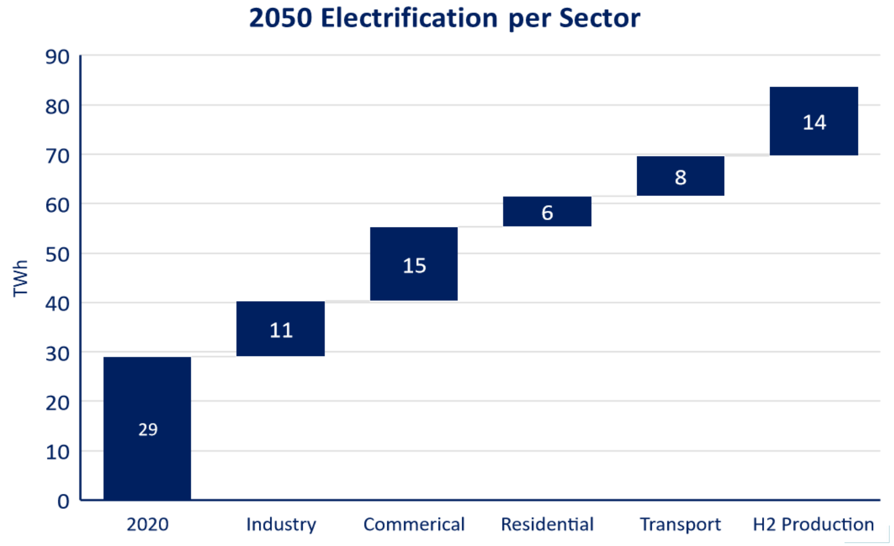
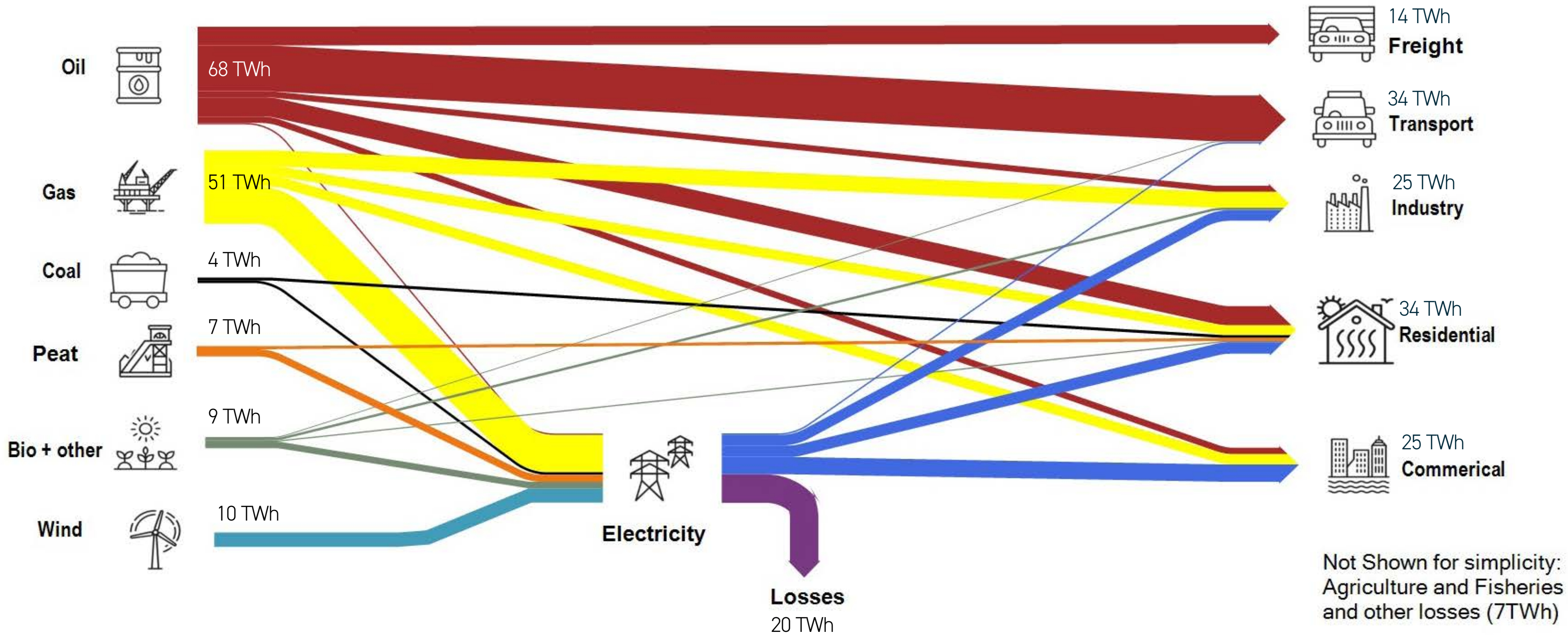


Figure 4: Ireland Final Electricity Demand-TWh (model output)

Ireland's Energy System 2019

157 TWh Primary Energy*



[Click here to understand how to read these diagrams]

Primary Energy*
32 MWh/capita

Energy Emissions
37 Million tonnes

Renewable Energy
12%

Renewable Electricity
37%

Import Dependence
70%

Figure 5: Ireland's energy system in 2019 * Excludes International Aviation and shipping

2030 Energy System: Energy Efficiency is key but incredibly challenging

2030 Key Points

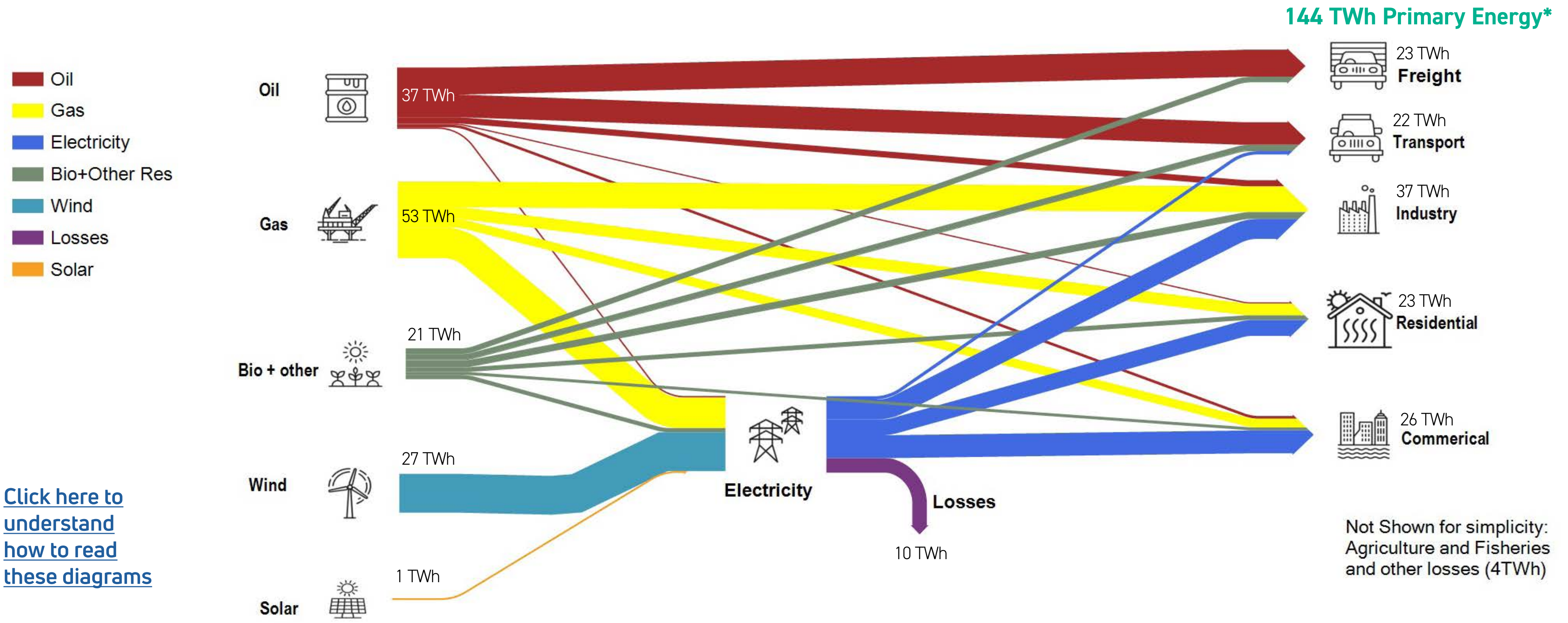
The energy system in 2030 must decarbonise significantly to stay within the defined carbon budget of 376 Mt. This requires action on both the supply and demand side of energy but also in the infrastructure elements to deliver it. The most demanding requirement is a need to move almost completely away from solid fuels and oil in the residential sector by 2030. In this analysis this involved 650,000 homes. This requires a two-step process where homes are retrofitted to a BER B2 level to reduce the heating requirement followed by a change in heating system to electricity driven heat pumps. The cost of bringing a home to an optimal standard is determined by a number of factors including the size and type of home as well as the starting condition of the home. A cost-optimal analysis commissioned by the Department of Housing, Planning and Local Government in Ireland estimated the cost to achieve a B2 rating from a starting point of a D or E rating to be in the range of €21,000 - €39,000. The challenge in this sector is amplified by a number of factors. There is a strong tendency for homeowners to continue using their existing heating system until it breaks down. Similarly, when homeowners replace their existing heating system, they often replace it with the same technology. At the same time, awareness and understanding of heat pump technology in Ireland is low. Regulatory measures, and their potential to influence consumer behaviour, should also be considered to encourage further uptake of heat pumps in coming years. As well as heating there is the continued requirement for more efficient appliances, lighting and equipment in all sectors. Without the delivery of these energy savings it is unlikely that the energy system will stay within the carbon budget unless there is more widespread deployment of negative emissions technologies later in the horizon.

In Transport, the progress of blending sustainable bioliquids in conjunction with the deployment of electric vehicles is needed to reduce emissions in this sector. The process of electrification of heat and transport (over 840,000 passenger EVs) are key requirements for reducing emissions in Ireland and must keep pace with the deployment of renewable electricity. Two key challenges are this takes time (650,000 individual decisions for home heating changes) and a significant investment is needed. Otherwise, if clean electricity is not used in Ireland, it is exported and the emissions benefit to Ireland is foregone.

Grid infrastructure is vital in the electricity sector

In the electricity sector, the achievement of 70% renewable electricity is key to decarbonisation as well as the delivery of the enabling infrastructure such as grid, markets and EirGrid's DS3 (and follow on) program. During feedback with Wind Energy Ireland members, it was noted that the delivery of grid infrastructure was considered as a key challenge. Previous modelling by MaREI showed that this infrastructure is required for both the 70% Renewable Electricity Target and the associated system wide emissions reduction it enables. Emissions in the electricity sector are modelled at 4.5 Mt and to stay within the carbon budget of 376 Mt electricity sector emissions in Ireland should be below 4 Mt in 2030. This requires options such as the level of minimum generation units online, onsite energy storage at data centres or increased wind capacity with additional interconnection to be considered. In the absence of emissions reduction from these options, then the role of carbon capture and storage in the electricity sector may be required. Conventional generation using natural gas is required to supply the remain electricity and provide generation over low wind periods.

Ireland's Energy System 2030



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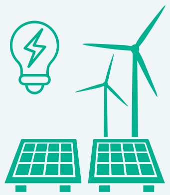
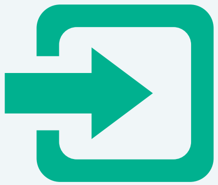
Primary Energy*
27 MWh/capita

Energy Emissions
24 Mt



Renewable Energy
34%

Renewable Electricity
72%



Import Dependence
65%

Figure 6: Ireland's energy system in 2030 * Excludes International Aviation and shipping

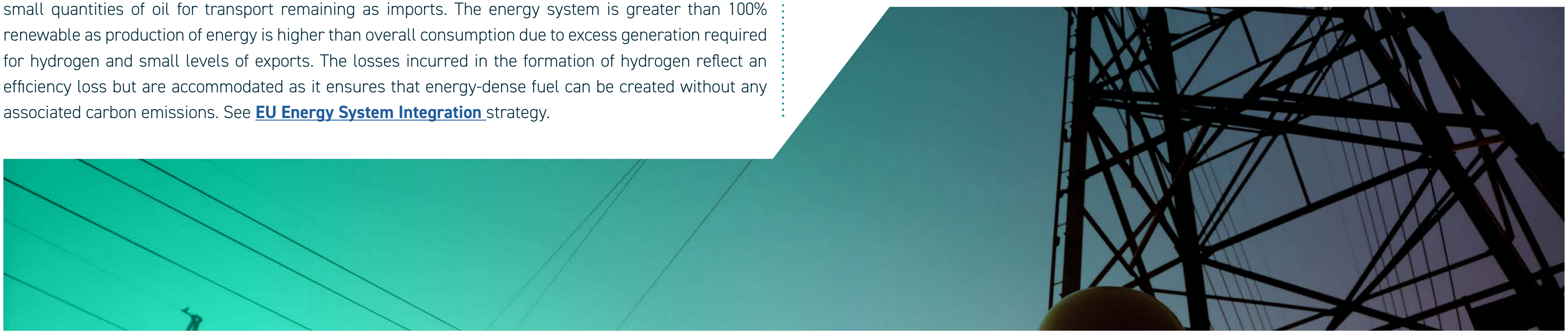
2050: The electricity system becomes the backbone of our energy system

2050 Key Points

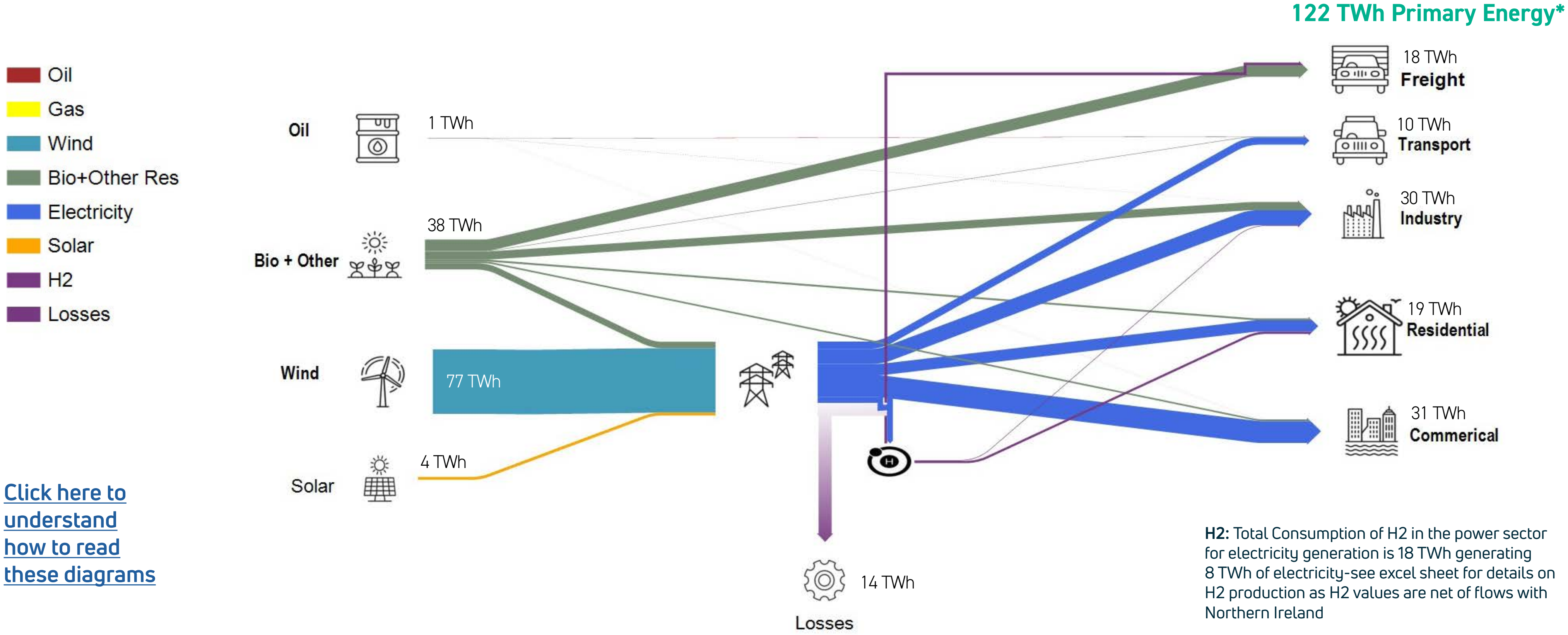
Achieving the ambition of Net Zero for the energy system requires a significant transformation in the way we produce, use and transport energy. The changes required are not incremental, they are remarkable. In this analysis the 2050 energy system is very different to today. Electricity is the main energy carrier with renewables as the main energy source. The energy system is almost 100% fossil fuel free with the main modes of transport and heating being predominantly electrified. In the hard to decarbonize areas such as industrial heat and heavy freight, bioenergy plays an important role in both liquid, gas and solid form with most of Ireland's sustainable indigenous required. New energy carriers are also needed for these areas and hydrogen is used heavy freight and other areas. In this analysis hydrogen also plays an important role as a decarbonized gas and storage vector that is generated using renewable electricity, stored and used as a decarbonized fuel in gas fired generation in periods of low wind speeds. On the supply side, over 25 GW of renewable generation meet the new demands for electricity and hydrogen generation. Biomass is used in a bioenergy carbon capture and storage plant to remove 2 million tonnes of CO_2 from the atmosphere allowing a balanced emissions reduction to 2050 and removal of residual emissions from industrial processes such as cement from the system. Overall primary energy use on a per capital basis has significantly reduced from 2019 reflecting the important role of energy efficiency across the economy and the more efficient use of electricity in meeting mobility and heating needs on the supply side. Overall import dependance of fuels has reduced to 5% with liquid bioenergy imports and small quantities of oil for transport remaining as imports. The energy system is greater than 100% renewable as production of energy is higher than overall consumption due to excess generation required for hydrogen and small levels of exports. The losses incurred in the formation of hydrogen reflect an efficiency loss but are accommodated as it ensures that energy-dense fuel can be created without any associated carbon emissions. See **EU Energy System Integration** strategy.

The Age of Electricity

Whereas oil is the backbone of today's energy system, in 2050 it will likely be electricity, meeting almost 65% of final energy use on contrast to 20% today. The electricity system will need to be more flexible as weather driven renewables such as wind and solar become dominant. Grid infrastructure will be fundamentally important to this vision and will build on the enhancement and upgrades required for 2030. Flexibility can be incorporated in many ways and it is likely that all, or some of the following mix of measures of options will be required. Grid improvements, interconnection, storage systems, smart heating and flexible EV loads, incorporating zero carbon flexible generation, adding demand-side management will all deliver flexibility. Battery storage will help integrate renewables into the grid and improve power quality characteristics such as ramp rate, frequency, and voltage stability. Demand-side response in the buildings and industry will help provide short-term flexibility. Importantly, for peripheral EU countries like Ireland with limited geographical spread for interconnector options, some form of mass energy storage or decarbonised conventional generation is required to cover energy balancing over a number of days and weeks. These options such as conventional power plant with carbon capture, hydrogen as a fuel, and Bio-energy with carbon capture and storage (BECCS), are more expensive than other energy sources but are required to keep the energy system operating in a reliable and robust manner. More cost-effective solutions may emerge in the interim and these options should be kept under review.



Ireland's Energy System 2050



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H2: Total Consumption of H2 in the power sector for electricity generation is 18 TWh generating 8 TWh of electricity-see excel sheet for details on H2 production as H2 values are net of flows with Northern Ireland

Primary Energy*
22 MWh/capita

Energy Emissions
0 (-2) Mt

Renewable Energy
100%

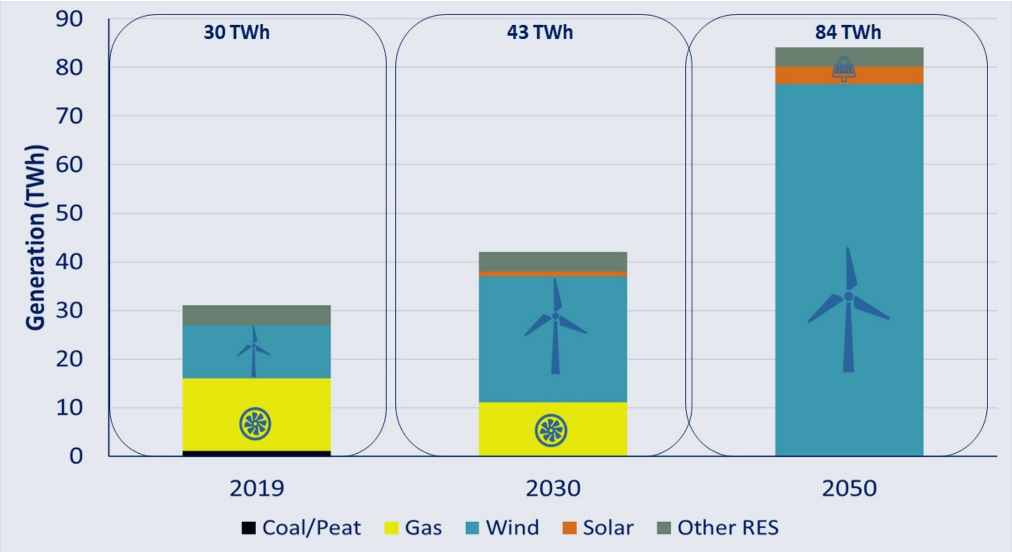
Renewable Electricity
+100%

Import Dependence
5%

Figure 7: Ireland's energy system in 2050 * Excludes International Aviation and shipping- Note that values don't round out due to rounding assumptions and exchanges with Northern Ireland

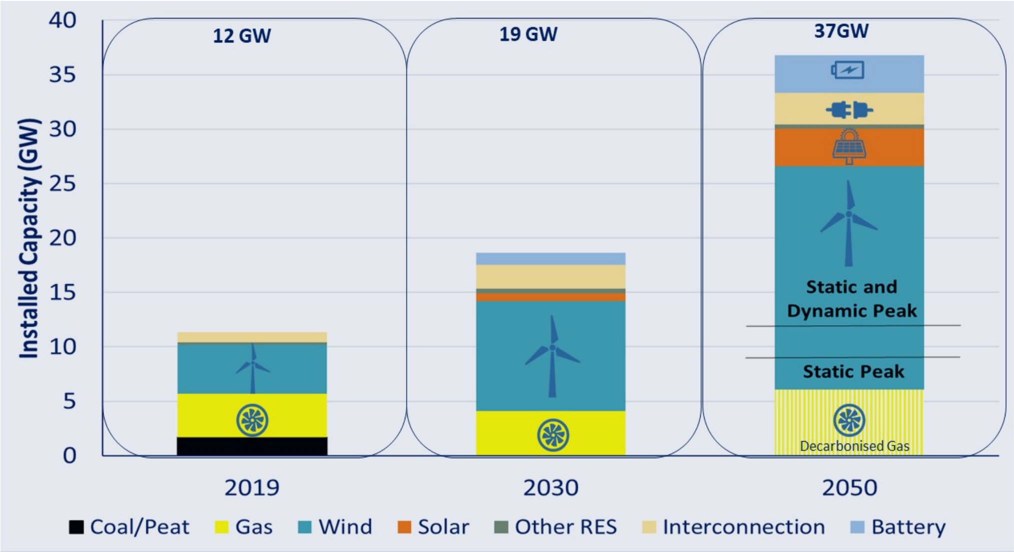
Electricity System Capacity and Generation

Ireland | 2019 to 2050 Electricity Generation



From an electricity generation perspective, wind generation grows steadily from 2020 to 2050 to become the primary source of energy **(77 TWh)** in a Net Zero energy future. This is complemented by solar **(4 TWh)**, other renewables such as existing hydro units and one carbon capture plant powered by indigenous biomass **(3 TWh)**. Depending on different policies and prices the mix of solar and wind energy may vary but, in this analysis, variable renewables are the dominant energy providers. Electricity generation increases by just under a factor of 3. Note that to avoid double counting the secondary generation of electricity from recirculated hydrogen **(8 TWh)** is not shown.

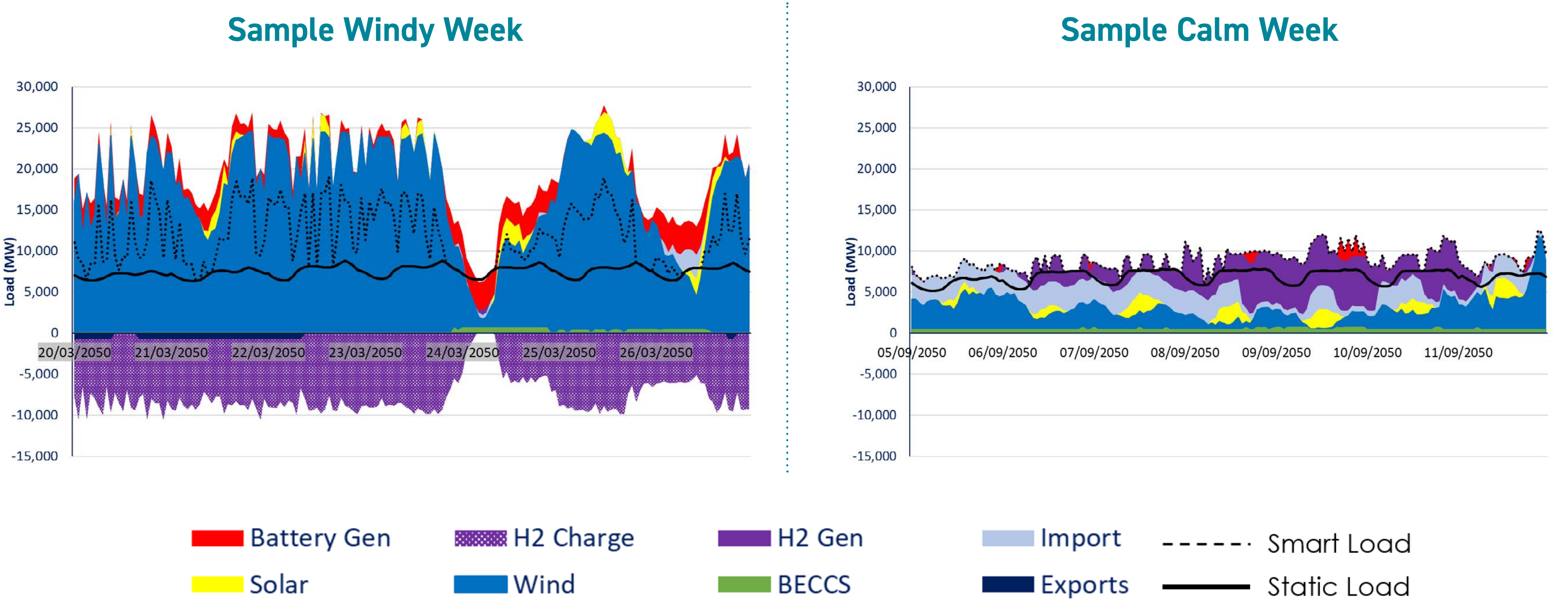
Ireland | 2019 to 2050 Power System Capacity



From an electricity capacity perspective, we see a significant requirement for capacity in terms of wind generation **(21 GW)** and solar PV **(4 GW)** but also for enabling capacity such as batteries **(3 GW)** , interconnection **(3 GW)** and decarbonised gas units **(6 GW)**, which in this study are assumed to run on hydrogen during period of low wind generation. The system static peak load (which excludes smart dynamic load such as EV charging) is **8.1 GW** but the dynamic peak which follow peak renewable generation during the day is **12.1 GW**.

Figure 8: Ireland's electricity from 2020 to 2050 (ROI Values)

Sample Weeks from 2050



These two images capture the diversity of weather and load scenarios for a sample windy week and calm week in the future 2050 electricity system. In the windy week (left hand side), excess wind generation is converted to hydrogen (**H2 Charge** shown below the line as a negative load)and stored as a fuel for reuse in gas turbines later **(H2 Gen)** in the year. If the storage is adequate to cover upcoming demand then power is exported. Batteries which have a higher round trip efficiency are also helping to balance the wind generation across time. A notable feature is the **smart load** (Dashed Line), which is predominantly made up of a heating load, follows peak renewable generation during the day. In the sample calm week (right hand side), where wind speeds are lower the system relies on conventional generation fired on decarbonised gas **(H2 Gen)**. The system also imports more electricity and smart load (this is a period with low heating load) are spread across the day. Note these images are for the All Island electricity system.

Figure 9: A sample windy and calm week of electricity system operation in 2050.

Climate Policy Options: No Regret and Future Energy Choices

There is, naturally, uncertainty about the most cost-optimal decarbonisation technologies. Based on today's understanding, there is clear evidence for increased electrification, deployment of market ready renewables and significant energy efficiency. These options can help us remove approximately 80% to 85% of energy system emissions and to go beyond this we must consider future energy choices such as hydrogen, carbon capture and storage and bioenergy with carbon capture. Depending on technology developments in the next ten years, one of these options could become more affordable than another, making it difficult to determine a clear winner now. A key uncertainty in this analysis is the role and availability of imported bioliquids which allows for a cost-effective decarbonisation of heavy transport. If this is constrained or not available, then choices like hydrogen in transport are more likely.

No Regret Measure 1: Energy Efficiency first

The energy efficiency first principle, including retrofitting homes, businesses and using more efficient appliances is a clear beneficial policy choice however it has been shown to be incredibly hard to implement at scale. It requires engagement with hundreds of thousands of homeowners and barriers such as access to finance for the initial investments, inconvenience and the availability of a skilled work force need to be overcome.

No Regret Measure 2: Deploy market ready Renewables

Ireland has success in deploying market ready renewables and this must continue and be accelerated. This includes variable renewables such as wind and solar but also sustainable bioenergy for hard to decarbonize areas such as heavy transport and industrial heat.

No Regret Measure 3: Electrify end use sectors

Electrification of end uses of transport and heating offer significant efficiency gains and if it is zero carbon at source it allows a wider reach of decarbonization into the economy.

Future Energy Choice 1: Hydrogen

The exact scale of hydrogen deployment in the future energy system is uncertain due to competing alternatives such as sustainable liquids for heavy transport and electrification for other modes. Hydrogen can also provide important energy storage capacity and its role will likely become clearer in the next number of years.

Future Energy Choices 2: Carbon Capture

Carbon capture and storage can be used in industry (cement production for example) and the electricity sector with conventional power plant. Its role will be influenced by costs, policy ambition and its capture rate of CO2.

Future Energy Choices 3: Negative Emissions

There are uncertainties about the scale of negative emissions such as BECCS and Direct Air Capture that may be possible in the future, and about their impacts and costs. However, their role is uniquely important in terms of emissions reduction and in reaching Net Zero. Additional natural options such as forestry and wood products in buildings will also be required.

Investment Needed

Total Energy System Investments

When looking at energy transformations and climate action, it is important to look at all modes of energy (electricity, transport and heat) across the full economy. This is why energy system costs as a percentage of GDP are used. Simply put, energy system costs represent the sum of fixed and variable costs for the energy system, including investments, operations and maintenance, as well as fuels. While we use the term 'cost' it is more appropriate to see this in term of investment. Energy system costs for the entire energy system include capital investments (for energy installations such as power plants and energy infrastructure, energy using equipment, appliances and energy related costs of transport), energy purchase costs (fuels + electricity) and direct efficiency investment costs, the latter being also expenditures of capital nature. This metric is helpful as it allows us to understand the economy wide investment required to reach a given target of climate ambition. For example, at an EU wide level, the European Commission estimate that increasing climate ambition from an 80% reduction in greenhouse gas to a Net Zero scenario increases the total energy system costs by 1.8% of GDP in 2050.

Our analysis is different as we consider carbon dioxide from the energy system in Ireland only, but it helps as a useful comparator. In Ireland total energy system costs as a % of GDP are approximately 8.5% which is below the EU wide average of 11.2% (EU Com 2015%). In our analysis we find that the incremental increase in ambition from an 80% reduction in CO2 to a Net Zero CO2 energy system is 1.4% of GDP in 2050. The exact number when looking at all greenhouse gasses from landuse and agriculture will be higher but from an energy system perspective this figure can be manageable if correct policies are put in place at an early stage.

It is important to remember that it is not just the end point of Net Zero that determines the climate outcome, the cumulative emissions along the way are important. In a Net Zero energy system scenario almost 50% less CO2 is emitted to the atmosphere when compared to an 80% reduction scenario. These investments do not capture health benefits stemming from less air pollution, well-being benefits from a better housing stock or economic benefits from increased employment opportunities.

The bulk if increased incremental investment (40% of final sum) will fall on the electricity generation sector as extra capital is needed to build infrastructure and generation capacity. The transport sector will also require further investments as deeper decarbonisation drives up the need for investment.

2050 Energy System Costs as % of GDP

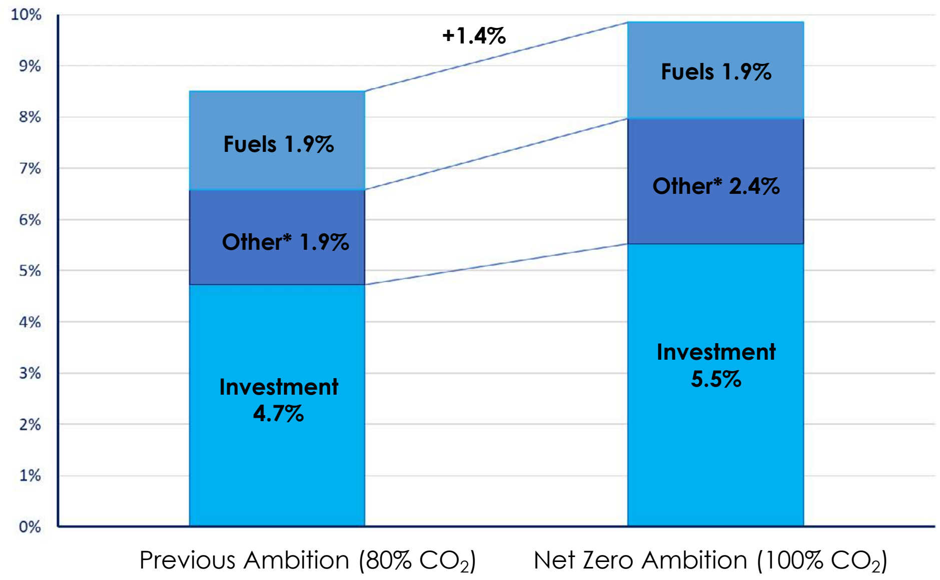


Figure 10: Energy system costs as % of GDP for 2050. Other costs relate to variable and fixed operation and maintenance

Further Ambition
Shipping and Aviation

Looking to aviation and shipping

In discussions with Wind Energy Ireland members, the role of international aviation and shipping was discussed as an important avenue for further ambition. These sectors are today outside of Ireland's national emissions inventories and are part of separate international cooperation mechanisms. For example, since 2012 aviation emissions have been included in the EU emissions trading scheme (EU ETS) and in 2016 the International Civil Aviation Organisation (ICAO) introduced the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) which is a market-based instrument designed to reduce international aviation CO2 emissions. In 2018, emissions from international aviation and shipping attributed to Ireland were reported as 3.3 Mt and 0.5Mt respectively. A recent **MaREI report** concluded that power-to-liquid electrofuels present the most feasible way to displace large quantities of fossil fuels from these sectors. When hydrogen is produced using renewable electricity, it can be combined with carbon that is captured to create 'green hydrocarbons'. There are many options (for example **here**) to capture the carbon and many fuels that can be produced, both liquid and gaseous, based on this principle. While these fuels are technically possible, they are thermodynamically and economically challenging, and require more research and development. If these challenges could be resolved and scaled-up globally then electrofuels fuels could potentially have a role.

The demand for aviation fuel in Ireland in 2050 is forecasted to be 18 TWh, so if Ireland was to use electrofuels to supply this demand of aviation fuel then it would require an additional 32 TWh of electricity. It would also require 5 million tonnes of CO2 to be captured from the atmosphere and if using direct air capture would require a significant heat load which could come from waste heat recovery from energy-intensive industries or renewable power plants. The electricity portion for further ambition on aviation equates to a further 7 GW of wind energy (assuming a capacity factor of 50%).

Shipping, which similar to aviation has not been included in the main analysis here since it is not part of Ireland's domestic carbon footprint accounting. An electrofuel currently investigated for shipping is **ammonia** (NH3) which can be made using hydrogen from water electrolysis and nitrogen separated from the air. These are then fed into the Haber process (also known as Haber-Bosch), all powered by sustainable electricity. In the Haber process, hydrogen and nitrogen are reacted together at high temperatures and pressures to produce ammonia. The demand for navigation fuel in Ireland in 2050 is forecasted to be approximately 3 TWh, which equates to a further 6 TWh of electricity or 1.5 GW of wind energy (assuming a capacity factor of 50%). Over the coming decade the costs and development of these fuel will become clearer and should be reviewed on a regular process.

***Direct Air Capture's** electricity requirements range between 0.4 and 0.5 MWh/tCO2 removed, and heat input between 1.5 and 2.2 MWh/tCO2 removed

Job Creation: Over 50,000 jobs could be created in critical sectors, requiring new skills and supply chains to be established

Specific Skillsets & Supply Chains Required

This study has created a detailed picture of what the energy sector could look like in 2050 once Ireland has committed to a legally binding net-zero carbon emission target under the Climate Action Bill. In line with the **No Regret Options** outlined earlier, future skills will be essential in:

- **Retrofitting Buildings.** Based on the investment required, we expect **approximately 25,000 jobs** will be created to retrofit Ireland's building stock to be compatible with the solutions identified here.
- **Expanding Renewable Electricity Capacity**, particularly onshore and offshore wind. Recent reports from **MaREI** and separate analysis from Wind Energy Ireland point to the significant potential for job creation due to the growth of wind energy in Ireland. Using key metrics from these reports and aligning that to the growth identified in this study, we expect **at least 25,000 jobs** will be created in the development of onshore and offshore wind to meet our zero carbon targets.
- **Electrifying our Heat and Transport Demands**, particularly heat pumps for buildings, electric cars for transport and hydrogen production for areas which cannot be directly electrified. The jobs created by electrifying our heat sector are already account for under Retrofitting Buildings as this includes the installation of heat pumps in buildings also. However, additional jobs will be created by electrifying other parts of the heat sector as well as transport. In particular, the creation of a hydrogen sector in Ireland will require a new supply chain which is currently not in place. Based on the investments identified in this study, we expect **at least 5,000 jobs** to be created in Ireland due to the new skills required by electrifying heat and transport.

Planning for Future Supply Chains

By quantifying the contribution of various technologies to a net-zero carbon energy sector in 2050, the analysis here has provided a roadmap and destination for the future supply chains of Ireland's energy sector. The 2050 Sankey Diagram shows that the fossil fuel sectors will contract to almost zero in the coming three decades. People will need to be retrained to move from coal, peat, oil and gas into other sectors like wind energy, solar power, electrification and retrofitting of buildings. Hydrogen is still a critical vector in 2050, so there may be scope to use the natural gas grid in a different way, so future research could investigate the potential of this in more detail.

Centres of Training Excellence

To kick start the uplift in new skills and re-training required, it is recommended that centers of training excellence are established across the three **No Regret Options** identified in this study. In particular, upskilling construction workers, plumbers and electricians in the area of **Retrofitting Buildings** will offer a quick-win to move jobs from the declining fossil fuel sector over to the rapidly growing sector of low-carbon buildings.

A centre of excellence is also required to train people in both **onshore and offshore wind energy development**. In particular, offshore wind offers a unique opportunity for Ireland's already well-established marine sector and those involved in fossil fuel exploration to move into jobs which require the expansion of renewable electricity capacity.

Finally, electrifying heat and transport will be vital in realising our net-zero carbon ambition. The analysis here identified the **hydrogen** economy as a critical part of this, which is an area which could offer significant job creation in the coming decades and so establishing a centre of excellence now, would put Ireland in a strong position to capitalise on this emerging sector.

Appendix

See associated excel file for input, assumption and sources

A 100% Renewable electricity System-Technical Perspectives

Across engineering and science there is a general consensus on the theoretical ability of a modern electricity system to operate without conventional generation. However, the necessary technical solutions in power electronics are not yet commercially available and innovation and large-scale testing would need to accelerate. High shares of variable renewables profoundly change the management of a electricity system and impact the system in a very different way to conventional power station. The stability of today's electricity systems is currently ensured by the inertia provided by conventional synchronous generators (gas, coal, hydro, biomass). These generators also provide a strong voltage support, as well as providing high fault current used for fault detection and resolution. Stability requires this three-fold contribution, provided historically by conventional generators. Unlike conventional power plant, which directly inject AC power into the grid, variable wind and PV generators are connected to the electricity system through power electronics called converters. These can be thought of as very fast digital switches that change the output of the variable renewable generator to match the electricity system. They are sometimes called 'grid following' as they "read" the frequency on the AC power system but do not impose a voltage and frequency reference to the network like conventional generators. When electricity systems remove conventional power stations and increase variable renewables two things happen. 1) inertia on the system decreases and if there is an incident or fault of a large unit the system frequency can vary more rapidly because there will be fewer conventional generators to absorb this shock. 2) A reduction in conventional power stations weakens the voltage reference signals and if the voltage is then not "strong" enough this makes it difficult to convert direct current into alternating current.

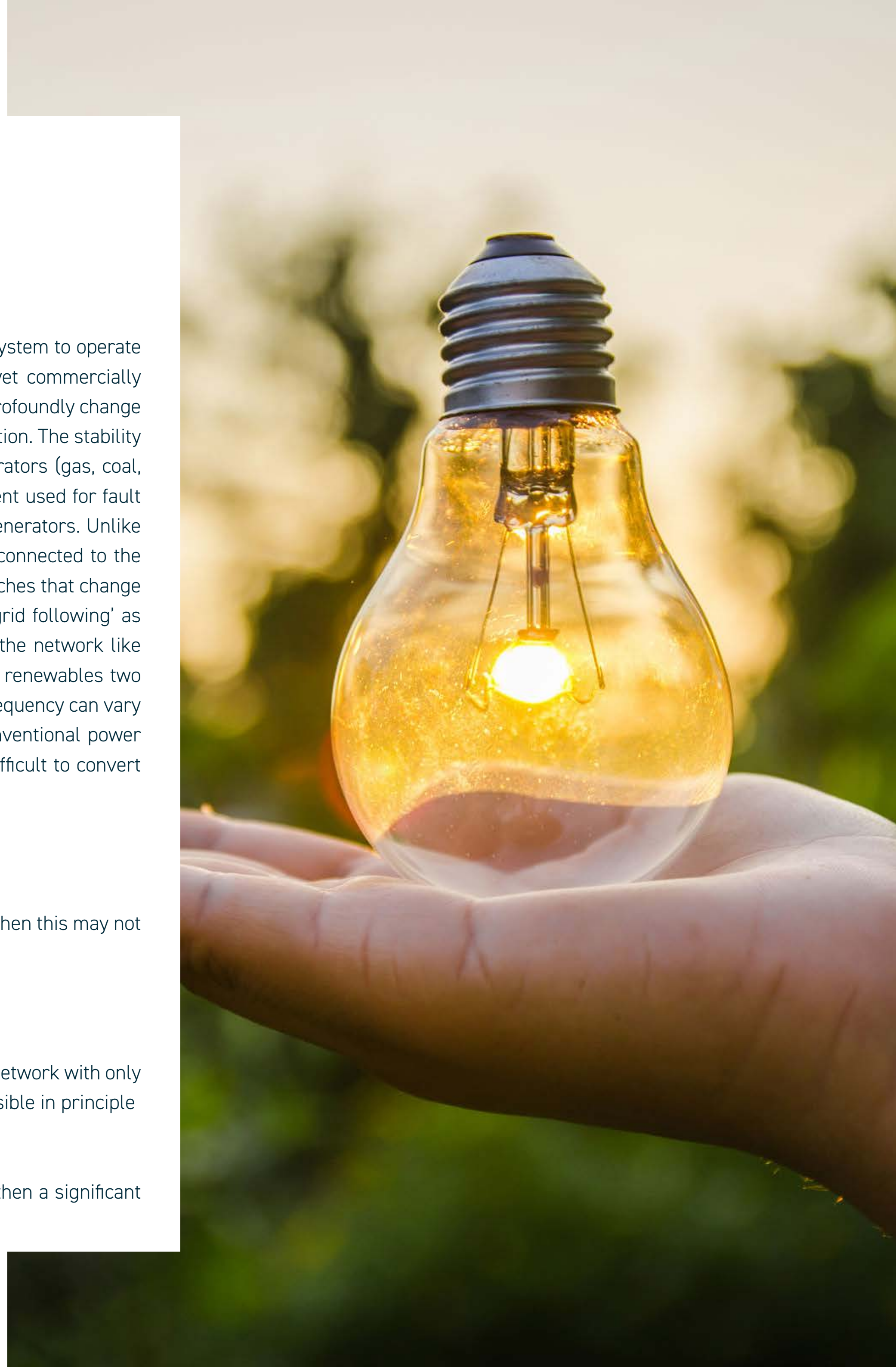
A number of options can conceptually be used to mitigate this:

1. Keep conventional plant on the system, but in the absence of widespread CCS with very high capture rates then this may not be compatible with a Net Zero vision.

2. Using synchronous condensers, which are similar to conventional power plant can be deployed.

3. Using innovative converters in renewable generation assets to provide 'grid-forming' services. Operating a network with only converter-based devices such as wind and PV while ensuring power system stability can be technically feasible in principle but needs further testing and demonstration at large scale.

In this analysis we assume a 100% renewable electricity system is possible post 2030. If this is not realisable then a significant capacity of zero carbon generation from conventional power plant would be required.



Study Assumptions

- We consider CO2 energy system emissions only and assume climate neutrality in the Agriculture and Land-Use sector.

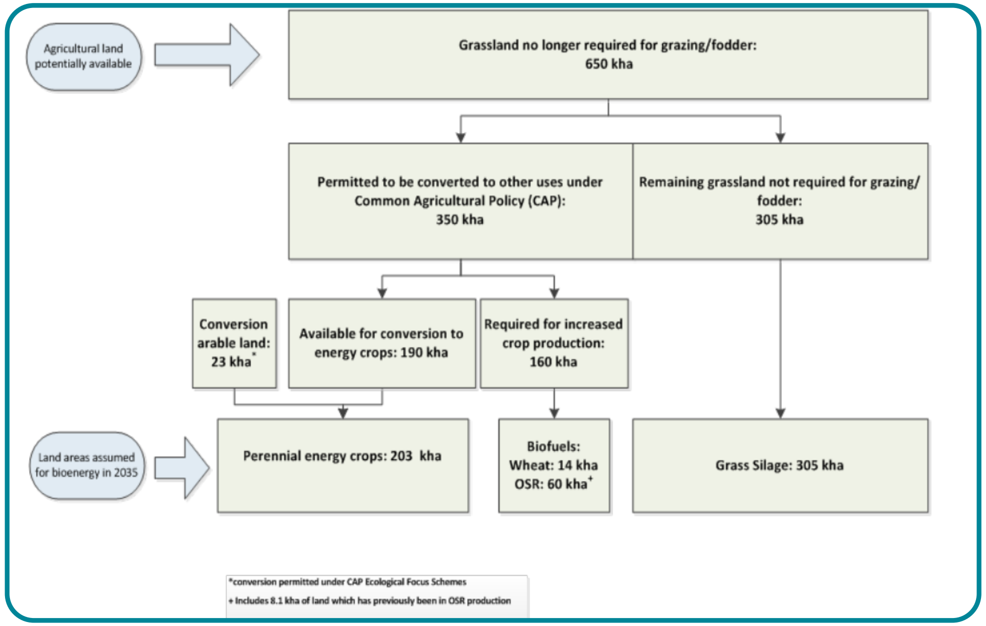
- We take a stylized approach which assumes Northern Irelands energy system follows a similar trajectory to Ireland in terms of economic growth, population and energy demand. This is due to a lack of equivalent data from Northern Ireland. Only the power sector is modelling in details for Northern Ireland.

- We used **SEAI data in bioenergy potential** in Ireland and assume Ireland has a population weighted import access to the sustainable bioenergy in Europe. The full bioenergy resource available is used.

- We assume fuel prices from the IEA WEO 2020

- Electricity system modelling is preformed using production cost methods with limited transmission system representation. Interconnectors are represented, but intra-regional transmission is not.

- We assume a 100% non-synchronous electricity system is feasible from 2030
  (see more in Appendix)



Land Availability Assumptions in SEAI Bioenergy Potential Study (see Figure 7 of report)
For context, the CSO recorded 4569 kha of agricultural land in Ireland in 2010.

Glossary of Terms

- **Net Zero** refers to the balance between the amount of greenhouse gas produced and the amount removed from the atmosphere.
- **Carbon budget.** Carbon budgets are a way to measure the additional emissions that can enter the atmosphere, if the world wishes to limit global warming. They are based on the fact that the amount of warming that will occur can be approximated by total CO2 emissions?
- **Carbon Capture and Storage (CCS)**. CCS is a climate change technology that can prevent CO2 from being released in the atmosphere from the use of fossil fuels or biomass combustion by capturing it and placing it in geological storage.
- **Gross Domestic Product (GDP)** Note that the GDP projection used in this study predate the significant influence of factors such as income of redomiciled companies, depreciation on R&D service imports and trade in IP and depreciation on aircraft leasing and are as such closer to the definition of Modified GNI.
- **Primary energy** is the total amount of energy used. It includes the final energy used directly by the end-user, but also the energy inputs to transformation processes such as electricity generation and oil refining and other losses such as electricity transmission and distribution.
- **The Intergovernmental Panel on Climate Change (IPCC)** is the United Nations body for assessing the science related to climate change.
- **Bio-energy with carbon capture and storage (BECCS)** is the process of extracting bioenergy from biomass and capturing and storing the carbon, thereby removing it from the atmosphere.
- **Direct Air Capture (DAC)** is a technology that captures carbon dioxide directly from the air with an engineered, mechanical system.
- **Electrofuels** are electricity based gaseous or liquid fuels which can be used in internal combustion engines.
- **Synchronous condensers** act similar to conventional power plant but do not generate power.

How to Use this Analysis and FAQs

- **What are the weaknesses in this analysis:** This report does not provide forecasts or predictions. It provides information to help us make informed decisions about the future based on analysis. The analysis is strong on technology and economic aspects and weak on representing human behaviour. Equally Ireland's industry sector is limited due to lack of detailed data.
- **What are the strengths of this analysis:** This analysis looks at energy across the full economy and allows us to see interactions across all modes of energy into the future.
- **What would change results most:** The availability and price of sustainable bioliquids for heavy transport has a significant impact on costs and outcomes beyond the no regret options. Lower access to these liquids raises system costs. The assumption of a 100% non-synchronous electricity system post 2030 is also a significant assumption that would change results if it were not attained.
- **Where did the assumptions come from?** Please see the accompanying excel sheet.
- **Is your model and data available to me?** The TIMES model is large and complex and requires training for competent use. The learning curve is approximately 9-14 months. We are happy to provide the model to people who complete the training. Summary input data is provided in the accompanying excel sheet.
- **Who funded this report and why?** This study was funded by Green Tech Skillnet and supported by Wind Energy Ireland to establish what a net zero energy system for Ireland entails and secondly, to establish on the role of Ireland's wind energy sector in this energy system. Six Wind Energy Ireland members also provided funding to support the work which were: ElectroRoute, ESB, energia, Ionic Consulting, Scottish Power and RWE.
- **Who contributed to this report?** This report was written and coordinated by Paul Deane. Modelling was undertaken by James Glynn, Xiufeng Yue and Paul Deane. Feedback was provided by Hannah Daly, Fionn Rogan, Laura Mehigan, Niall Hore, Jason Mc Guire and Nathan Gray. Quality Control was undertaken by Brian Ó Gallachóir.
- **Is this aligned to the government target of a 7% per annum reduction in emission to 2030?** No, we look to a carbon budget for Ireland of 376 Mt. This is consistent with a 33% to 50% probability of meeting a 1.5°C target with mitigation action commencing in 2020. A 7% per annum reduction would require a greater level of reduction to 2030. This is unlikely to change any of the No Regret options and would likely bring the decisions on Future Choices forward.
- **Why did you not look at nuclear energy and other options?** This report examines one pathway to a net zero energy system for a given carbon budget and presents 'No Regret options' that are robust policy choice. Nuclear energy and other decarbonization options such as steam methane reforming, low growth scenarios, wide scale district heating would require a separate in-depth detailed study beyond the current scope of work.

How to Read Sankey Diagrams

- Sankey diagrams show the flow of energy across the economy from primary energy (left hand side) and Final End Use (right hand side). Transformation of Energy into electricity is shown in the middle. The key to reading and interpreting Sankey Diagrams is remembering that the width is proportional to the quantity represented. Individuals fuels such as Oil and Gas are show by different colours and this follows the fuel from it primary energy to final consumption.

- On the left are the primary energy inputs to the Irish energy system. Primary energy includes the raw fuels that are used for transformation processes such as electricity generation and oil refining.

- On the right are the sources of demand for final energy. Final energy includes the energy used directly in the different sectors such as transport, residential and industry. Final energy does not include energy lost during transformation processes such as electricity generation. The sum of all final energy used in all sectors is known as Total Final Consumption (TFC).

- The sum of all the TWh's on the right hand side (supply) is equal to the sum of the TWh's on the Left hand side (demand) + System Losses (central). Note that to calculate the full Primary energy you have to add in small amount for agriculture and fisheries which are noted in the graphs as text but not shown for simplicity.

- The numbers on the Sankey Diagrams will not round out to zero, this is because values are rounded to the nearest TWh and in the 2050 Sankey Diagram the flows of electricity from Northern Ireland and Ireland have a small impact on how losses are attributed.

- Note that EV's in transport and air source heat pumps for heating are very efficient and require much less energy to meet the same level of energy service demand hence their contribution looks small in comparison to other fuel source which require more energy for the same energy service demand.

Green Tech Skillnet

Sycamore House, Unit 5B/5C,
Millennium Park, Naas, Co. Kildare, W91 D627

T: +353 45 899341
E: mark@windenergyireland.com
W: https://windenergyireland.com/learning-hub/green-tech-skillnet

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An Roinn Breisoideachais agus Ardoideachais, Taighde, Nuálaíochta agus Eolaíochta
Department of Further and Higher Education, Research, Innovation and Science

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