2050 Pathways Calculator for Ireland

Energy Institute

In conjunction with global accords, the European Union has committed to reducing its greenhouse gas emissions by at least 80% by 2050, relative to 1990 levels. For this to happen, we need to transform the Irish economy while ensuring access to secure and affordable low-carbon energy supplies to 2050.

We face major choices about how to move to a secure, low carbon economy over this period. Should we do more to cut demand, or rely more on increasing and decarbonising the energy supply? How will we produce our electricity? Which technologies will we adopt?

The analysis in the 2050 Pathways work presents a framework through which to consider some of the choices and trade-offs which we will have to make over the next thirty-five years. It is system-wide, covering all parts of the economy and all greenhouse gas emissions released in Ireland. It shows that it is possible for us to meet the 80% emissions reduction target in a range of ways, and allows people to explore the combinations of effort which meet the emissions target while matching energy supply and demand.

It is rooted in scientific and engineering realities, looking at what is thought to be physically and technically possible in each sector. It allows you, as the user of the Calculator, to explore all the available options and some of their key implications.

For each choice four trajectories have been developed, ranging from little or no effort to reduce emissions (trajectory 1) to extremely ambitious changes that push towards the physical or technical limits of what can be achieved (trajectory 4). The choices for each lever should be viewed along the lines of:

1. Very little or no effort, advances toward greater efficiency are purely market driven.
2. This trajectory reflects current trends and achieves targets which require medium effort.
3. This trajectory assumes significantly more effort is applied to decarbonisation and reducing energy demand, ambitious targets are achieved and medium effort targets are exceeded.
4. Extremely ambitious, maximum physical and technical potential.

The assumptions behind these trajectories for each of the levers are explained below.

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Domestic transport behaviour

In 2013 each of us travelled an estimated 13,000 km per year, excluding trips abroad. About 84% of this distance was by car or motorcycle, 3% was by rail, 10% by bus, 2.5% on foot, and 0.5% by bike.

Trajectory 1

Trajectory 1 assumes that by 2050 each of us travels 800 km or 6% more than in 2013. The share by mode of transport stays the same. Occupancy rates in cars fall as single person driving becomes more prevalent.

Trajectory 2

Trajectory 2 assumes that by 2050, each of us travels the same distance as we do today. Greater flexibility in working hours and increased use of teleconferencing are offset by rebound effects in non-commuter travel. Slightly less travel is by road and slightly more is by foot, bicycle and bus. The share of distance travelled is 80% by road, 3% rail, 13% bus, 3% foot and 1% by bike. Occupancy rates in cars and other vehicles stay the same.

Trajectory 3

Trajectory 3 assumes that by 2050, each of us travels the same distance as we do today and that there is a shift away from cars towards public transport and bicycles: 75% road, 4% rail, 16% bus, 3% foot, and 2% bike. One in 20 car trips are shared with one extra person.

Trajectory 4

Trajectory 4 assumes that in 2050 each of us travels 6% less than we do today. Urban planning facilitates access to local services and alternatives to commuting such as teleconferencing; flexible working arrangements are encouraged. There is a big shift away from the car: 70% road, 5% rail, 17% bus, 3% foot, and 5% bike. One in 10 car trips are shared with one extra person, cycle use increases to rates observed in the Netherlands, and rail passenger travel distance is 130% higher (including impact of population growth).

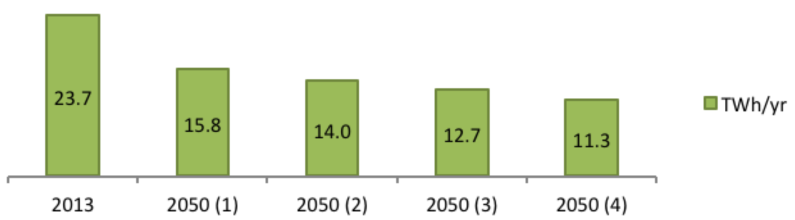
Interaction with other choices

We can power Ireland's cars, buses and trains by biofuel rather than diesel or petrol, or rely on electricity or hydrogen fuel cells. In the 2050 Calculator, the technology used and hence the emissions created is influenced by how much transport is electrified, how much electricity is decarbonised, and how much bioenergy is available for transport.

Table 1. Assumptions on distance travelled and the split of how that distance is travelled.

	2013	2050 T.1	2050 T.2	2050 T.3	2050 T.4
Km travelled/ person/ yr	12,872	13,664	12,872	12,872	12,100
% of km by:					
Walking	2.5%	2.5%	3.0%	3.0%	3.0%
Pedal cycles	0.5%	0.5%	1.0%	2.0%	5.0%
Cars, Vans, and Motorcycles	84.0%	84.0%	80.0%	75.0%	70.0%
Buses	9.9%	9.9%	12.9%	15.9%	16.9%
Railways	3.0%	3.0%	3.0%	4.0%	5.0%
Domestic air travel	0.05%	0.05%	0.05%	0.05%	0.05%

Figure 1. TWh/y assuming Trajectory 1 on 'Shift to zero emission vehicles' (20% hybrid vehicles, 2.5% zero emission cars) and assumes Trajectory B on 'Choice of electric or hydrogen car technology'



Shift to zero emission transport

In 2013, almost all of Ireland's domestic passenger transport was powered by diesel or petrol. By 2020, revised government targets aim for 50,000 electric vehicles (around 3% of private cars) on the road. Zero emission transport includes battery electric or hydrogen fuel cell cars and buses, and electrified domestic rail, all of which have zero emissions at the tailpipe. Hybrid or plug-in hybrid vehicles have both petrol/diesel engines and electric motors and are therefore not zero emission. However as plug-in hybrids receive most of their energy from the electricity socket, they can produce 45% less CO_2 from their tail pipe compared to conventional internal combustion engine vehicles.

Trajectory 1

Trajectory 1 assumes that by 2020, 1% of cars and 6% of buses are hybrids. Trajectory 1 assumes that by 2050, 20% of passenger kilometres are in plug-in hybrid electric cars, with batteries that can be charged from the mains, and 2.5% are in zero emission cars. The use of hybrid buses reaches 40%; trains are largely unchanged.

Trajectory 2

Trajectory 2 assumes that 2% of private cars are zero emission and that 1% are hybrids in 2020. By 2050 about 35% of passenger-km are travelled in conventional petrol or diesel engine cars, 54% of cars are plug-in hybrids and 11% are zero emission. Some 60% of buses are hybrids of electric motors and diesel engines. The electrification of passenger rail travel increases from 20% to 35%.

Trajectory 3

Trajectory 3 assumes that by 2050, 20% of passenger-km journeys are in conventional internal combustion engine cars, with 32% in plug-in hybrid vehicles and 48% in zero emission vehicles. About 20% of bus travel is in fully electric or fuel cell electric buses, with 60% of buses powered by hybrid diesel-electric engines. 65% of passenger rail travel is electrified.

Trajectory 4

Trajectory 4 assumes that by 2050 all car travel is either powered by an electric motor or by hydrogen fuel cells. Some 85% of passenger trains are electrified and 50% of bus travel is fully electrified (25% from batteries and 25% via fuel cells), with the remainder being diesel-electric hybrids.

Interaction with other choices

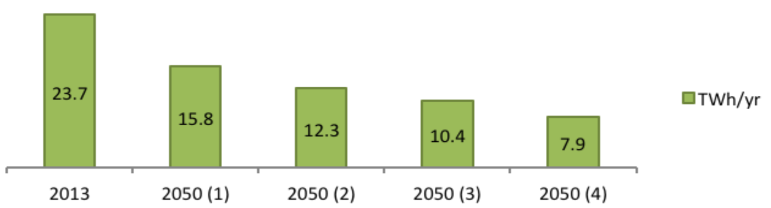
Users can specify the type of zero emission car technology to come onto the market by selecting any one of the choices A to D of the 'choice of fuel cells or batteries slider.

The 'domestic transport behaviour' lever influences how much people travel and by what mode.

Where vehicles are not electrified (and even in Trajectory 4, buses are expected to be at least partially powered by liquid fuel) they can run on biofuel rather than diesel or petrol. This option can be selected in the 2050 Calculator by choosing bioenergy imports, or choosing to dedicate land to biomass and to turn that biomass into liquid biofuel.

% of car travel by:	2013	2050 T.1	2050 T.3	2050 T.2	2050 T.1
Conventional car	~100	77.5	35	20	0
Plug-in hybrid	0	20	54	32	0
Zero emission car	0	2.5	11	48	100

Figure 2: Energy requirement in TWh/y assuming Trajectory 1 on 'domestic transport behaviour' and Trajectory B on 'Choice of electric or hydrogen car technology'



Choice of fuel cells or batteries

In 2013, almost all vehicles were powered by diesel or petrol engines. Between now and 2050, it is anticipated that the use of zero emission vehicles (such as battery electric or hydrogen fuel cell vehicles) will increase.

The 'Shift to zero emission transport' slider allows users to specify the proportion of zero emission vehicles in the domestic vehicle fleet.

Options A to D allow the user to choose the proportion of those zero emission vehicles that are either fully electric or run on hydrogen fuel cells.

In practice other technologies such as 'hybrid' electric-hydrogen vehicles (hydrogen fuel cell range extender) could exist, using all-electric for short journeys and hydrogen for long journeys. However, for now atleast, the Calculator only models fully battery electric or hydrogen fuel cell vehicles.

Option A

Option A assumes that by 2050, all (100%) of zero emission domestic vehicles are fully electric.

Option B

Option B assumes that by 2050, four out of five (80%) of zero emission electric vehicles are fully electric, and one in five (20%) have hydrogen fuel cells.

Option C

Option C assumes that by 2050, 20% of zero emission domestic vehicles will be fully electric and 80% of vehicles will have hydrogen fuel cells.

Option D

Option D assumes that by 2050, all zero emission domestic vehicles will be powered by hydrogen fuel cells.

Interaction with other choices

The trajectory of transport electrification selected in the 'Shift to zero emission transport' slider and the assumptions about 'Domestic Transport Behaviour' will influence the overall numbers of electric and hydrogen fuel cell cars and vans on the road.

The Options A to D allow for different mixes of all electric and fuels cells; they not impact on the technologies and choices in the 'Shift to zero emissions transport' slider where conventional and plug-in hybrid cars, buses, trains and aviation and shipping are all included.

Domestic freight

In 2013, 99.1% of all Irish freight movements were by road and 0.9% was by rail. Almost all freight transport was powered by diesel or petrol engines. In 2013, the total amount of goods-movement was 9,985 million tonnes-kilometres – that equates to 2,219 tonne-kilometres per person. The share of goods moved by road and rail is assumed to stay constant up to 2050. Changes in the distance of freight travelled in terms of vehicle-kilometres and improvements in engine efficiency are presented in the levers.

Freight transport reported here include heavy goods vehicles (HGVs), light goods vehicles (LGVs), 'marine navigation' and the fuel consumption of service and construction vehicles, encompassed in the 'unspecified' category in the Irish energy balance.

Trajectory 1

This trajectory assumes that goods movement as measured by vehicle-kilometres increases by 33% from 2013 to 2050 and that per capita it falls by 2%. A growth in movement of freight by rail in line with road freight growth reflects spare bulk rail transport capacity. The energy efficiency of road freight improves by 15%to 2050.

Trajectory 2

Trajectory 2 assumes that the efficiency of goods vehicles improves by 20% and that the vehicle-kilometres travelled increases by 25% by 2050.

Trajectory 3

Trajectory 3 assumes that by 2050, the movement of freight grows but less quickly than economic output (GDP). Lorries are twice as efficient. This trajectory assumes that overall vehicle-kilometres increases by 10% from 2013 to 2050. Taking account of population increase, there is a drop of 19% in vehicle-kilometres per person.

Trajectory 4

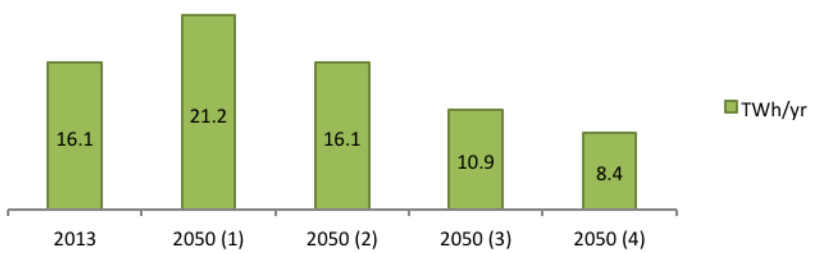
Trajectory 4 assumes that the volume of freight grows less quickly than GDP. All freight trains are electric. This trajectory assumes overall goods moved in 2050 stays the same as 2013. There is a drop of 26% in goods-movements per person. Lorries are almost 60% more efficient.

Interaction with other choices

Choices about building different sorts of infrastructure, about the use of waste, bioenergy and other fuels, and shifts in the size of Irish industry will all influence freight transport demand. The 2050 Calculator does not model the impact on freight of these choices; you have to make sure your choices are consistent.

We can power Ireland's lorries and trains by biofuel instead of diesel or petrol. To bring this about in the Calculator, choose either (i) to import bioenergy or (ii) to dedicate land to biocrops; and then turn those biocrops into liquid fuel.

Figure 3: Energy demand in TWh/yr for domestic freight (including HGVs, LGVs, marine navigation, and service vehicles)



International aviation

In 2013, 24.6 million international aviation passengers used Irish airports. According to Eurocontrol, the European Organisation for the Safety of Air Navigation, passenger air travel in Europe by 2050 may increase by up to 150% in a high growth scenario; this is reflected in trajectories 1 and 2. In a fragmenting global growth and high fuel price scenario, passenger numbers may grow at slower pace, increasing by 30% by 2050 compared to 2013 (Trajectory 4).

Now there is no agreed way of allocating international aviation emissions to different countries. Such emissions are not currently included in Ireland's 2050 target, largely for this reason. However, they are included in the 2050 Calculator to ensure complete coverage of all sectors.

Trajectory 1

By 2050, the number of international passengers using Irish airports increases by about 150%. Action to reduce inefficiencies in air traffic related operations, and action to promote behavioural change amongst leisure passengers improves efficiency by 0.9% per year. By 2050 the sector uses 70% more fuel than in 2010.

Trajectory 2

Trajectory 2 assumes the number of international passengers using Irish airports increases by 150%. Air carriers improve the match between aircraft and flight requirements and international action to introduce CO_2 standards and international fuel burn goals lead to efficiency improvements averaging 1.2% per year. By 2050 the sector uses 50% more fuel than in 2010.

Trajectory 3

Trajectory 3 assumes the same efficiency improvements as in Trajectory 2. By 2050 the number of international passengers using Irish airports more than doubles to 110% above 2013 levels. The sector uses 30% more fuel than in 2010.

Trajectory 4

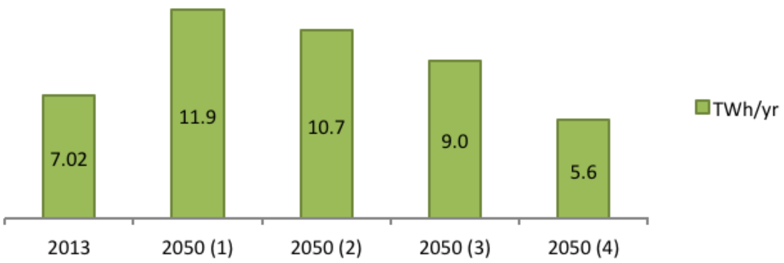
Trajectory 4 assumes that all the efficiency measures in trajectory 2 and 3 hold but that by 2050 the number of international passengers using Irish airports increases by only 30%. The sector uses 20% less fuel than in 2010.

Interaction with other choices

Test flights have demonstrated the possibility of using biofuels in aviation. However biofuel is available in limited quantity and it is subject to competing demands for its use. In the future, aircraft may be able to use biofuels in really significant quantities. To choose a 2050 Calculator pathway where biofuels are used in aviation, either select a pathway that has bioenergy imports, or select a pathway that has both Irish bioenergy production and conversion to mainly liquid bioenergy.

Figure 4: Boeing 737 MAX, due to be rolled out in 2017 with at least 10-12% improved efficiency.

Figure 5: Energy demand in TWh/yr for international aviation in Ireland.



Building Energy Ratings (BERs)

The energy performance of buildings in Ireland is measured and expressed by way of a Building Energy Rating (BER) certificate that categorises and ranks buildings according to their energy consumption per square metre and associated CO2 emissions. BER certificates range from G to A1 on a 15-point scale, where the A-rated properties are the most energy efficient. In 2013, approximately 7% of homes had a rating in the range of A to B2, 34% had a B3 to C3 rating, 22% were D rated, and 36% were rated E to G. At an average annual housing growth rate of 0.9% and an obsolescence rate of 0.8% in 2013 declining to 0.25% in 2050, there will be over 1 million new residential properties in Ireland by 2050. If all new builds are constructed to a minimum standard of B2, with no further retrofits of existing buildings, 50% of homes will be rated A to B2 in 2050.

Trajectory 1

Allows for existing A and B rated buildings, plus all new builds up to 2050. Some 50% of buildings have a rating in the range A to B2 by 2050.

Trajectory 2

Trajectory 2 assumes that all new builds and continued retrofits of existing buildings leads to 20% of homes having a B2 rating or higher in 2020, rising to 60% of homes in 2050.

Trajectory 3

According to Trajectory 3, some 75% of homes have B2 energy rating or higher in 2050, 15% have a rating between B3 and D2, and 10% have an E rating or lower.

Trajectory 4

Trajectory 4 assumes that 45% of homes will be B2 rated or higher in 2030 and 90% of homes will have a B2 rating or higher in 2050. Certain buildings such as protected structures remain in lower categories. Retrofits gradually increase over time driven by lower costs and higher building standards. There will be 40,000 to 50,000 home retrofits between 2040 and 2050.

	2013	2050	2050	2050	2050
		T.1	T.2	T.3	T.4
Number of homes (million)	1.67	2.35	2.35	2.35	2.35
BER rating:					
A-B2	7%	50%	60%	75%	90%
B3-C3	16%	9%	7%	4%	2%
C2-C3	19%	10%	8%	5%	2%
D	22%	12%	9%	6%	2%
E, F and G	36%	19%	15%	10%	4%

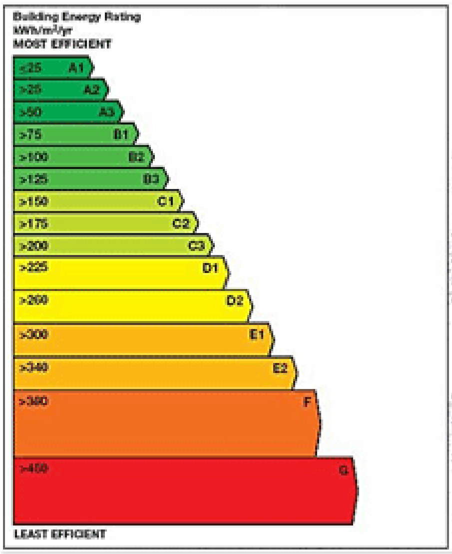
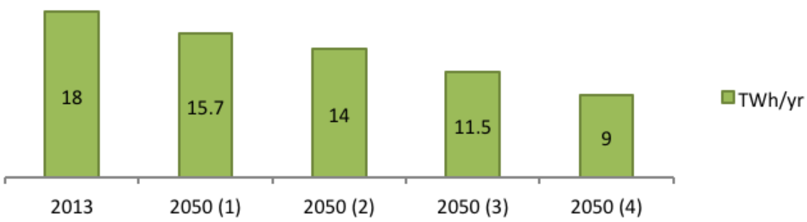


Figure 6: Building Energy Rating Scale from A1 to G in kWh/m^2/yr

Figure 7: Residential space heat demand (TWh/yr)



Smart metering and home heating

The National Smart Metering Programme, initiated in 2007, plans to roll out smart electricity and gas meters to households in Ireland. These will help consumers to manage and use energy more efficiently. Over 5,000 residential electricity customers in Ireland had smart meters installed in Phase 1 of the project. The average recorded reduction in energy consumption was 3% per year, however, savings reached up to 9% in some cases.

Trajectory 1

Trajectory 1 assumes no further roll-out of smart meters.

Trajectory 2

Trajectory 2 assumes that all homes will be installed with a smart electricity-meter by 2025 and 40% of homes have a smart gas-meter in 2050. The average energy demand for electric space heating in homes with meters installed is reduced by 3%.

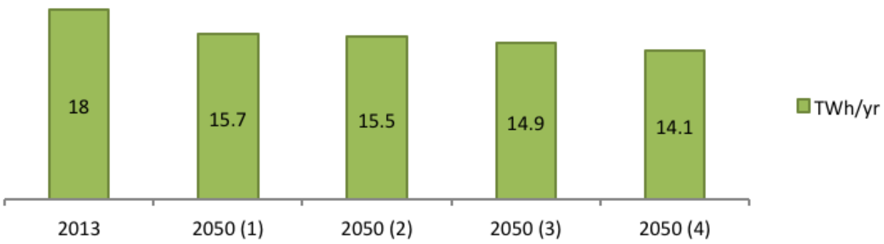
Trajectory 3

Trajectory 3 assumes that smart meters for electricity are installed in all homes and that 70% of homes have one for gas. The average annual energy demand for heating in homes with meters is reduced by 9% for those relying on electric heat and 6% per year for those using gas.

Trajectory 4

Trajectory 4 assumes that by 2050 smart meters for electricity are installed in all homes and that 90% of homes have a smart meter for gas. As users become more aware of their consumption and billing information, through better energy management and conservation, and due to a higher share of properties switching to electric heating enabling demand shifting during peak periods, savings reach 15% on average (10% for the smaller share still using gas).

Figure 8: Home energy demand in TWh/y assuming Trajectory 1 on BER lever and Trajectory 2 on Electrification lever.



Commercial demand for heating and cooling

This sector considers the amount of energy for heating, cooling and hot water in commercial buildings such as shops, hotels, offices, and schools; it doesn't include industrial buildings which are covered under the industry sector. In 2013, commercial premises used an estimated 8.1 TWh/y of energy for heating, 1.4 TWh/y for hot water, and 1.0 TWh/y for cooling.

The 2050 Calculator assumes that the number of commercial properties increases by 1% per year, from 109,000 in 2013 to ~160,000 in 2050.

Trajectory 1

Trajectory 1 assumes that in 2050, heating and hot water demand are higher than in 2013, reaching 11.7 TWh/y for heating and 2 TWh/y for hot water. This means that in 2050 each building requires about the same heat and hot water as in 2013. Almost half of commercial buildings are air-conditioned in 2050, increasing energy demand for cooling to 3 TWh/y. The total energy demand for commercial heating and cooling in 2050 is 17 TWh/y.

Trajectory 2

Trajectory 2 assumes that in 2050, heating demand grows to 9.4 TWh/y, while hot water demand grows by 33% to 1.9 TWh/y. This means each building requires 20% less heat and 10% less hot water in 2050. The share of commercial buildings with air conditioning is similar to today (~23%), increasing energy demand for cooling by 40% to 1.4 TWh/y. The total energy demand for commercial heating and cooling in 2050 is 13.8 TWh/y.

Trajectory 3

Trajectory 3 assumes that in 2050, total heating and cooling demands remain at 2013 levels, at 9.5 TWh/y for heating and 1 TWh/y for cooling. This means each building requires 45% less heat and air-conditioning in 2050. The total energy demand for commercial heating and cooling in 2050 is 11.6 TWh/y.

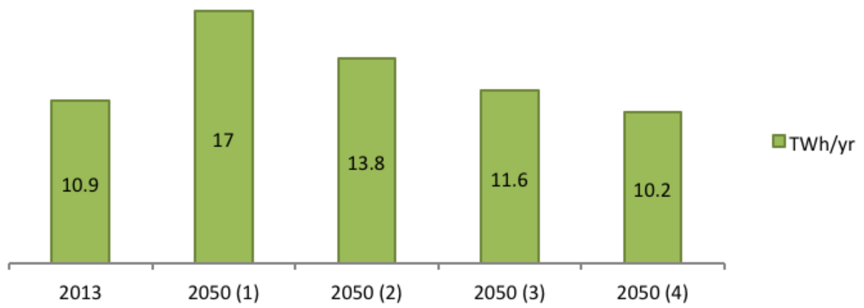
Trajectory 4

Trajectory 4 assumes that in 2050, total heating and cooling demands are slightly lower than in 2013. Heating demand falls to 7 TWh/y, hot water demand grows to 1.5 TWh/y, and cooling demand falls to 0.6 TWh/y. This means each building needs 40% less heat, 30% less hot water and 60% less air-conditioning in 2050. The total energy demand for commercial heating and cooling in 2050 is 10.2 TWh/y.

Interaction with other choices

2050 Calculator users should choose the technologies for heating and air-conditioning in the 'Domestic and commercial heating choices' sector.

Figure 9: Energy demand in TWh/y assuming Trajectory A on electrification and commercial heating that is not electric (primarily gas).



Domestic and commercial heating choices

In 2013, 62% of homes were heated with oil boilers (in terms of total domestic heat demand by technology), 33% with gas boilers, and the remaining 5% used electricity, biomass, heat pumps or thermal solar. It is expected that the heating systems in existing homes will need to be replaced by 2050 and the systems in approximately 1 million new homes (including rate of obsolescence) will need to be installed.

In 2013, 43% of commercial heating was supplied by gas boilers, 30% by electric heaters, 23% by oil boilers, 3% by biomass, and 1% via heat pumps. It is also expected that all commercial heating systems will need to be replaced by 2050, so the choices offered in the Calculator reflect the range of replacement options.

The 2050 Calculator considers eleven technologies for heating buildings. Combinations of these can be selected through two choice steps, one that mainly influences the trajectory of amount of electric heating and the other that influences the choice of heating alternative to electricity.

The table below sets out the technologies covered by each choice.

- **Electrification choice** is selected by the levers ‘Home heating electrification’ and ‘Commercial heating electrification’ as applied to the home and commercial sectors;

- **Other heating choice** is selected by the levers ‘Home heating that isn't electric’ and ‘Commercial heating that isn't electric’.

The technology which could be used to supply Ireland’s building heat in 2050 include:

- **Conventional gas boilers**, assumed to be capable of using either biogas or natural gas. (Their use is maximised by choosing A for electrification and A for the other heating choice).

- **Solid fuel boilers**, assumed to be capable of using either coal or biomass. (Maximised by choosing A for electrification and B for the other heating choice).

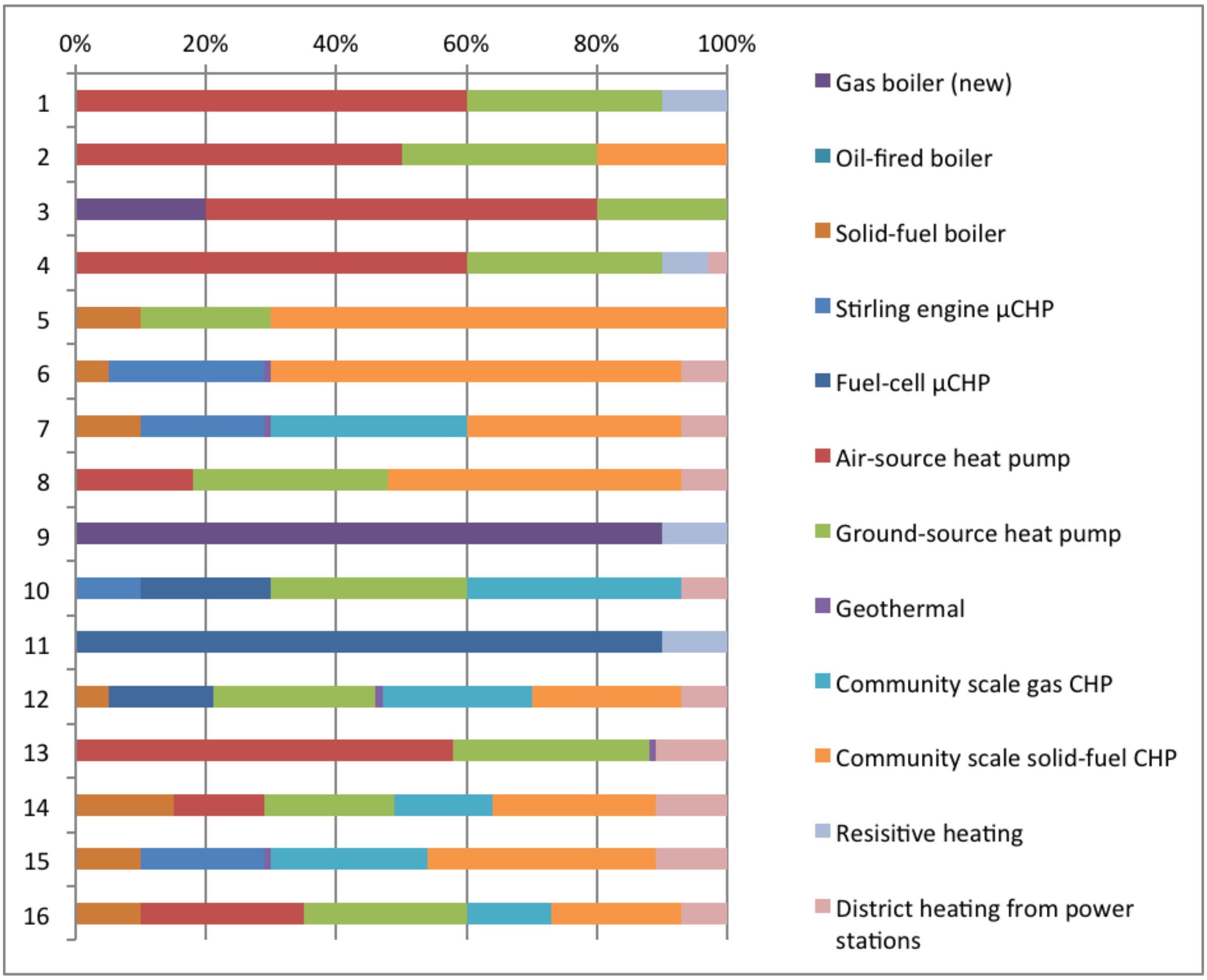
- Electrification via the installation of **resistive heating technologies, ground-source and air-source heat pumps**. (Maximised by choosing D for electrification and D for the other heating choice).

- Home heating technologies, designed to produce electricity while they are producing heat, e.g. **micro-Combined Heat and Power** (µCHP). (Maximised by choosing B for electrification and A for the other heating).

- Piped-in heat, for example **district heating** that takes steam or hot water from large power stations (Maximised by choosing A for electrification and C for the other heating choice), or from community scale gas or solid-fuel CHP systems (Maximised by choosing B for electrification and C for the other heating choice).

Electrification trajectory	Primary non-electric source			
	Gas (A)	Solid (B)	District (C)	Mixed (D)
Very low (A)	9	6	15	7
Low (B)	11	5	14	12
Medium (C)	10	8	13	16
High (D)	3	2	4	1

Figure 10: There is a large existing stock of heating systems dominated by oil. Every year heating systems are replaced, and the table below shows the split by technology of those new heating systems.



Lighting and appliances

Domestic and commercial ownership of electric lighting and appliances such as refrigerators, ovens, televisions and computers is steadily increasing. The energy performance of many such devices continues to improve. Around half of all light bulbs installed are now more efficient than incandescent models, and the average energy consumed per appliance is falling.

In the 2050 Calculator, the lighting and appliance sector's future energy use is determined by:
- demand and efficiency (described here);
- electrification of cooking (described in a separate note).

Trajectory 1

Trajectory 1 assumes that the energy demand per household for lighting and declines by 15% between 2013 and 2050 (but because of the growth in the number of households overall demand increases by 20%). There is a market trend towards more energy-efficient equipment, but this is partially counteracted by more electronics and computers in each home. This level also assumes that overall energy demand from commercial lighting and appliances increases by 20% between 2013 and 2050.

Trajectory 2

Trajectory 2 assumes that the demand per household declines 30% by 2050 (total domestic demand stays relatively stable). All appliances are replaced with efficient alternatives and smart meters are used to monitor and manage home energy consumption. This level also assumes that by 2050 the demand from commercial lighting and appliances increases by 10%.

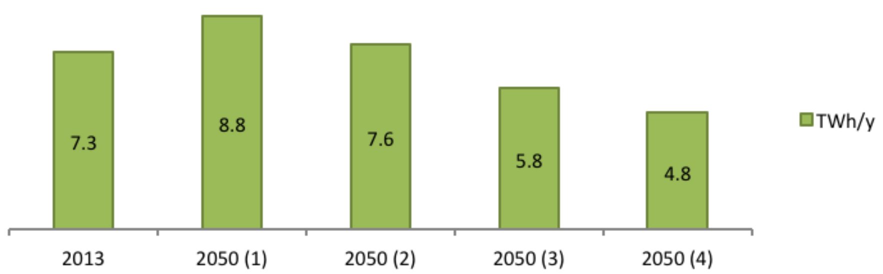
Trajectory 3

Trajectory 3 assumes that demand per household declines by 50% by 2050 (total domestic demand falls by around 30%). All lighting is replaced with very efficient light emitting diodes (LEDs); appliance manufacturers take substantial extra steps to improve the energy efficiency of their equipment; and consumers are smarter about how and when they use equipment. This level also assumes that overall demand from commercial lighting and appliances decreases by 10% by 2050.

Trajectory 4

Trajectory 4 assumes that demand per household declines by 60% by 2050. There are technological breakthroughs in the efficiency of equipment and households take substantial care in how they use energy. Equipment manufacturers act to reduce power consumption by their products. This trajectory also assumes that the energy demand for commercial lighting and appliances decreases by 25% by 2050; that 90% of lights are high-efficiency LEDs; that commercial fridges are much more efficient designs; and that computing systems are designed to be low energy.

Figure 11: Lighting and appliance use (only) by domestic and commercial buildings (TWh/y)



Electrification of cooking

Currently all lighting and most appliances are powered by electricity; for cooking there is a choice between gas and electricity. In 2013, 65% of commercial cooking and 28% of domestic cooking was on gas, with the balance of 35% and 72% using electricity.

In the 2050 Calculator the lighting and appliance sector's future energy use is determined by:

- electrification (described here) and
- demand and efficiency (described on the 'Lighting and appliances' page).

The choice here is of different pathways rather than an increasing scale of effort. It is not to be seem as like Trajectorys 1-4 for other sectors and have therefore been labelled as 'A' and 'B" rather than '1' or '2' i.e., Trajectories A and B.

Trajectory A

Trajectory A assumes that in 2050 the cooking energy mix remains the same as in 2013; 65% of commercial cooking and 28% of domestic cooking is by gas and the rest is by electricity.

Trajectory B

Trajectory B assumes that in 2050 all commercial and domestic cooking is electrified. Gas hobs and ovens have been replaced with traditional electric, induction or microwave alternatives.

Interaction with other choices

The 2050 Calculator allows biogas to be used to replace natural gas in cooking. This can be chosen by dedicating land to biocrops and then choosing to turn those biocrops into gaseous fuel. However biogas is very limited in quantity and there are many other competing uses for biofuels across the transport, heating and electricity generation sectors.

Growth in industry

The industry sector includes the manufacture of pharmaceuticals, food and drink as well as metals, minerals, and chemicals. In 2013 industry was responsible for about 21% of Ireland's energy demand. In addition to emissions from the energy used, the sector emitted 2.4 Mt $C0_2$e originating in manufacturing processes. Some 28% of industry's energy demand was met by gas, 36% by electricity, and the rest by oil, coal or biomass.

In the 2050 Calculator the industrial sector's future energy use is determined by two factors:

- industry growth (described here) and
- industry energy intensity (described on another page).

The choice here is of different pathways rather than increasing scale of effort. They are different to the Trajectorys 1-4 in other sectors and have therefore been labelled as Trajectories A, B and C.

Each trajectory uses the same projected rate of economic growth. However the composition of the growth is different in each trajectory. Trajectory A assumes that industry accounts for a high proportion of Irish GDP, and Trajectories B and C assume the industry accounts for progressively lower proportion of GDP growth.

Trajectory A

Trajectory A assumes that Irish industry will expand availing of the opportunity to manufacture new low-carbon technologies, and low-carbon replacements for existing goods and machinery. At an average growth rate of 2.5% to 2050 industrial output will more than double.

Trajectory B

Trajectory B assumes that the growth trend of 2000 to 2013 continues, leading to a 45% increase in industrial output by 2050.

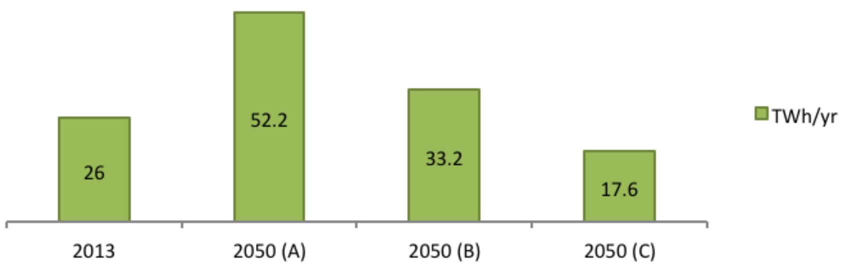
Trajectory C

Trajectory C assumes Ireland's economy shifts from industry into other sectors, leading to industrial output declining by 30-40% between 2013 and 2050.

Interaction with other choices

The size of the industrial sector affects the need for freight, but this dependence is not handled automatically by the Calculator – you can choose the setting for each independently.

Figure 12: Energy demand in TWh/y assuming Trajectory 1 on industry energy intensity



Energy intensity of industry

The industry sector includes the manufacture of food and beverages, metals, minerals, and other products. In 2013 industry consumed about 21% of Ireland's final energy. In addition to emissions from the energy used, industry emitted 2.4 $MtCO_2e$ of greenhouse gases directly from its processes. 28% of industrial energy demand was for gas, 36% was for electricity, with the rest from oil, coal or biomass.

In the 2050 Calculator the sector's future energy use is determined by two factors:

- industry energy intensity (described here) and
- industry growth (described on another page).

Trajectory 1

Trajectory 1 assumes that process emissions remain constant and that there is a 10% reduction in the energy intensity of manufacturing between 2013 and 2050.

Trajectory 2

Trajectory 2 assumes a 20% improvement in energy intensity; a 25% reduction in process emissions per unit of output and that 39% of industrial energy demand is met by electricity.

Trajectory 3

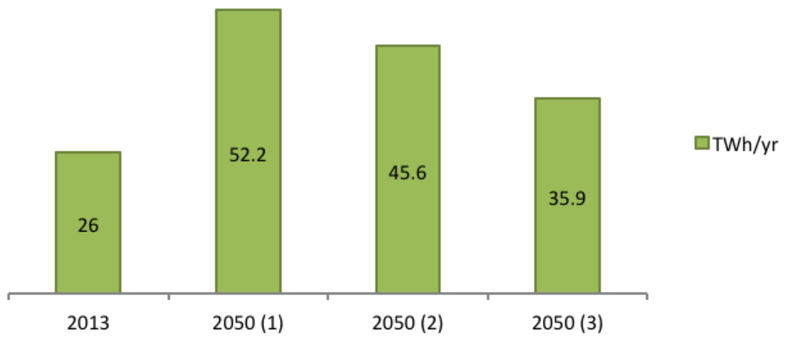
Trajectory 3 assumes that there is a 40% improvement in energy intensity and at least a 30% average reduction in process emission intensity. 66% of energy demanded is for electricity.

Interaction with other choices

The coal, gas and oil used by industry could be replaced with bioenergy. To do this in the 2050 Calculator, select bioenergy imports, or choose to dedicate land to biomass and to turn that biomass into solid, liquid or gaseous biofuel.

There may be significant demand for carbon dioxide (CO_2) transport infrastructure and storage capacity in three sectors: industry, carbon capture and storage, and geosequestration. Calculator users may wish to consider these options together to take a view on whether the total demand for CO_2 transport and storage infrastructure is feasible.

Figure 13: TWh/y assuming trajectory A for industry growth



Nuclear power stations

In 2013, Ireland had no nuclear power stations. Given the potential system demand in Ireland relative to the minimum efficient capacity of a nuclear facility (around 1 GW), Ireland would only have use for one nuclear plant. It is assumed that a nuclear power station would begin to be built in 2025 as Moneypoint is decommissioned with 1 GW capacity available from 2030 onwards.

Trajectory 1

Trajectory 1 assumes that no new nuclear power stations are built.

Trajectory 2

Same as trajectory 1

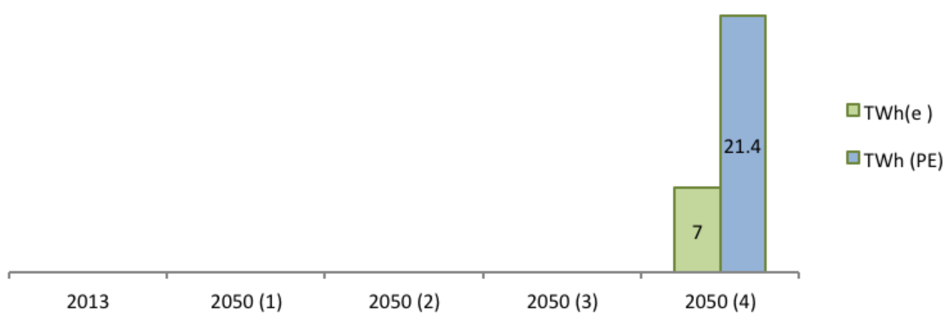
Trajectory 3

Same as trajectory 1

Trajectory 4

Trajectory 4 assumes an increase in capacity to 1 GW of nuclear by 2050 from one power station following the decommissioning of Moneypoint. Around 7 TWh/y of electrical output is generated.

Figure 14: There are two possible ways of measuring the energy produced by a nuclear power station, modelled in the chart below. Most of the figures in this document show the electrical energy delivered (the green bars), but sometimes it is conventional to display the primary energy (the blue bars), which is the heat generated by the nuclear processes. The electrical energy is smaller than the primary energy due to the inherent conversion losses and the energy requirements of the power station itself. If the nuclear power station was located near to buildings with heat demand they could generate combined heat and power: in return for a modest loss in electrical output much of the 'waste' heat can be delivered to the heat-users.



Carbon capture and storage power stations

Carbon capture and storage (CCS) technology captures carbon dioxide (CO_2) from fossil fuel power stations, which is then transported via pipelines and stored in deep underground structures such as depleted oil and gas reservoirs. Up to 90% of the carbon dioxide from a fossil fuel power station could be captured using CCS technology. CCS is unproven on a large scale, as yet.

In the 2050 Calculator the future shape of the CCS sector is determined by two choices:

- the CCS power station build rate (described here) and
- the CCS power station fuel mix (described on another page).

Trajectory 1

Trajectory 1 assumes no CCS plants or retrofitting of CCS technology to power stations.

Trajectory 2

Trajectory 2 assumes that CCS technology is demonstrated successfully and that by 2050 Ireland sequesters between 2.4 and 3.1 million tonnes of CO_2 per year (depending on whether the fuel is gas or coal). 800 MW of available CCS-fitted power plant capacity would be equivalent in size to Ireland's existing coal power station, Moneypoint, and provides around 5 TWh/y of electricity. That means building about 2*500 MW power stations with construction starting in 2040.

Trajectory 3

Trajectory 3 assumes that the Ireland builds 2.3 GW of CCS power station available capacity by 2050 with construction beginning in 2035, which is about 5*500 MW power stations, producing around 15 TWh/y of electricity, comparable to current gas and coal generation in Ireland.

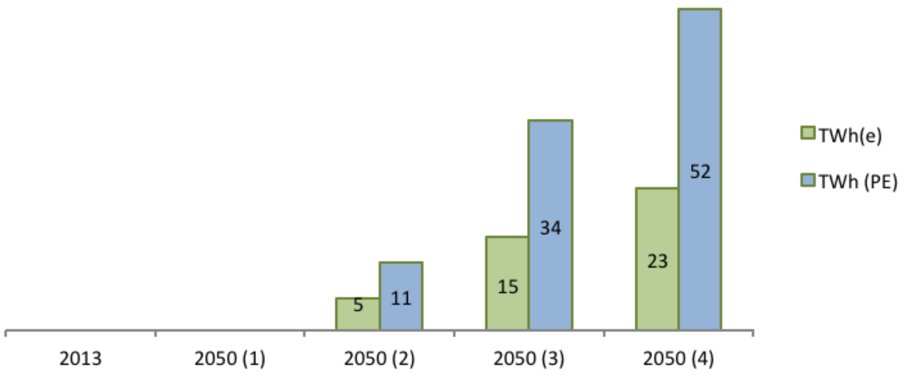
Trajectory 4

Trajectory 4 assumes that Ireland builds 3.5 GW of CCS power stations by 2050, equivalent to around 7*500 MW power stations, producing around 23 TWh/y of output (comparable to current electricity consumption). Construction runs from 2030 to 2050 at a rate of around 200 MW per year. This amount of CCS plant also requires the construction of infrastructure for transporting and storing the captured CO_2 on a large scale.

Interaction with other choices

There is significant demand for CO_2 transport infrastructure and storage capacity in carbon capture and storage power stations. Calculator users may wish to consider these options together to take a view on whether the total demand for CO_2 transport and storage infrastructure is feasible.

Figure 15: Electricity produced and primary energy requirement for CCS under 4 trajectories



Carbon capture and storage power station fuel mix

The 2050 Calculator allows CCS power stations to be fuelled by either solid fuel (coal or biomass if available) or a gaseous fuel (natural gas or a biogas if available). Any available biofuel is used in preference to fossil fuel.

In the 2050 Calculator the future shape of the CCS sector is determined by two choices:

- the CCS power station fuel mix (described here) and
- the CCS power station build rate (described on another page).

Trajectory A

Trajectory A assumes that all CCS power stations use solid fuel (coal or biomass).

Trajectory B

Trajectory B assumes that two-thirds of CCS power stations use solid fuel (coal or biomass), and the rest use gas (natural gas or biogas).

Trajectory C

Trajectory C assumes that two-thirds of CCS power stations use gas (natural gas or biogas), and the rest use solid fuel (coal or biomass).

Trajectory D

Trajectory D assumes that all CCS power stations use gas (natural gas or biogas).

Interaction with other choices

Trees and growing plants capture CO_2 from the atmosphere, which they store in the form of plnat tissue or woody biomass. Ireland can take advantage of this by harvesting the biomass and burning it in electricity generation plants which are fitted with CCS facilities and storage infrastructure. This would ensure that up to 90% of the CO_2 sequestered from the atmosphere by plants is stored underground in designated CCS facilities. This process is called bioenergy plus carbon capture and storage (BECCS).

A 2050 Calculator user can select BECCS by:

- Assuming that CCS is in commercial operation, by selecting any one of Trajectories 2-4 for CCS.
- Selecting options for biomass to be grown in Ireland and/or to be imported.
- Ensuring that the biomass is in the same form as the type of fuel required by the CCS power plants. For example, gas CCS power plants require biogas.

Offshore wind

Ireland has jurisdiction over about 650,000 km^2 of marine territory, 10 times the country's land area. The Sustainable Energy Authority of Ireland (SEAI) Wind Energy Roadmap identifies offshore wind potential of up to 30 GW capacity in Irish waters by 2050. Full deployment of offshore wind is centred around the potential to export energy to the UK and participation in a future North West European energy market which is not included in the present analysis. As the levelized cost of offshore wind continues to decline, the competitiveness of offshore and onshore wind farms are expected to align post 2030. We have therefore included a maximum choice for both in trajectory 4, equivalent to current domestic electricity demand. If selecting trajectory 4, there would be no requirement for onshore wind to meet domestic demand.

Trajectory 1

In 2013, Ireland had 25 MW of offshore wind located in the Arklow Bank Wind Park, off County Wicklow, consisting of 7*3.6 MW turbines. Trajectory 1 assumes that Arklow Bank Wind Park is decommissioned and no further offshore wind is built up to 2050.

Trajectory 2

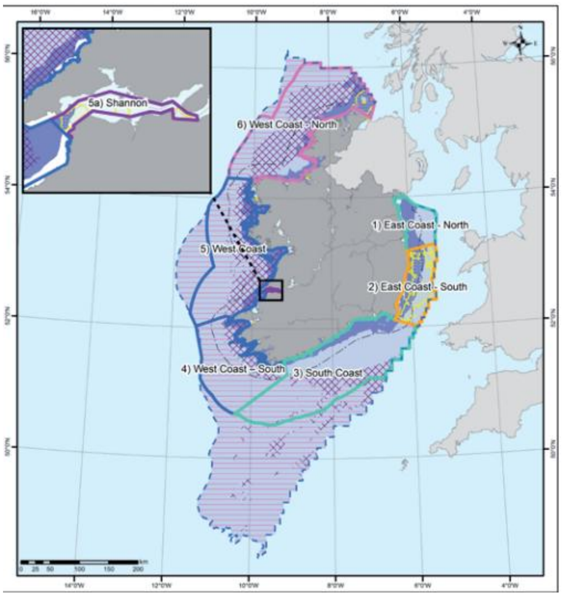
Trajectory 2 assumes that further development of offshore wind off the east coast goes ahead with capacity reaching 520 MW by 2030 (phase 2 of Arklow Bank Wind project). By 2050, offshore wind capacity exceeds 1.5 GW. This is equivalent to around 260*5.8 GW turbines. The sea area occupied by wind farms is 76 km^2. 1.5 GW of offshore wind turbines with a capacity factor of 45% in 2050 generates around 6 TWh/y.

Trajectory 3

Trajectory 3 assumes that capacity rises to 3.7 GW by 2050. This is equivalent to around 640*5.8 MW turbines by 2050 and a sustained build rate of around 160 MW (or 15-25 turbines) per year from 2030 to 2050. The sea area occupied by wind farms is 190 km^2. 3.7 GW of offshore wind turbines with a capacity factor of 45% generates around 15 TWh/y in 2050.

Trajectory 4

Trajectory 3 assumes that capacity rises to 6 GW by 2050. This is equivalent to around 1,000*5.8 MW turbines by 2050 and a sustained build rate of around 350 MW (or 60 turbines) per year from 2040 to 2050. The sea area occupied by wind farms is 190 km^2, over double the size of Lough Derg. 6 GW of offshore wind turbines with a capacity factor of 45% generates around 23 TWh/y in 2050, which is equivalent to total demand.



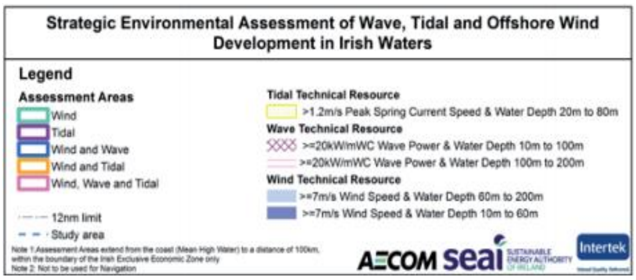


Figure 16: Strategic Environmental Assessment of Wave, Tidal and Offshore Wind Development in Irish Waters. Source: SEAI, AECOM

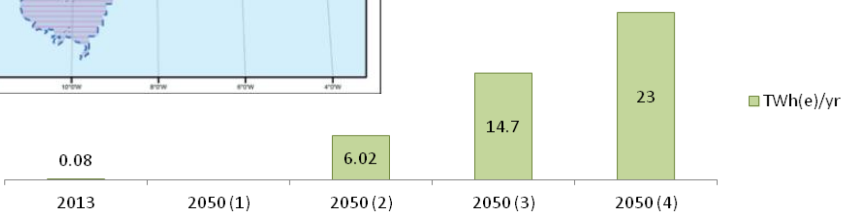


Figure 17: Electricity produced by offshore wind under the 4 trajectories in TWh/yr

Onshore wind

In 2013 Ireland had a nominal 1.8 GW of onshore wind capacity (installed). This figure excludes small wind turbines (micro and mini turbines), which are considered separately.

Trajectory 1

Trajectory 1 assumes that only turbines that are in the planning process today are built. Onshore wind capacity peaks at 2.5 GW before 2020 and falls to zero in 2050 as the turbines reach the end of their useful life.

Trajectory 2

Trajectory 2 assumes that capacity rises to 4 GW in 2025 and is maintained at that level by replacing retired turbines. Trajectory 2 represents an additional 300 MW/y from 2015 onwards, consistent with the build rate under the National Renewable Energy Action Plan for Ireland up to 2020. By 2025, there would be a total of around 1,600*2.5 MW turbines. This would be just over double the onshore wind capacity in 2025 compared to today, with a repowering rate of around 120 turbines per year post 2025. The electricity output from 4GW of onshore wind is about 10 TWh/y.

Trajectory 3

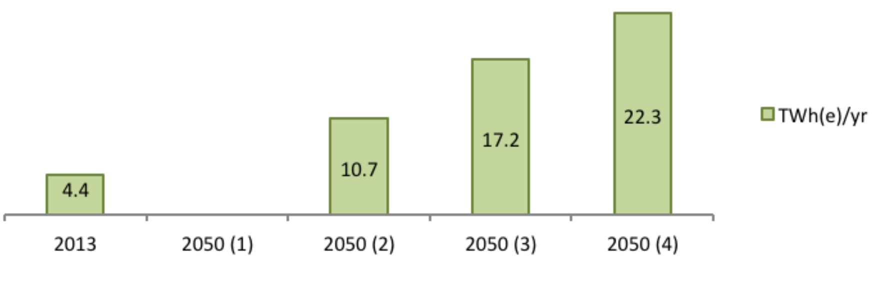
Trajectory 3 assumes that capacity rises to 4 GW by 2025, then to 6.6 GW by 2050. Trajectory 3 assumes that capacity is built at the rate of 800 MW/y from 2030 onwards. That means building about 2,650 2.5-MW turbines across the country. The total area of the wind farms would be about 220 km^2. 6.6 GW of onshore wind turbines generates around 17 TWh/y in 2050.

Trajectory 4

Trajectory 4 assumes that capacity rises to 8.6 GW in 2050 with a sustained build rate of about 400 turbines a year from 2035. Interconnection and storage requirements are large, as discussed in the section on 'Storage, demand shifting and interconnection'. The Trajectory 4 output of 22.3 TWh/y could be delivered by about 3,500*2.5 MW turbines in 2050, although in reality turbine capacities will likely increase over that time period. The total area of the wind farms would be about 300 km^2, or about 0.4% of Ireland's land area.

While up to 16GW of onshore wind potential in Ireland has been identified in SEAI's Wind Energy Roadmap up to 2050, we have constrained the growth of onshore and offshore wind to a level similar to current electricity consumption to align with domestic demand rather than export potential.

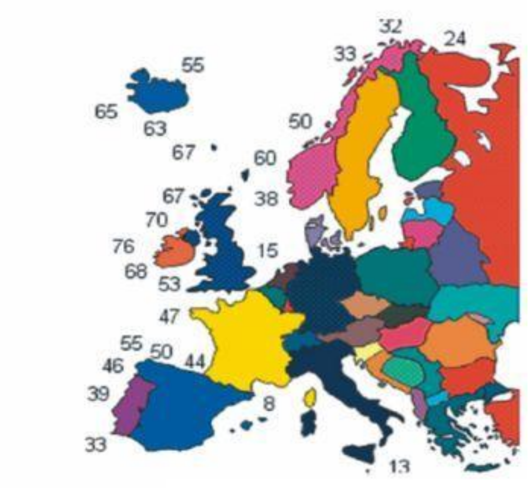
Figure 18: Electricity generated by onshore wind under 4 trajectories in TWh/yr.



Wave

Most of the wave power approaching Ireland comes from the Atlantic. The average wave power in Ireland is the strongest in Europe reaching 76 kW per metre of exposed coastline off the west coast (see figure 19 below). As with offshore wind, wave energy in Ireland beyond 2020 is centred around the potential to export and therefore only a share of the total potential capacity for domestic use is assessed. Refer to SEAI's Ocean Energy Roadmap for estimated total potential capacity for export in 2050.

One of the leading offshore wave devices is the Pelamis, a 'sea snake' which floats in deep water and faces nose-on to oncoming waves. The waves make the snake flex, and these motions are resisted by hydraulic generators. The peak power from one snake is 750 kW; in the best Atlantic location one snake would deliver 300 kW on average. Other designs such as the Wells and Impulse turbines are in development led by the Wave Energy Research Team (WERT) in the University of Limerick. A national full scale test site for wave energy in Ireland is located in Belmullet, Co. Mayo.



Trajectory 1
Trajectory 1 assumes there is little investment in wave power, with no wave machines deployed up to 2050.

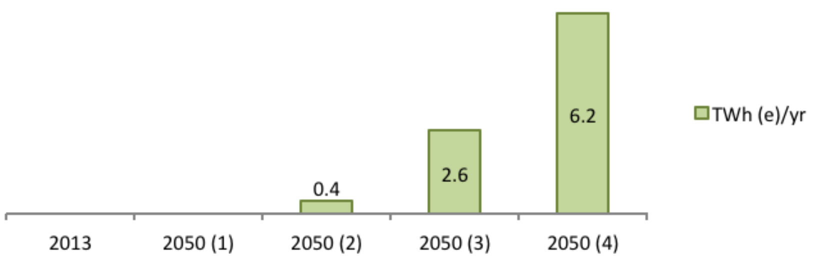
Trajectory 2
Trajectory 2 assumes that Ireland deploys the equivalent of 3 km of Pelamis wave farms in the Atlantic by 2050. This requires a Pelamis every 30 metres over the 3 km stretch, totalling around 90 machines. The machines deliver 15 kW per metre of the wave farm (25% of the waves' raw power) with an availability of 90% (allowing time for maintenance). The total output of these wave farms is 0.4 TWh/y.

Trajectory 3
Trajectory 3 assumes that Ireland deploys the equivalent of 670 Pelamis machines over 17.5 km of the Atlantic coastline by 2050, delivering the same power per machine as in Trajectory 2. The total output of these wave farms is 2.6 TWh/y.

Trajectory 4
Trajectory 4 assumes that Ireland deploys the equivalent of around 1,600 Pelamis machines over a 42 km stretch. With a capacity of 2.4 GW, the total output of such wave farms is 6.2 TWh/y.

Figure 19: European Wave Energy Atlas, Average Theoretical Wave Power.

Figure 20: Electricity generated by wave energy under 4 trajectories in TWh/yr.



Tidal stream

Tidal stream technologies harness the energy from the tides using underwater turbines. The stream flows through the stationary turbines, causing them to turn using the same principle as a wind turbine. There are various different designs of tidal stream turbines such as seabed standing and surface floating designs.

While tidal barrage or range technology is a firmly established technology, tidal stream technology is in its infancy. The world's first commercial scale tidal stream power generating device called SeaGen was installed in Strangford Lough, Northern Ireland in 2008 (see figure 21). It generates 1.2 MW for between 18 and 20 hours a day. The majority of Ireland's tidal power lies on the east coast, with the potential on the west coast concentrated in the Shannon Estuary and Bull's Mouth. Note that the maximum potential for tidal stream is lower than wave or offshore due to resource constraints (see Figure 16).

Trajectory 1

Trajectory 1 assumes that no tidal stream devices are installed in the Republic of Ireland by 2050.

Trajectory 2

Trajectory 2 assumes that tidal stream capacity grows to 100 MW by 2050, equivalent to roughly 50*2 MW tidal stream devices, larger than the 1.2-MW SeaGen device shown in figure 21. This capacity generates 300 GWh/y of electricity.

Trajectory 3

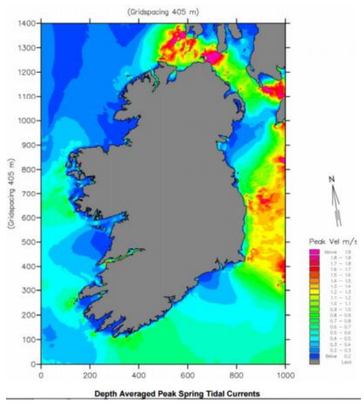
Trajectory 3 assumes that tidal stream capacity grows to 300 MW by 2050, equivalent to 150* 2 MW devices. This generates 900 GWh/y of electricity.

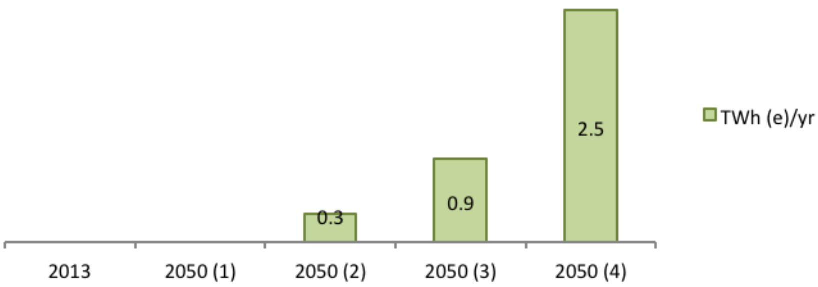
Trajectory 4

Trajectory 4 assumes that tidal stream capacity grows to 800 MW by 2050, equivalent to 400*2 MW devices. This generates 2.5 TWh/y of electricity.

Figures 21 and 22: SeaGen, Strangford Lough and Tidal Flow Map for Ireland. Source: SEAI

Figure 22: Electricity produced under 4 trajectories (TWh/yr)





Biomass power stations

In 2015 Ireland will have one biomass co-firing plant in Edenderry burning peat and biomass, with 35 MW biomass capacity. If this plant was running 80% of the time, it would require around 47 km^2 of land for purpose-grown energy crops, either imported or produced locally. See biomass imports and land use levers for user choices.

Trajectory 1

Trajectory 1 assumes 30% co-firing in Edenderry peat plant remains constant up to 2030. All peat plants and co-firing plants are discontinued from 2030 onwards as allocated peat reserves decline.

Trajectory 2

Trajectory 2 assumes 30% co-firing in all three peat power plants by 2025, with an installed capacity of 105 MW. All peat and biomass co-firing plants are discontinued from 2030 onwards as allocated peat reserves decline.

Trajectory 3

Trajectory 3 assumes 30% co-firing in the three peat power stations in Ireland by 2020 and 50%-80% co-firing by 2050, with an installed capacity of 245 MW. The biomass power plants require solid biomass amounting to 7 times Ireland's current use. If this were all from purpose-grown energy crops they could cover an area the size of 310 km^2

Trajectory 4

Trajectory 4 assumes that Ireland converts all of its existing peat plants to biomass and constructs a biomass power station roughly equivalent in size to Ireland's current coal station, Moneypoint. Total capacity reaches 105 MW by 2030 and 1.2 GW by 2050. Based on the size of today's average power stations, this requires 3 dedicated biomass power stations and 1 coal-plant-sized equivalent. The power stations generate 8.4 TWh/y, representing 1600 km^2 of energy crops, an area around the size of County Leitrim. To select this trajectory, the user must choose whether solid biomass is sourced domestically or imported from abroad.

Figure 23: Edenderry co-firing plant, commissioned by Bord Na Mona in 2000.

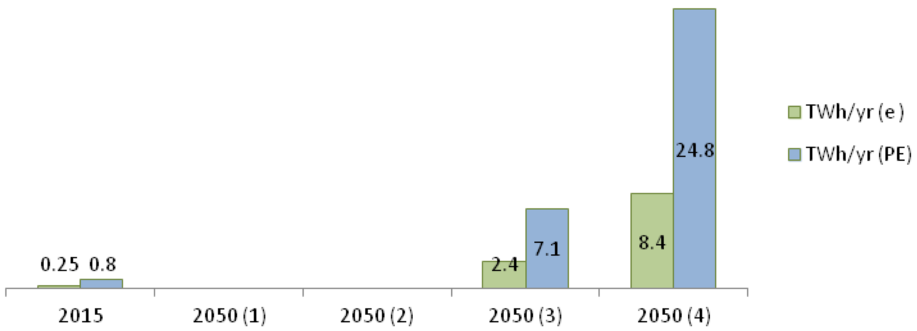


Figure 24: Primary energy requirement and electricity produced by bioenergy through co-firing (power from peat excluded in chart) or biomass only power plants.

Solar panels for electricity

Ireland currently has no support mechanism for the generation of electricity via 'solar photovoltaic' or PV panels. However, it is feasible to provide for photovoltaic power in Ireland's energy future.

Trajectory 1

Trajectory 1 assumes no use of solar PV up to 2050.

Trajectory 2

Trajectory 2 assumes that the installed capacity of solar PV reaches 500 MW in 2030 (producing 400 GWh per annum) and 2,000 MW (2 GW) by 2050 (producing 1.7 TWh/y). At this trajectory there is 1.5 m^2 of solar PV panel for every person in Ireland.

Trajectory 3

Trajectory 3 assumes that Irish solar PV capacity reaches 2 GW in 2030 (producing 1 TWh annualy) and 6 GW by 2050 (producing 5 TWh/y). This is the equivalent of 4.5 m^2 of panel covered roof area for every person by 2050 or 11 m^2 per household.

Trajectory 4

Trajectory 4 assumes that solar PV capacity reaches 2 GW in 2030 (producing 1.7 TWh/y) and 12 GW by 2050 (producing 10 TWh/y). The area of panels required is about 9 m^2 per person, roughly the same as the area of all South-facing roofs of domestic homes.

Alternatively, Trajectory 4 can be visualized as solar farms, where the land area required to deliver 10 TWh/y if 20% efficient is 53 km^2 (assuming a power per unit land-area of 5 W/ m^2).

Figure 25: Solar PV farm

Figure 26: Roof mounted solar PV. The average peak power delivered by solar PV is assumed to be 0.5 kW, equivalent to 20 W/m2.

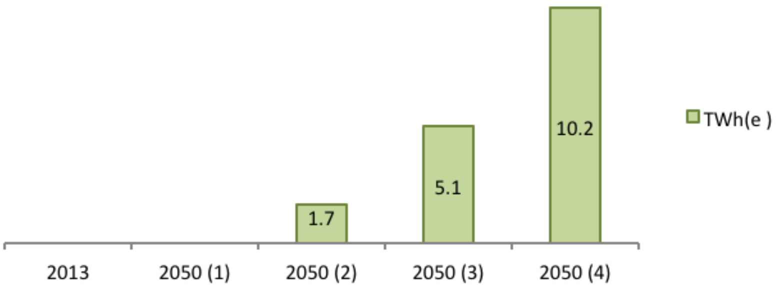


Figure 27: Electricity produced under 4 trajectories (TWh/yr)

Solar panels for hot water

Solar water heating systems (also known as 'solar thermal') use sunshine to warm water which is stored in a hot water cylinder. In 2013 less than 1% of buildings had solar hot water systems.

To estimate the roof area available for panel installation we have used the average floor area of houses in Ireland (119m^2). If we assume that the practical roof resource is 25% of the floor area, and some access constraints, the available average roof area per house is about 22m^2.

Trajectory 1

Trajectory 1 assumes that in 2050, as today, only a very small proportion of buildings have a solar thermal system.

Trajectory 2

Trajectory 2 assumes that in 2050 about 30% of suitable buildings have 30% of their annual hot water demand met by solar thermal. In 2050 solar thermal delivers around 1.2 TWh of heat annualy.

Trajectory 3

Trajectory 3 assumes that all suitable buildings have some solar thermal heating system in 2050, meeting 30% of the buildings hot water demand. This reuires 1.3 m^2 of panels per person or about 3m^2 per household generating 3.5 TWh of heat annualy.

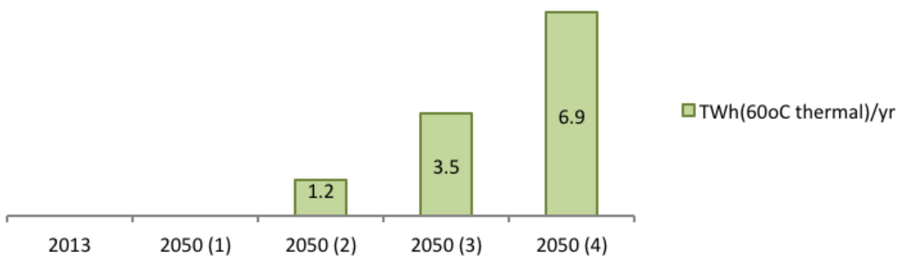
Trajectory 4

Trajectory 4 assumes that in 2050 all suitable buildings have 60% of their annual hot water requirments met by solar thermal. This means 2.5 m^2 of solar panels per person, delivering 6.9 TWh of heat annualy. Given that all south-facing domestic roofs could accommodate 5 m^2 per person, this is technically feasible.

However, there could be competition for roof space between solar photovoltaic and solar thermal panels, in which case some solar panels may appear as ground-based solar farms instead.

It is estimated that 1.5 m^2 of solar thermal panel per person is needed to supply all households with summer hot water using today's technology. Trajectory 4 assumes almost double this area of panels. To avoid wasting the excess heat delivered in the summer, seasonal heat storage systems are needed to store heat so that it can be used during the winter.

Figure 28: Thermal energy produced under 4 trajectories (TWh/yr)



Small scale wind

In 2013 Ireland had almost no small-scale wind turbines.

There are two types of micro-wind turbine: mast mounted, free standing and erected in a suitably exposed position; or roof mounted, smaller than mast mounted systems and can be installed on the roof of a home. Today's roof-mounted micro-turbines don't contribute significantly as they are simply too small. Therefore Trajectories 2, 3 and 4 are presented in terms of 5-kW mini-turbines suitable for domestic purposes or larger 100-kW turbines for agricultural or commercial sites. Both cases are discussed in the trajectories.

Trajectory 1

Trajectory 1 assumes no significant increase, with small-scale wind turbines having negligible impact on Ireland's energy system or the landscape.

Trajectory 2

Trajectory 2 assumes that capacity increases to 50 MW in 2050, delivering 0.1 TWh/y. Reaching trajectory 2 requires about 10,000 domestic 5-kW turbines or 500 larger 100-kW turbines on commercial or agricultural sites.

Trajectory 3

Trajectory 2 assumes that capacity increases to 100 MW in 2050, delivering 0.2 TWh/y. Reaching trajectory 2 requires about 20,000 5kw turbines covering around 50 km^2, or 1,000 100-kW turbines.

Trajectory 4

Trajectory 4 assumes that capacity increases to 200 MW in 2050, delivering 0.4 TWh. This corresponds to 40,000 mini-turbines, equivalent to a turbine in 1-2% of domestic households. If we assume that each of those mini-turbines 'occupies' an area of 30 m × 30 m, the area occupied at trajectory 4 is 100 km^2. Alternatively, trajectory 4 would represent 2,000 100-kW turbines on farms or commercial properties, which would equate to around 1-2% of all farms in Ireland having its own micro turbine.

Figure 29: A 5.5m diameter Iskra 5-kW free standing turbine at a height of 12m in the lowlands of the UK has an average output of 11 kW per day. For comparison, the average Irish person's share of electricity consumption is 14 kWh per day.

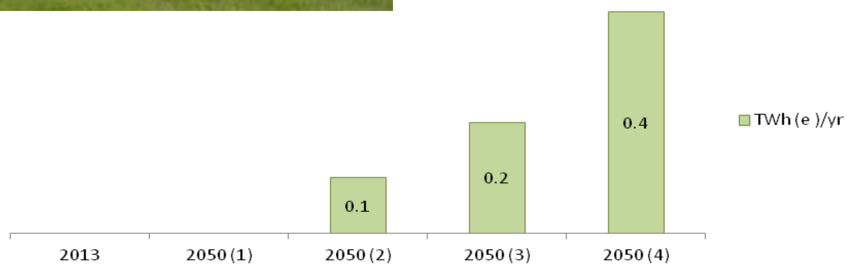


Figure 30: Electricity produced under 4 trajectories (TWh/yr)

Electricity imports and exports

Low carbon electricity can be imported as well as being produced in Ireland. Imports could come from sources such as geothermal energy from Iceland, wind energy from Norway's North Sea, or solar energy from southern Europe or northern Africa. These other countries could oversupply electricity and then export it to Ireland.

Trajectory 1

Level 1 assumes that in 2050 Ireland imports no electricity from abroad.

Trajectory 2

Level 2 assumes that in 2050 Ireland imports 3 TWh/y of electricity (similar to today's level of imported electricity from UK for balancing).

Trajectory 3

Level 3 assumes that in 2050 Ireland imports 6 TWh/y of electricity. The current capacity of the interconnector would be sufficient to deliver this energy.

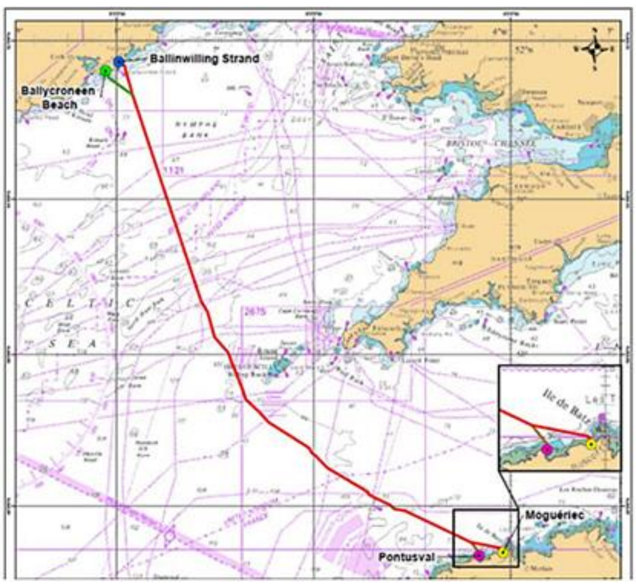
Trajectory 4

Level 4 assumes that in 2050 Ireland imports 10 TWh/y of electricity. The capacity of the interconnector would have to increase to 1.4 GW, consistent with current plans for grid expansion.

Electricity exports

Conversely, an oversupply of renewable electricity generated domestically could be exported elsewhere, which would require improving the electricity connections with Europe. While the trajectories in this model have been developed in line with domestic emissions targets and energy demand in 2050, it is possible to generate a large of over-supply of renewable electricity if multiple renewable levers are chosen together. Over-production of low carbon electricity in the model is assumed to be consumed abroad and the interconnector necessary to access these markets is calculated and included. In an extreme maximum electricity supply (where all supply sectors are set at trajectory 4) and minimum domestic demand scenario, up to an excess of 80 TWh/yr of clean electricity could arise. To deliver this energy, the capacity of the interconnector with Europe would have to be increased by 8 GW.

Figure 31: Proposed route for future interconnection between Ireland and France.



Land dedicated to bioenergy

In 2013, Ireland used 156 km^2 of land to grow energy crops, which is less than 0.2% of the country. For comparison, 45,000 km^2 of land was used for arable crops, livestock, and fallow land.

Trajectory 1

Trajectory 1 assumes that in long-term land management decisions until 2050, food production has priority over bioenergy. Land is split between activities similar to today, although we are able to get more food from the land due to increased crop yields. There is a significant increase in the fraction of wood cuttings and manure collected for energy use. If livestock numbers increase by 30%, the resulting energy available in 2050 is 12 TWh/y up from 1 TWh/yr in 2013.

Trajectory 2

Trajectory 2 assumes that current trends and drivers in land management continue to 2050, with more land covered by housing. However the area planted with bioenergy crops also increases, such that an additional 4,000 km^2 of grassland is converted to the production of woody energy crops in 2050. The collection of straw, manure and forestry clippings for energy use also increase. The resulting energy available in 2050 is 42 TWh/y.

Trajectory 3

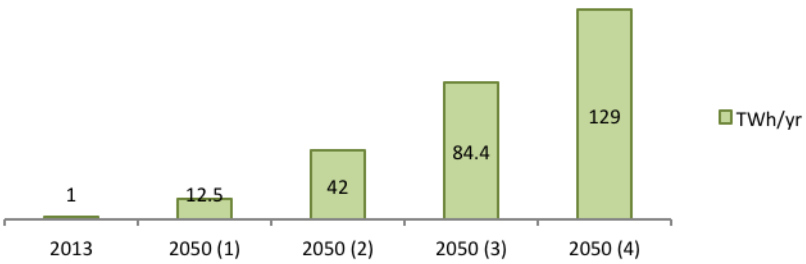
Trajectory 3 assumes that bioenergy becomes a significant part of domestic agricultural output, with 10% of Irish land used for growing energy crops by 2050, an area almost the size of Cork. There is an appreciable improvement in soil and crop management technologies, with some land now used for food crops being reassigned to bioenergy production and forestry. The resulting energy available in 2050 is 85 TWh/y.

Trajectory 4

Trajectory 4 assumes that Ireland has a strong domestic bioenergy production focus, with 15% of the country planted with energy crops. There is extensive carbon capture through forestry, and highly effective management and collection of waste materials for bioenergy use. The resulting energy available in 2050 is almost 130 TWh/y.

For comparison, Denmark's production of straw, woodchips, firewood, woodpellets, woodwaste, biogas, biooil, and biodiesel for energy in 2012 was 19 TWh/y. Denmark has an additional million people compared to Ireland (5.6 million in 2013) and around half the land area. Scaled by the land area ratio of Ireland to Denmark, this energy production is equivalent to around 40 TWh/y in Ireland.

Figure 32: Energy production from purpose grown energy crops, straw, manure collection/biogas, bio-oil and biodiesel under 4 trajectories in TWh (primary energy)/yr assuming Trajectory 1 in the 'livestock and their management' lever.



Livestock and their management

In 2013, there were over 26 million livestock animals (includes poultry), including over 1 million dairy cows. The 2050 Calculator contains two options relating to agricultural biomass and land use: livestock management (described here) and land use management (described on another page).

Trajectory 1

Level 1 assumes that, by 2050, domestic food production and exports take priority. Livestock numbers increase by 30% over 2013 levels. This means approximately 300,000 more dairy cows grazing on Irish grass in 2050 (in line with projections under the 2020 Food Harvest Strategy) and an additional 3 million cattle, sheep and pigs combined.

Trajectory 2

Level 2 assumes that livestock numbers remain constant through to 2050. However due to manure yields increasing by 0.2% per year, more energy from waste is generated from agricultural by-products.

Trajectory 3

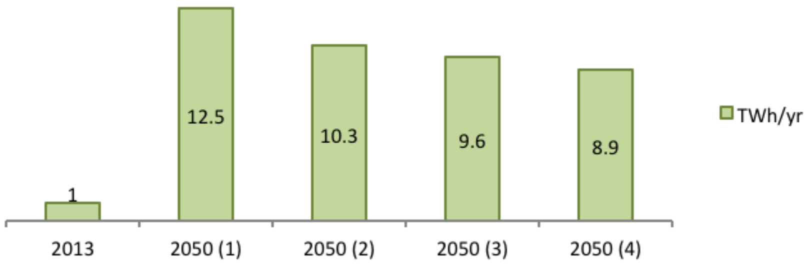
Level 3 assumes that livestock numbers reduce by 10% by 2050. This means there will be approximately 100,000 fewer dairy cows in Ireland by 2050.

Trajectory 4

Level 4 assumes a significant shift away from livestock production in Ireland, potentially caused by us eating less meat, by switching from beef to less land-intensive meats such as chicken, or increasing the agricultural focus on bioenergy. Livestock numbers decline by 20% on 2010 levels, equivalent to 200,000 fewer dairy cows by 2050 and 2 million less cattle, pigs and sheep.

Figure 33: The calculator assumes that every cow produces 400 oven dried kg of manure each year.

Figure 34: TWh(primary energy)/yr under the 4 trajectories assuming Trajectory 1 in the 'land dedicated to bioenergy lever'



Volume of waste and recycling

In 2013 Ireland produced around 2.5 Mt of municipal waste (household and commercial) and 3 Mt including wood waste, sewage sludge and other sources. In the same year, rates of recycling, energy from waste (EFW) and landfill were 40%, 19% and 41% respectively. Around 0.3 TWh/y of energy was generated from waste facilities, landfill gas, sewage gas and non-biodegradable waste in 2013. Around 36% of recovered municipal waste was exported for energy recovery or recycling.

Options for use of waste include energy recovery, but prevention, recycling, and re-use may be preferable.

The trajectories below represent different choices, rather than an increasing scale of effort. They cannot be compared with the Trajectories 1-4 in other sectors and have therefore been labelled as Trajectories A-D instead.

Trajectory A

Trajectory A assumes that the overall quantity of waste increases by 50% in the period from 2013 to 2050 with economic recovery, increased employment and population growth. A high quantity of waste is exported (50%); 18% is sent to waste to energy facilities in Ireland, 10% is recycled, and 24% is directed to landfill. Waste to energy capacity in Ireland increases to around 0.7 Mt. 0.9 TWh/y of primary energy is generated in 2050.

Trajectory B

Trajectory B assumes that the overall quantity of waste increases around 20% between 2013 and 2050. Double the share of waste is recycled domestically or sent to compost, 18% is incinerated and around 40% is exported for recovery abroad. The proportion of waste sent to landfill reduces to 11% in 2050. 0.9 TWh/y is generated in 2050.

Trajectory C

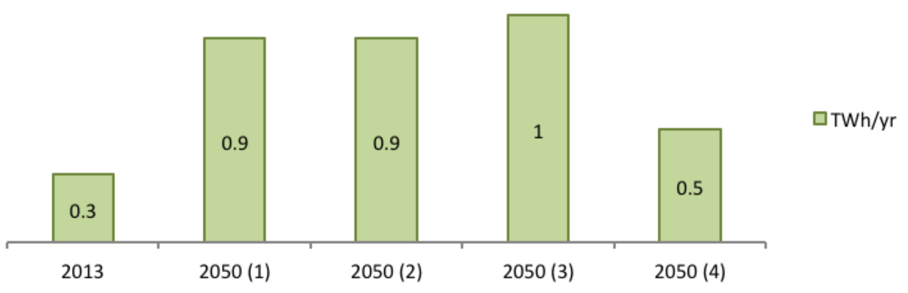
Trajectory C assumes that the quantity of waste increases around 33% between 2013 and 2050, and waste is efficiently handled through high-tech, industry-led approaches. By 2050, an overall recycling rate of 81% is achieved through post-collection sorting and treatment facilities, rather than a change in behaviour, half of which is recycled domestically and half is exported. The proportion of waste sent to landfill is reduced to just 2% by 2050. 1 TWh/y of primary energy is generated in 2050.

Trajectory D

This trajectory assumes a national focus on waste avoidance. The overall quantity of waste decreases by 20% between 2013 and 2050. This smaller volume of waste is managed efficiently and both recycling (80% share) and energy from waste (18% share). By 2050, 25% of municipal waste is exported and 3% of waste is sent to landfill. 0.5 TWh/y of primary energy is generated in 2050.

For comparison, Denmark's use of municipal waste for energy in 2012 was 10 TWh/y. Scaled to the Irish population, that level of waste to energy is the equivalent of 8 TWh/y in Ireland.

Figure 35: TWh of primary energy produced by municipal waste per year under the 4 trajectories above



Marine algae

This section looks at macro-algae such as seaweed. To turn macro-algae into usable fuel, most of the water should be removed by filters and centrifuging before the oil contained in the algae is extracted. In 2013 most of the macro-algae in Ireland grew naturally off the west coast but no significant quantities of this were harvested.

The trajectories below are compared to the amount of macro-algae growing naturally off the west coast but the intention would be to harvest purpose-grown commercial stocks, not natural ones.

Trajectory 1

Trajectory 1 assumes that macro-algae cultivation is not a significant source of liquid biofuel.

Trajectory 2

Trajectory 2 assumes that 400 km^2 of sea, equivalent to approximately half of Ireland's natural macro-algae stocks, is used for the commercial growth and collection of macro-algae by 2050. While feasible, this represents an unprecedented offshore agricultural proposition. The algae grown on this area of sea produces 3 TWh/y of energy output.

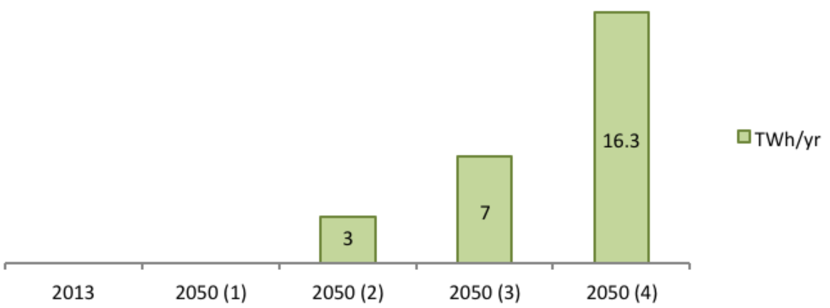
Trajectory 3

Trajectory 3 assumes that by 2050 marine algae is commercially grown in an area of 900 km^2, the same size as the lower range estimate of the total natural macro-algae stocks in Ireland. This amount of algae produces 7 TWh/y of energy output.

Trajectory 4

Trajectory 4 assumes that by 2050 an area of 2,100 km^2 is used to cultivate algae, which is the higher range estimate of Ireland's total macro-algae stocks. The algae grown on this area of sea generates about 16 TWh/y of usable energy per year. It is possible that cultivation at such large trajectories requires the addition of nutrients to help the algae grow. Water movements mean that such nutrient additions cannot be contained, so there is a risk of causing uncontrolled algal blooms. These might increase greenhouse gas emissions through ammonia and nitrous oxide production.

Figure 36: Primary energy produced by marine algae per year



Types of fuel from bioenergy

In the 2050 Calculator, the amount of bioenergy available for use is determined by the 'Land dedicated to bioenergy', 'Marine algae', 'Volume of waste and recycling' and 'Bioenergy imported' options (described on other pages). Biomass created through the first three of these levers is turned into bioenergy according to the options described here. Bioenergy imports are already being used as fuels.

Some types of biomass can only become particular fuels. For example landfill gas and manure are always turned into biogas, and first generation energy crops (crops usually used as fuel or animal feeds sources) are always turned into liquid bioenergy. Other types of biomass can be turned into several different biofuels, and the Calculator allows the user to specify the fuel.

In choosing between Trajectories A, B, C or D you decide whether second generation energy crops (derived from non-food crops), such as wood, algae and waste are turned into either solid, liquid or gas bioenergy. Table 1 shows the conversion efficiencies for 2020-2050, with lower efficiencies assumed before 2020. The Calculator assumes that solid bioenergy can be used in any situation that uses coal or peat (such as a power station), liquid bioenergy can be used in any situation that uses oil (such as a car engine), and gaseous bioenergy can be used in any situation that uses natural gas (such as heating).

When the user selects options which need coal in the 2050 Calculator, the fuels available are used up in a particular order. This order of fuel preference is:

1. Domestic biomass
2. Imported biomass
3. Imported coal

If there is not enough of the preferred fuel type available then the Calculator uses the next category until enough fuel has been found. The same order of preference is assumed for oil and liquid bioenergy, and also for natural gas and gaseous bioenergy, where bioenergy is used ahead of fossil fuel sources when it is available.

Trajectory A – Mixed fuels

Wood from forests, straw, and dry waste from residential, commercial and industrial waste is turned into solid bioenergy. Sewage, algae and the wet waste from residential, commercial and industrial waste are each turned into gaseous bioenergy. Second generation energy crops are converted to liquid bioenergy.

Trajectory B – Solid fuels

Wood from forests, straw, dry waste and second generation energy crops are turned into solid bioenergy. Sewage, algae and wet waste are used to produce gaseous bioenergy.

Trajectory C – Liquid fuels

All biomass apart from manure and landfill gas is turned into liquid bioenergy.

Trajectory D – Gaseous fuels

All biomass apart from first generation biocrops is turned into gaseous bioenergy.

Table 1. The conversion efficiencies when different types of biomass are turned into solid, liquid or gaseous biofuel, showing the percentage of the energy that is retained. x indicates that a particular conversion route is not possible. The assumptions above apply for the period 2020-2050, with lower efficiencies assumed up to 2020.

Raw biomass input	**Final biofuel output**		
	Solid biomass	**Liquid biofuel**	**Biogas**
Algae and wet waste	x	38%	85%
Straw, forests and dry waste	95%	45%	66%
2nd generation energy crops	95%	45%	66%
1st generation energy crops	x	32%	x
Gaseous waste	x	x	100%

Bioenergy imports

In 2013 Ireland imported 0.2 TWh/y of liquid and solid biofuels from overseas producers.

The International Energy Agency (IEA) estimates that 4–8 million km^2 of land could be used globally for growing energy crops by 2050. That area would produce around 42,000 TWh/y of bioenergy. The IEA assumes that 40% of this bioenergy would be exported from the producer countries, with potential global supply of 17,000 TWh/y. If exports were split equally across the global population then the maximum 'fair market share' for the Ireland would be about 12 TWh/y. The 2050 Calculator assumes that the bioenergy imported is already processed ready to use, and is half in solid and half in liquid state, as replacements for coal and oil respectively.

Considerable uncertainty remains about these estimates (including uncertainty about the potential for plant breeding and technology enhancements to improve yields), and there are important questions about the sustainability and impacts of bioenergy imports.

Trajectory 1

Trajectory 1 assumes Ireland does not import any bioenergy by 2050, with the amounts of bioenergy imported gradually declining from 2013 levels to zero.

Trajectory 2

Trajectory 2 assumes that by 2050 Ireland is importing around half of its fair market share under the assumptions outlined above. This means a 30-fold increase of imports, using about 1,140 km^2 of land in other countries, providing up to 6 TWh/y of bioenergy.

Trajectory 3

Trajectory 3 assumes that by 2050 Ireland is importing its fair market share under the assumptions outlined above. This means a 60-fold increase of imports, using about 2,300 km^2 of land in other countries (approximately equivalent to the size of County Meath), providing up to 12 TWh/y of bioenergy.

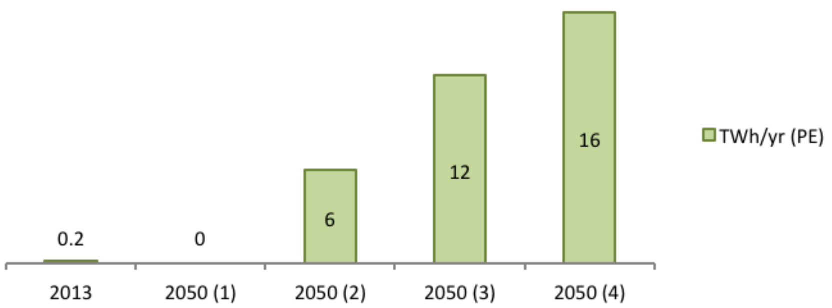
Trajectory 4

Trajectory 3 assumes that by 2050 Ireland is importing over its fair market share under the assumptions outlined above. This means a 80-fold increase of imports, using about 3,000 km^2 of land in other countries, providing up to 16 TWh/y of bioenergy.

Interaction with other choices

In the 2050 Calculator bioenergy is only imported if there is demand for it, up to the maximum limit allowed under the chosen trajectory of imports and after all domestic bioenergy has been used up. For example, if Trajectory 2 imports is selected (maxiumum 6 TWh/y) but only 5 TWh/y is demanded, then only 5 TWh/y will be imported.

Figure 37: Primary energy from bioenergy imports every year under 4 trajectories



Geosequestration

Geosequestration technologies can remove carbon dioxide (CO_2) directly from the atmosphere and store it in soils, building materials, rocks or other parts of the geochemical system. In 2013 these were new and emerging techniques which did not exist at commercial scale.

Technologies that capture carbon dioxide in power stations and industrial facilities, rather than from the atmosphere are described separately in the Carbon Capture and Storage (CCS) and industry sections.

Trajectory 1
Level 1 assumes that Ireland does not implement any geosequestration by 2050.

Trajectory 2
Level 2 assumes that by 2050 about 0.3 $MtCO_2$ a year is removed from the atmosphere by optimising some processes such as chalk and cement production, to maximise their capture of CO_2; and by burying biochar in soils.

Trajectory 3
Level 3 assumes that by 2050, carbon sequestration by chemical processes outlined in Trajectory 2 removes about 0.4 $MtCO_2$ a year.

Trajectory 4
Level 4 assumes that by 2050, carbon sequestration machines remove 5.4 $MtCO_2$ a year (roughly 1% of Ireland's CO_2 emissions in 1990). Up to 17 TWh of electricity is required to power the sequestration machines in Trajectory 4, comparable to the total electricity produced by gas and coal generation in Ireland in 2013. If the options chosen for the supply sectors mean greenhouse gases are released in the production of this electricity, then the net sequestration will be lower.

Interaction with other choices
There is significant demand for CO_2 transport infrastructure and storage capacity under three sectors: industry, carbon capture and storage, and geosequestration. Calculator users may wish to consider these options together to take a view on whether the total demand for CO_2 transport and storage infrastructure is feasible.

Storage, demand shifting and interconnection

To avoid power outages, electricity demand needs to balance with electricity supply at all times. This is a tricky task as both demand and some forms of supply fluctuate throughout any day, over a week and between the seasons. Some electricity generation fluctuates more than others, as for example the supply from renewable sources such as wind and solar depends on the weather and the level of sunshine.

At present Ireland has a number of tools to balance the electricity network, including the north south 100-200 MW interconnector between the Republic of Ireland and Northern Ireland, the 500 MW Moyle interconnector between Northern Ireland and Scotland (reduced to 250 MW in 2011 due to outages), and the 500 MW east-west interconnector between Ireland and Wales. During 2013 the Ireland imported 2.5 TWh and exported 0.4 TWh to the UK.

In addition Ireland has 300 MW of pumped hydro storage in Turlough Hill, County Wicklow. There is also some ability to shift demand through demand side management (DSM) schemes, which rewards large industrial electricity users for reducing their electricity demand at peak winter hours if the grid has a shortfall in supply. In the future we could have a smart grid that could shift the timing of millions of pieces of demand, to help balance the grid.

Level 1

Level 1 assumes that by 2050 pumped storage capacity increases from 2 GWh to 8 GWh and interconnection capacity increases from 0.8 GW to 1.4 GW for balancing.

Level 2

Level 2 assumes that by 2050 Ireland has developed 1.8 GW of storage, with a storage capacity of 14 GWh, and 1.8 GW of interconnectors. Around 25% of all electric vehicles and plug-in hybrid electric vehicles allow flexible charging, enabling co-ordinated electricity demand shifting.

Level 3

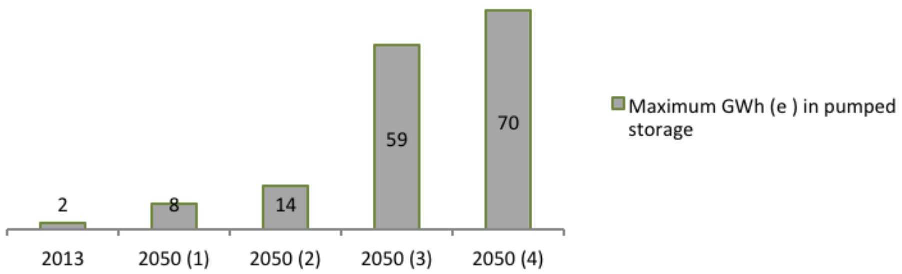
Level 3 assumes that by 2050 Ireland has developed 3.5 GW of (air or hydro) pumped storage, with a storage capacity of 60 GWh, and 2.8 GW of interconnectors. This level also assumes that around 50% of electric cars allow flexible charging for co-ordinated demand shifting.

Level 4

Level 4 assumes that by 2050 Ireland has 5 GW of storage, with a storage capacity of 70 GWh, and 4.8 GW of interconnectors. This level also assumes that around 75% of electric cars allow flexible charging.

Figure 38: The assumed maximum energy that can be kept in pumped storage in GWh. Note that this energy can be stored and then released many times over a year, and therefore these figures are not directly comparable to the TWh/y charts that appear at the bottom of other sector notes.

The EC's Joint Research Centre estimates that Ireland has up to 100 GWh of realisable pumped hydro energy storage.



The balancing stress-test

To avoid power outages, electricity demand needs to balance with electricity supply at all times. This is a tricky task as both demand and some forms of supply fluctuate throughout any day, over a week and between the seasons.

For comparison, today's average electricity consumption in the Republic of Ireland is 3 GW and in pathways with high levels of electrification of the system in 2050 average electricity consumption reaches up to 9 GW. The output from 9 GW of onshore wind, the maximum level assumed in the 2050 Calculator, could vary between 0 GW and 9 GW.

Significant additional interconnection, demand shifting and storage requirements would be needed. For example, the existing interconnectors between Ireland and England total 0.8 GW and the Turlough Hill pumped storage facility has a capacity of 300 MW. The scale of balancing systems required may involve the construction of about 2 GW of additional interconnection from Ireland to Europe and new storage systems able to absorb a further 5 GW.

The 2050 Calculator includes a 5-day 'stress-test' which models the impact of a period of cold temperatures and low winds, in order to understand the scope of the balancing challenges during such adverse weather conditions. It is assumed that over a 5-day period the Irish temperature drops to below zero which increases heating demand (to a degree that depends on buildings' insulation levels). It is also assumed that the output of both onshore and offshore wind drops to 5% of installed capacity, and solar generation levels are below 80% of average output. Each 2050 pathway which is selected by a user generates a different electricity balancing challenge, and the 5-day stress-test indicates how much of the total capacity of the electricity network is used.

If the chosen pathway exceeds 100% of that capacity then the Calculator contains 2 further options:

1. The user can increase the level of storage, demand shifting and interconnection.
2. The Calculator computes the capacity of backup generation required to cover the electricity shortfall, assumed to be unabated gas-fired power stations.

Interaction with other choices

The renewable technologies chosen (in particular onshore wind, offshore wind and wave power), the degree to which heating is electrified, and the number of electric cars chosen under the transport option determine what the requirement for back-up generation is and how much demand shifting is possible.

Figure 39: The stress-test assumes that there could be a complete drop in wind during 5 cold winter days. The graph to below shows the total output of all wind capacity in Ireland (including Northern Ireland) in 2015, with a five day lull in wind visible during the second week of June. Data are provided every 15 minutes by eirgrid.com.