Annex B. Energy infrastructure options

August 2019

Energy infrastructure options for Guernsey

PricewaterhouseCoopersLLP (PwC) was commissioned by the Office for Environment and Infrastructure for the States of Guernsey (SoG) and Guernsey Electricity Limited (GEL) to provide an energy demand forecast and analysis of potential policy considerations.

We have performed several pieces of analysis to help GEL make informed infrastructure decisions and to help inform energy policy for SoG. As part of this work we have analysed six renewable energy infrastructure options using marginal abatement cost curves to understand the impact of two drivers of change in the energy sector: the energy transition away from carbon and the development of renewable energy.

The costs and benefits of these renewable energy technologies have been assessed in comparison to our baseline forecast of the Guernsey energy sector.

We have modelled the impact of the following technologies:

- Utility-scale solar photovoltaics (PV)
- Offshore wind
- Guernsey-France (GF1) interconnector
- Solar PV microgeneration
- Electric vehicle uptake
- Domestic thermal efficiency improvements

For the GF1 interconnector and electric vehicles uptake scenarios, two versions have been calculated to reflect sensitivities surrounding government policy.

This report begins with a summary of the results for all energy infrastructure options. We then lay out our assumptions regarding market structure and energy security before providing the in depth results and methodology for each scenario.

We present a graph showing the annual capital cost, operating cost and benefits and a graph showing the annual greenhouse gas abatement, measured in kgCO2 equivalent.

We have then used our economic model to understand the wider economic impact of each infrastructure option.

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High level results

Evaluating energy infrastructure options

The key results of the energy infrastructure analysis are presented on page 6. We have used the following measures to evaluate each option.

Direct benefit-cost ratio: For every £1 spent on infrastructure installation and maintenance, the direct benefit-cost ratio reflects the benefit generated from fuel savings.

Benefit-cost ratio including wider economic benefits: To ascertain the full impact we then model the benefit of the investment in terms of employing local suppliers to install and maintain the infrastructure and reducing the leakage of money from the island to pay for imports.

Energy savings in 2050: The energy savings in 2050 reflect the scale of each infrastructure option. For grid-level generation infrastructure options, this figure reflects the generation potential of the infrastructure. The total consumption of electricity remains constant, however the source of electricity changes. For electric vehicles, the energy saving reflects the increased efficiency of electric vehicles compared to ICE vehicles. Less electricity is required than petrol or diesel to travel the same distance.

Emissions savings in 2050: The reduction in CO2 equivalent emissions in 2050 also reflects the scale of the infrastructure option.

Example Utility-scale solar PV

Direct benefit-cost ratio: £1.12

- Every £1 spent on implementing utility-scale solar PV will generate £1.12 of benefits in terms of fuel savings.

Benefit-cost ratio including wider economic benefits: £3.22

- Every £1 spent on implementing utility-scale solar PV will generate £3.22 of benefits in terms of fuel savings and wider effects such as the creation of construction jobs to implement the infrastructure.

Energy savings in 2050: 40.7 GWh, 4.79%

- Utility-scale solar PV will generate 42.4 GWh of electricity to replace imported and generated electricity. This amounts to 4.79% of total energy consumption in 2050.

Emissions savings in 2050: 1.31 ktCO2e

- The imported and generated electricity that utility-scale solar PV will replace will reduce CO2 equivalent emissions by 1.31 kt.

All infrastructure options are net neutral or net beneficial

All possible options at least pay for themselves, therefore the choice of energy infrastructure option depends on the objectives for the energy policy.

Domestic energy use interventions tend to be more efficient, as shown by their higher direct benefit-cost ratios, and create greater spillover effects, reflected in their higher benefit-cost ratio including wider economic benefits.

However, in general **grid-level generation infrastructure allows for greater energy saving** in terms of imports by 2050. Electric vehicle uptake is the exception to this, as these vehicles are more efficient than ICE vehicles and their uptake is expected to accelerate.

	Scenario	Direct benefit-cost ratio	Benefit-cost ratio including wider economic benefits	Energy saving in 2050		Emissions saving in 2050* (ktCO2e)
				GWh	%	
Grid-level generation	Utility-scale solar PV	£1.12	£3.22	40.7	4.79	1.31
	Offshore wind	£0.91	£1.98	98.4	11.6	5.80
	GF1 interconnector and N-1 policy	£0.71	£1.96	69.8**	8.21	30.66
	GF1 interconnector and N policy	£0.81	£2.43	69.8**	8.21	30.66
Domestic energy use	Solar PV microgeneration	£3.36	£5.60	17.1	2.01	0.53
	Electric vehicles with fuel duty	£3.48	£6.19	238.3	28.0	63.59
	Electric vehicles without fuel duty	£1.98	£3.94	238.3	28.0	63.59
	Thermal efficiency for housing	£2.15	£3.92	22.5	2.65	3.41

*Assuming 85% of electricity is imported.

**This refers to fossil fuel energy saving, the same quantity of electricity will be imported therefore there will be no overall change to energy imports.

The direct benefit-cost ratio for grid-level generation infrastructure shows these measures are net neutral, while domestic interventions are more efficient

We have analysed six energy infrastructure options that would affect the generation and use of energy in Guernsey using marginal abatement cost curves.

We compared the scenarios using the benefit-cost ratio of the scenario over the period 2018-2050. This measure gives the benefit accrued for every £1 spent on implementation in order to compare the viability of each scenario – both including and excluding the shadow price of carbon, as calculated by Defra (2007).

Any benefit-cost ratio greater than £1 therefore indicates a net direct benefit to the Guernsey economy. This has been discounted at 3.5%, in line with UK Green Book (2013) advice.

For the GF1 interconnector and electric vehicles scenarios, two versions have been calculated to reflect sensitivities around government policy.

	Scenario	Direct benefit-cost ratio	Direct benefit-cost ratio including shadow price of carbon*
Grid-level generation	Utility-scale solar PV	£1.12	£1.13
	Offshore wind	£0.91	£0.93
	GF1 interconnector and N-1	£0.71	£0.80
	GF1 interconnector and N	£0.81	£0.91
Domestic energy use	Solar PV microgeneration	£3.36	£3.36
	Electric vehicles with fuel duty	£3.48	£3.74
	Electric vehicles without fuel duty	£1.98	£2.24
	Thermal efficiency for housing	£2.15	£2.23

*Assuming 85% of electricity is imported.

Assuming only 75% of electricity can be imported from Jersey increases the benefit-cost ratio for all interventions

We have modelled a sensitivity of only importing 75% of electricity to reflect uncertainties surrounding electricity supply from the GJ1 interconnector.

On-island electricity generation is more expensive than importing electricity, therefore increasing the proportion of electricity that is generated on-island increases the generation cost. Therefore, this sensitivity increases the benefit-cost ratio for grid-level infrastructure options as the cost savings of each intervention are greater.

The impact on the benefit-cost ratio is most pronounced for the GF1 interconnector, as this infrastructure option would remove almost all need for Guernsey to produce electricity from fossil fuels. Therefore, if the baseline level of fossil fuel generation is higher, the benefit of this intervention is greater.

Benefit-cost ratios for domestic interventions are affected less as the cost of energy to end consumers is not affected by the generation ratio. However, the benefit-cost ratio including the shadow price of carbon is affected due to the increased carbon intensity of electricity in the baseline.

	Scenario	Direct benefit-cost ratio	Direct benefit-cost ratio including shadow price of carbon*
Grid-level generation	Utility-scale solar PV	£1.16	£1.18
	Offshore wind	£0.94	£0.97
	GF1 interconnector and N-1	£0.87	£0.98
	GF1 interconnector and N	£0.96	£1.08
Domestic energy use	Solar PV microgeneration	£3.36	£3.38
	Electric vehicles with fuel duty	£3.48	£3.74
	Electric vehicles without fuel duty	£1.98	£2.24
	Thermal efficiency for housing	£2.15	£2.24

*Assuming 75% of electricity is imported.

Accounting for the wider economic impact substantially increases the net benefit of all infrastructure options

The results of the direct impact assessment have been simulated in our model of Guernsey to fully understand their impact on the wider economy.

In this way we can assess the impact of each technology on the Guernsey economy, stretching beyond GEL and the consumers' costs and benefits. The wider benefit-cost ratio is higher than the static ratio for all scenarios as the introduction of each technology allows Guernsey to rely less on imported fuels, either for direct consumption or for electricity generation.

This creates two types of wider benefit in our economic model:

- While much of the technology will have to be imported, the construction and ongoing maintenance creates jobs on the island
- The money that no longer leaves the island to pay for imported fuels and electricity will instead be spent in the Guernsey economy

The multiplier effect means that each £1 now spent on-island will have a greater overall impact on GDP.

	Scenario	Benefit-cost ration including wider economic impact	Benefit-cost ration including wider economic benefits and shadow price of carbon*
Grid-level generation	Utility-scale solar PV	£3.22	£3.22
	Offshore wind	£1.98	£2.00
	GF1 interconnector and N-1	£1.96	£2.06
	GF1 interconnector and N	£2.43	£2.53
Domestic energy use	Solar PV microgeneration	£5.60	£5.60
	Electric vehicles with fuel duty	£6.19	£6.45
	Electric vehicles without fuel duty	£3.94	£4.20
	Thermal efficiency for housing	£3.92	£4.01

*Assuming 85% of electricity is imported.

Choosing which energy infrastructure option to invest in depends on which objectives are most important

In this analysis we consider three possible objectives for energy policy.

Objective for energy policy	Selection criteria	Most appropriate energy infrastructure option in 2050
Economic efficiency Achieve the greatest benefits at the lowest cost	Choose the energy infrastructure option with the highest direct benefit-cost ratio and benefit-cost ratio including wider economic benefits.	**Electric vehicle uptake** or **solar PV microgeneration**
Energy security Increase Guernsey's energy security by expanding reliable generation capacity	Choose the grid-level generation infrastructure option with the most reliable supply that would enable N-2 policy to be relaxed to N-1 or N without increasing the risk to energy security.	**GF1 interconnector**
Carbon reduction Maximise the reduction in carbon emissions by replacing the consumption of fossil fuels the most significantly	Choose the energy infrastructure option that leads to the greatest scale of energy saving and therefore carbon emissions reduction.	**Electric vehicles** GF1 interconnector results in the second largest reduction in carbon emissions. If the GJ1 interconnector is unavailable, the GF1 interconnector would lead to a larger reduction.

2

Energy security and market structure

Energy infrastructure decisions have implications for the N-2 policy

As an island that currently imports nearly all sources of electricity, energy security is of utmost importance for Guernsey.

As the sole supplier of electricity on the island, GEL is obliged to retain additional fuel stocks to meet a regulatory target and ensure extra generators are kept in order as back up to meet N-2 policy. N-2 policy requires GEL to maintain adequate generation capacity to be able to meet total electricity demand on Guernsey in the event that the interconnector and two largest on-island generation assets are out of service.

The proposed GF1 interconnector would greatly expand Guernsey's import capacity and would connect Guernsey to the French grid entirely independently of the Guernsey-Jersey interconnector. Therefore, GEL has suggested that N-2 security may be unnecessarily high as if either cable failed the other would be able to meet the majority of Guernsey's electricity demand. In this case energy policy could be reduced towards N-1 or N level security without increasing the level of risk, allowing GEL to reduce maintenance cost by £1m or £2m respectively each year.

Current insight from GEL suggests that the intermittent nature and limited scale of renewable electricity means that this capacity could not be included as part of N-2. However, with the increasing efficiency of technology and falling energy storage prices, eventually N-2 may be able to be expanded to allow for renewable sources.

We have assumed the energy market structure will remain unchanged

In building the marginal abatement cost curves we have made a number of assumptions surrounding the future provision of energy and other services. Here, we list these assumptions to ensure our modelling remains transparent.

We assume that the structure of electricity and energy markets remains the same and, with the exception of the GF1 interconnector scenario, that the N-2 policy is maintained. The following scenario-specific assumptions have been made surrounding the provision of infrastructure and services:

Utility-scale solar PV	Offshore wind	GF1 interconnector	Solar PV microgeneration	Electric vehicle uptake	Thermal efficiency improvements
• All investment in solar panels will come from GEL • Technology will be imported but installation and maintenance will be done by local firms	• SoG/GEL will provide all investment in installing and maintaining wind turbines • Technology will be imported	• SoG/GEL will provide all investment in installation and maintenance for the interconnector • Technology will be imported	• Households will purchase solar panels for microgeneration from private suppliers • Solar PV technology will be imported • Installation and maintenance work will be carried out by local firms	• Households will replace their internal combustion engine (ICE) vehicles with electric vehicles and contract local suppliers to install home charging points • Public charging points will be installed and maintained as a public-private partnership	• Households will invest in improving the thermal efficiency of their dwellings and engage local private suppliers to do so

A role for Guernsey as an electricity exporter?

The electricity generation from the proposed 30MW offshore wind farm previously investigated by SoG and GEL would already enable Guernsey to reduce electricity imports from Jersey.

By maintaining current imports of electricity from Jersey and using electricity generated by wind power, Guernsey could offset a proportion of HFO and gas oil generation, and could export and excess electricity generated.

Going further, by increasing their investment Guernsey could expand the capacity of the offshore wind farm in order to export. A greater investment would also reduce the levelised cost of electricity due to the economies of scale associated with a larger project.

However, if the times at which Guernsey has a surplus of wind-generated energy coincide with times at which there is a similar surplus across Europe, the price achieved for such electricity may be lower.

GF1 interconnector has greater electricity import capacity than Guernsey requires.

Rather than using only a portion of the interconnector's capacity, Guernsey could import excess electricity to export either to other Channel Islands or to the UK.

Further investment would be required to install the cables linking Guernsey with the electricity export destination. The extent of the investment necessary to export electricity to the UK may mean this venture is unviable.

Jersey already has three interconnectors between the island and France, therefore is unlikely to need exports from Guernsey. However, this opportunity could be used to bolster the energy security of islands in the Bailiwick of Guernsey or Channel Islands further afield.

3 Methodology

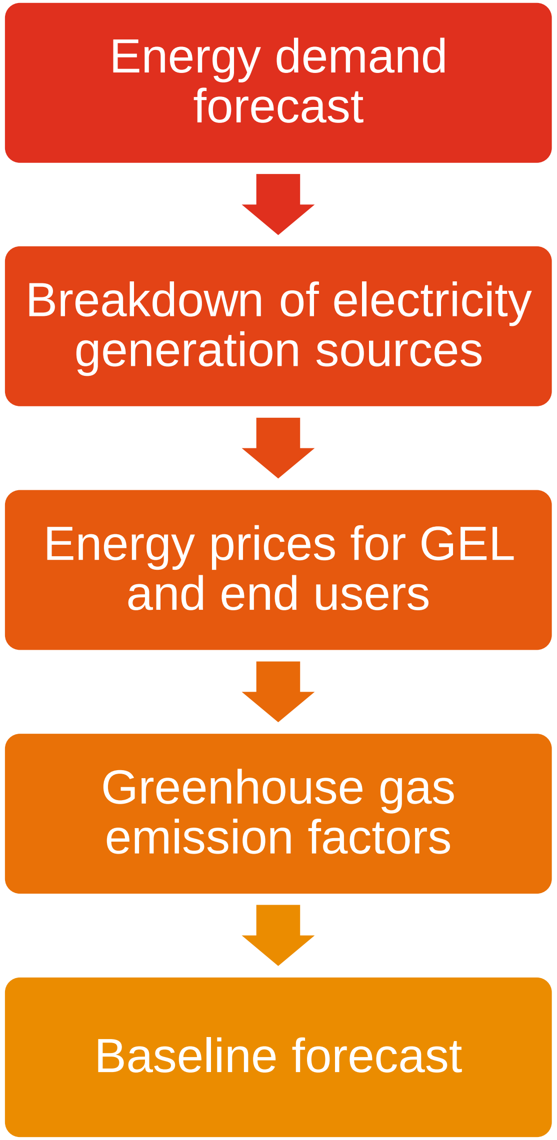
Developing a baseline

The initial step in assessing the potential impact of these measures was to develop a baseline perspective of the Guernsey economy out to 2050 if no measures were implemented.

We take the energy demand forecast as our baseline for fuels and electricity consumed in Guernsey. Regarding electricity and transport fuel demand, we use the forecast that excludes electric vehicle uptake as this will be modelled in one of our scenarios. However, the baseline does account for other forms of electrification to ensure it is as realistic as possible.

GEL has provided us with data on the current breakdown of electricity generation sources and the cost of each source. We use GEL's intended ratio of imports to fossil fuel generation and ratio of HFO to gas oil and apply these to future electricity demand to give the quantity of electricity generated from each source going forward. We also build in the utility-scale solar PV that GEL informs us could be installed and take this out of the portion of electricity that is imported, as is currently the case. We use the per unit cost data supplied by GEL to calculate the spend on electricity generation in the baseline.

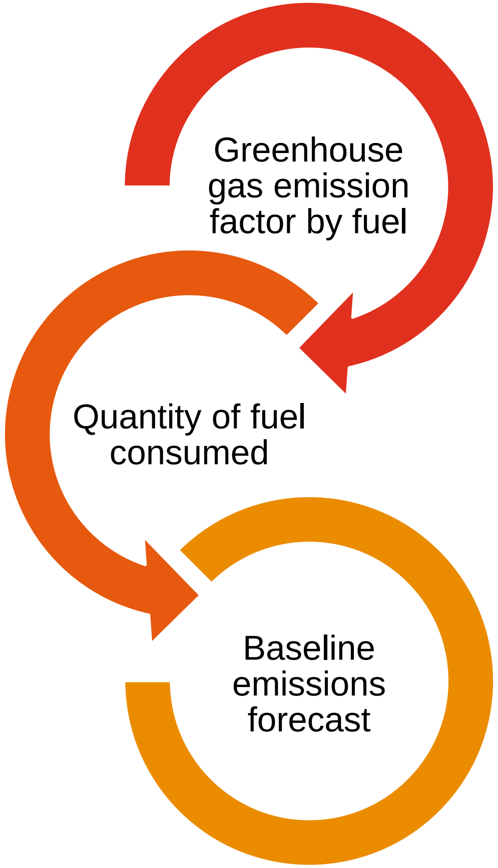
Regarding the cost of energy, for electricity we use the same price as the baseline energy demand forecast of 17.6815p per kWh with a 2.5% increase per annum. We use forecasted prices of petrol and diesel as calculated by the energy demand forecast and use these to determine the total spend on these fuels in the baseline.



Incorporating greenhouse gas emissions

In the interest of understanding the impact of the energy infrastructure options on Guernsey's carbon intensity, we have accounted for greenhouse gas emissions in our baseline.

To calculate greenhouse gas emissions in the baseline we use emission factors produced by the UK Department for Business, Energy and Industrial Strategy for company reporting. We multiply the quantity of each fuel consumed in kWh or MT by the relevant emission factor to derive the kgCO2 equivalent produced in the consumption of each fuel. For electricity imported from France via Jersey, we use the emission factor provided by GEL of 0.005 kgCO2e/kWh. We also use the solar emission factor provided by GEL to incorporate greenhouse gas emissions produced by the solar PV installed in the baseline scenario.



Scenario modelling

To assess the impact of each scenario, we calculate the generation potential or energy usage of the technology being introduced along with the associated costs, savings and greenhouse gas emissions then compare this to the baseline.

For scenarios involving alternative electricity sources, either for the grid or on a micro scale, we calculate electricity generation in the scenario by taking the total annual capacity of the technology and multiplying by the performance ratio to give the actual generation potential.

The costs we include in the model are the initial capital costs and ongoing operating costs, these may be on the behalf of either the end consumer or GEL as the electricity supplier depending on the scenario. In calculating the costs and benefits we assume prices are not affected by any of the measures. We also assume an inflation rate of 2.5% for prices unless otherwise specified.

In the scenarios that alter the grid's electricity generation mix, the benefits are counted as the reduced requirement for GEL to import fossil fuels or electricity in comparison to the baseline. This saving is calculated by multiplying the volumes no longer needed by their prices. In the scenarios that affect the demand for energy, the benefits are the reduction in fuel or electricity bills resulting from the technology.

As different scenarios vary the quantity of electricity demanded of the grid, we assume that GEL will maintain the generation mix of 85% import 15% fossil fuel for the remaining required electricity throughout the period analysed. However, as we have not forecast the load shape out to 2050 we cannot determine how feasible this will be. We assume throughout that there is no unplanned disruption to the GJ1 interconnector, although were this to happen then evidently the ratio for remaining generation would shift heavily towards fossil fuels. We also assume that baseline level solar PV generation will remain constant when other sources of generation are introduced and will offset imported electricity.

The emissions saving is the result of multiplying the difference in fuel consumption in the scenario and in the baseline by the emission factor for that fuel – this may be the use of the fuel directly by consumers, by GEL to generate electricity or in the generation of imported electricity.

4

Utility-scale solar PV

The direct impact of utility-scale solar PV is almost neutral, however including the wider economic impacts adds over £1 to the benefit-cost ratio

GEL currently has 100kW of solar PV installed to power the grid. If it proves commercially viable, this could be scaled up to 1MW by 2021. In this scenario we model increasing the capacity steadily each year to achieve a total capacity of 20MW in 2050.

The results of our modelling show a gradual increase in the annual capital costs of increasing solar generation capacity up to 2026 as installation and construction costs rise faster than the cost of the technology cost falls. From 2026 onwards, construction costs gradually fall as we scale down the cost to reflect the number of years for which the model captures the benefit of the infrastructure. Further capital costs come from the replacement of solar technology installed in 2022 as it arrives at end-of-life after 25 years. Operating costs rise as the stock of solar panels in need of maintenance increases every year.

The benefits and greenhouse gas emission abatement increases steadily as generation capacity expands. From 2047 onwards the benefits rise at a steeper rate as the replacement technology is more efficient than the solar PV that had been installed initially.

Direct benefit-cost ratio	£1.12
Direct benefit-cost ratio including shadow price of carbon	£1.13
Benefit-cost ratio including wider economic effects	£3.22
Benefit-cost ratio including wider economic effects and shadow price of carbon	£3.22

Figure B3. Benefit-cost ratio for utility-scale solar PV

Costs, benefits and greenhouse gas abatement increase over time

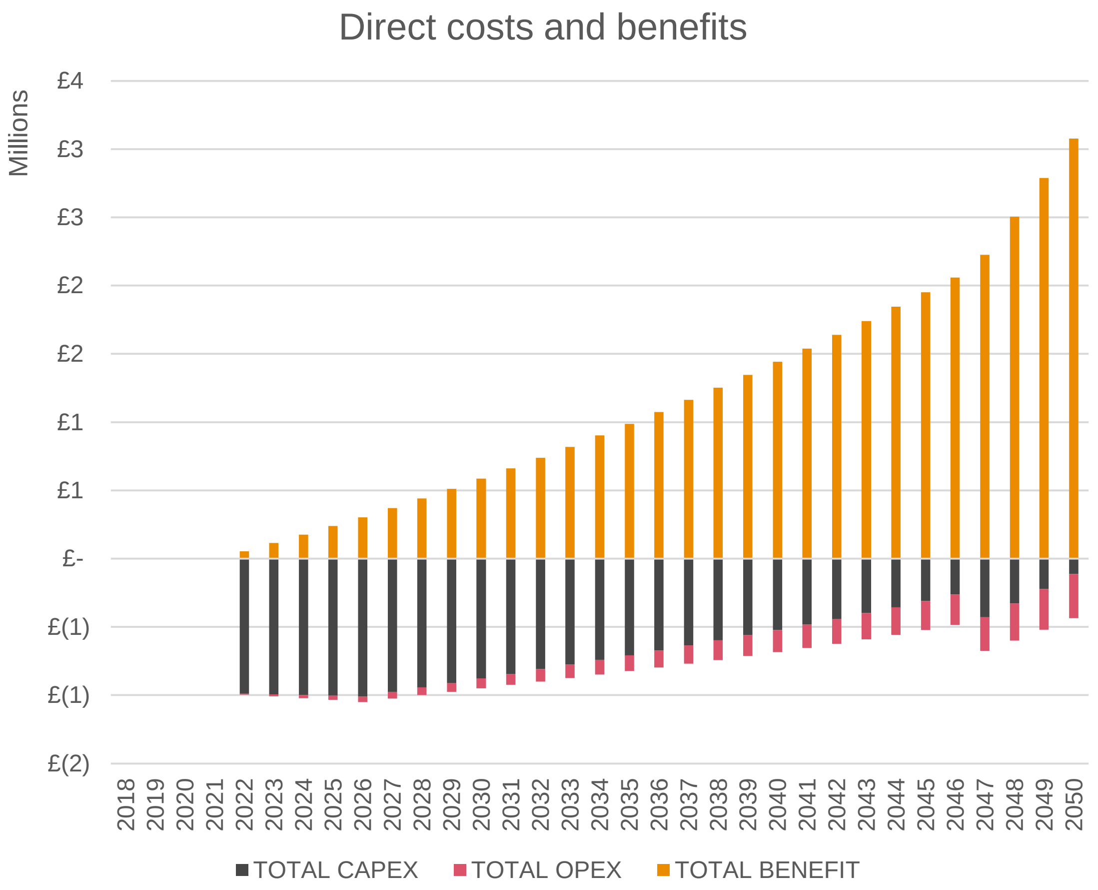


Figure B4. Direct costs and benefits of utility-scale solar PV

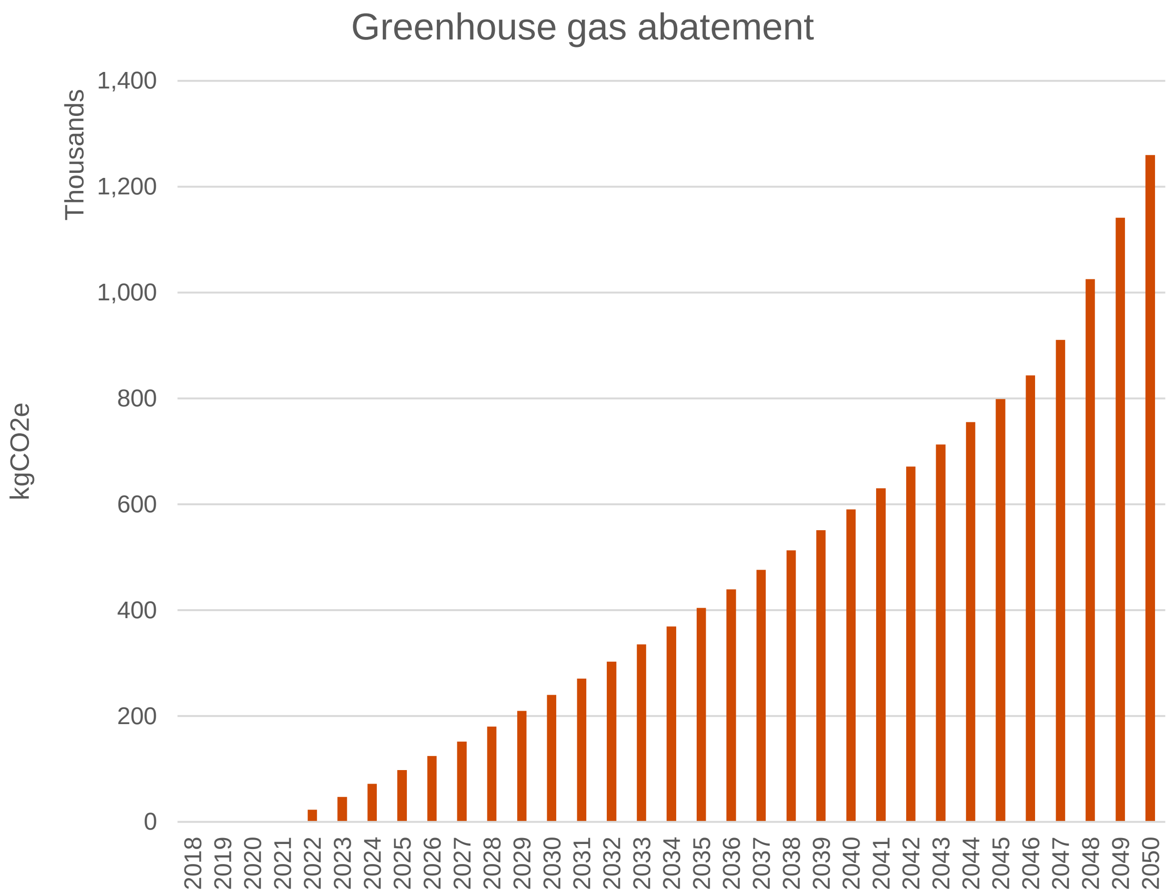


Figure B5. Greenhouse gas emission abatement for utility-scale solar PV

Calculating the direct impact of utility-scale solar PV

We model the planned installation of 1MW solar PV by 2021 as part of the baseline, therefore no cost or benefit relative to the baseline scenario is seen until 2022. GEL have provided us with cost, performance ratio and emission factor figures for this technology.

Given the rapidly evolving solar PV market we have forecast a decline in cost figures using Bloomberg New Energy Finance's New Energy Outlook 2017 which predicts that solar PV costs will fall 71% 2017-2050. However, this only applies to the hardware involved therefore we have split the capital costs into "hard" and "soft" costs, assuming a 40-60 split as seen in recent UK investments, and only applied the cost reduction to hard costs. We assume that soft costs (i.e. labour and installation costs) rise in line with inflation.

The lifetime of utility-scale solar PV is 25 years. Therefore, we incorporate the cost of replacing the infrastructure 25 years after it's installation. However, we also scale down the installation cost for the last 25 years of the period assessed to reflect the number of years for which the model will capture the benefits of the infrastructure.

We calculate the generation potential of solar PV using the performance ratio provided by GEL, which is predicted to increase over time. The benefits of this investment are the savings in imported electricity, HFO and gas oil for GEL. We are assuming that solar generation capabilities are evenly spread across the year which in reality may not be the case.

To calculate the greenhouse gas emission savings we again look at the reductions in imported electricity, HFO and gas oil and multiply by the UK emission factors. We account for emissions from the lifecycle of solar PV using the emission factor provided by GEL.

The wider economic effect increases annually as greater capacity is installed

Economic benefits	2018	2030	2050
Fuel saving	-	1,214,753	4,888,800
Capital cost	-	772,272	45,366
Operational cost	-	168,247	489,012
Net position	-	2,155,272	5,423,178

Direct benefit-cost ratio	£1.12
Direct benefit-cost ratio including cost of carbon	£1.13
Benefit-cost ratio including wider economic impact	£3.22
Benefit-cost ratio including wider economic impact and cost of carbon	£3.22

Figure B6. Wider economic impact of utility-scale solar PV

5

Offshore wind

An offshore wind farm would be almost net neutral, but generate significant wider economic benefits

In this scenario we have assessed the impact of building a 30MW wind farm off the North Shore of Guernsey.

Capital costs scale up in the five years preceding the operation of the wind farm, then cease until 2043 when they begin to scale up in advance of the installation of the replacement wind farm in 2048. The replacement wind farm is cheaper than the initial technology due to expected developments in the sector during this time. Furthermore, we only account for 2/25th of the capital cost of this investment as the model only captures two years of benefit out of the infrastructure's 25 year lifespan.

Throughout the lifetime of the wind farm there is an ongoing operating and maintenance cost. This too is much lower for the replacement wind farm due to technology developments.

The benefits and greenhouse gas emission abatement remain constant as the generation potential does not change therefore neither do the savings in terms of HFO and gas oil.

Direct benefit-cost ratio	£0.91
Direct benefit-cost ratio including shadow price of carbon	£0.93
Benefit-cost ratio including wider economic effects	£1.98
Benefit-cost ratio including wider economic effects including shadow price of carbon	£2.00

Figure B7. Benefit-cost ratio for offshore wind

After the initial construction cost, operating costs, benefits and greenhouse gas abatement are constant during the wind farm's lifetime

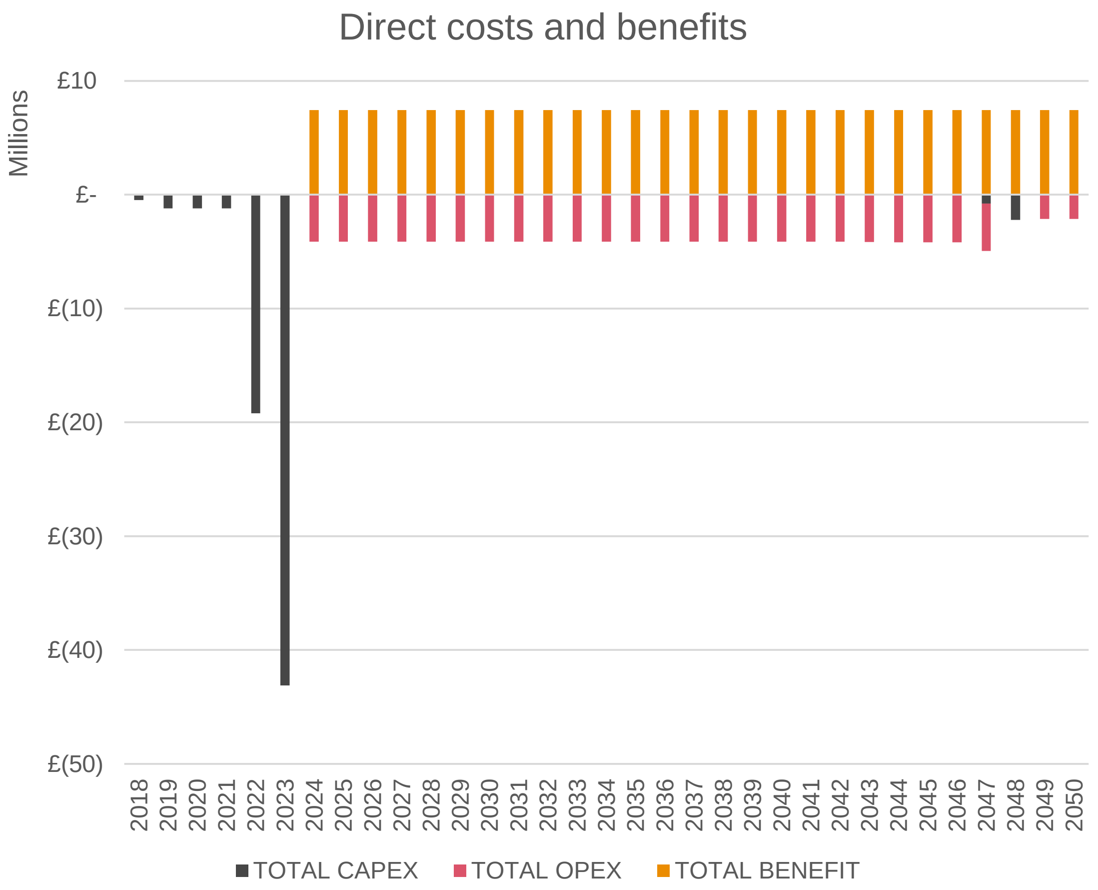


Figure B8. Direct costs and benefits of offshore wind

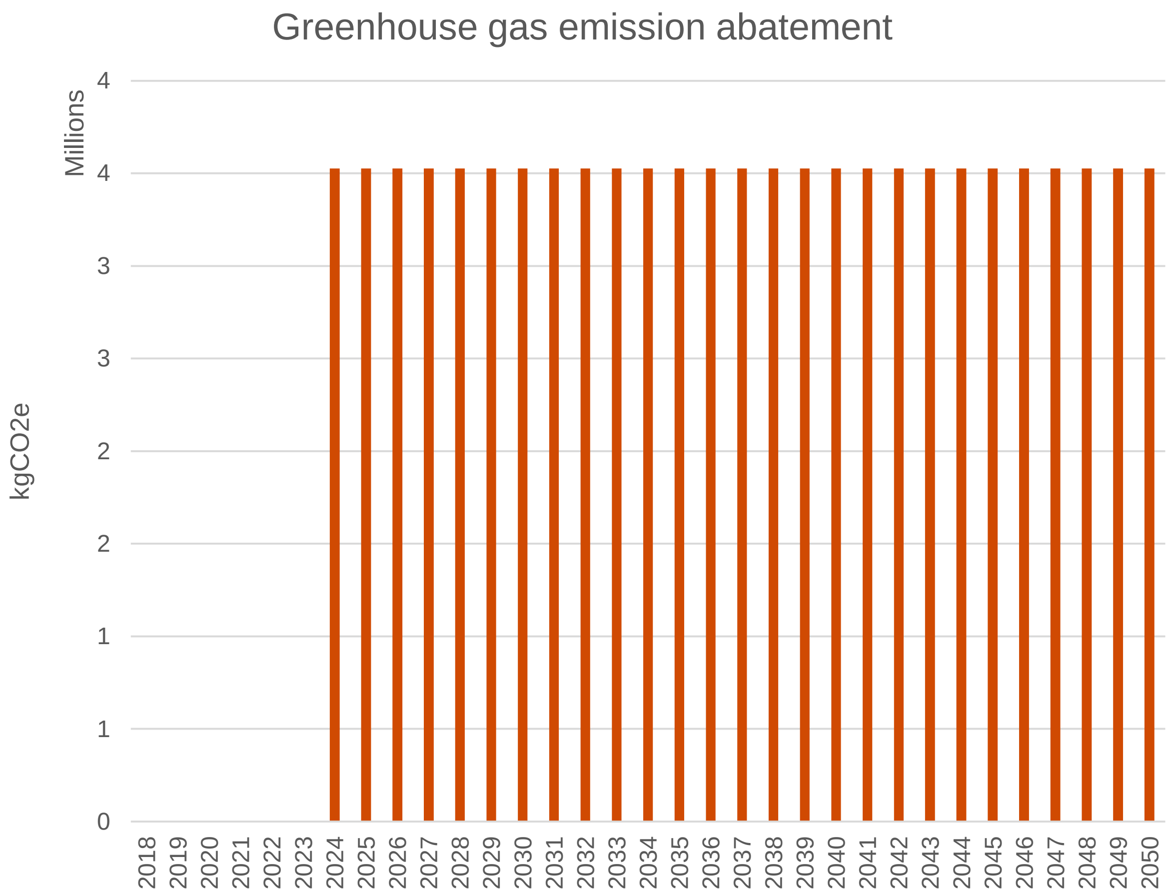


Figure B9. Greenhouse gas emission abatement for offshore wind

Calculating the direct impact of an offshore wind farm

In 2016 States of Guernsey and Guernsey Electricity Limited commissioned a Feasibility Report into the possibility of constructing such a wind farm. Given the rapid developments in the offshore wind market we have updated the cost figures provided using the New Energy Outlook 2017 from Bloomberg New Energy Finance which predicts the cost of wind energy will drop by 58% by 2050. We assume that this fall in costs will occur linearly and assume that costs for the entirety of the wind farm’s lifetime will be set in the first year of the project’s investment; i.e. annual maintenance costs will be constant throughout the wind farm’s operation, but when it is replaced the capital and maintenance costs will be lower. Annual capital costs grow in the five years preceding the operation of the offshore wind farm following the advice provided in the Feasibility Report. These costs grow similarly in advance of the replacement wind farm in 2048, at the end of the initial wind farm’s 25 year lifetime. However, they have been scaled down to reflect that the benefit of this infrastructure is only captured for two years in the model, despite having a 25 year lifetime.

The Feasibility Report also provides us with the capacity, availability and performance ratio of the proposed wind farm which we use to calculate a generation potential of 98.4GWh per year.

The benefits of such an investment are calculated as the savings in imported electricity, HFO and gas oil costs on behalf of GEL. We are assuming that offshore wind generation capabilities are evenly spread across the year meaning that each generation source can be reduced proportionally. However, the estimates for offshore wind generation occurring evenly across the year is conservative as wind generation is more likely during winter months.

To calculate the greenhouse gas emission savings we again look at the reductions in imported electricity, HFO and gas oil and multiply by the UK emission factors. We do also account for the life cycle carbon emissions of offshore wind power, using figures from ClimateXChange, advisers to the Scottish Government on climate change research and policy.

The wider economic impact grows during construction then remains largely constant during the wind farm's operation

Economic benefits	2018	2030	2050
Fuel saving	-	10,103,588	11,329,999
Capital cost	96,578	-	-
Operational cost	-	4,870,395	2,574,757
Net position	96,578	14,973,983	13,904,756

Direct benefit-cost ratio	£0.91
Direct benefit-cost ratio including cost of carbon	£0.93
Benefit-cost ratio including wider economic impact	£1.98
Benefit-cost ratio including wider economic impact and cost of carbon	£2.00

Figure B10. Wider economic impact for offshore wind

6

GF1 interconnector

Constructing the GF1 interconnector would be largely net neutral, but generates less of a wider economic benefit than the previous grid-level infrastructure options

Currently, all the electricity that Guernsey imports from France comes via Jersey. This scenario assesses the impact of building a direct interconnector with France.

The initial capital cost is incurred in 2024. Given the 30 year lifetime of the interconnector, we do not capture the decommissioning and replacement cost. We scale down the capital cost to reflect the fact that only 27 years of benefit from the infrastructure are captured in the model. The cost from 2024 onwards is the operating cost, which rises in line with inflation each year, and the cost of importing extra electricity. This cost grows slightly each year as demand for electricity increases and therefore imports increase.

The benefits rise slightly each year, as electricity demanded rises meaning the quantities of HFO and gas oil that would have had to be imported without the interconnector grow. Due to the substantial capital cost of construction, this change in benefits and operating costs is less evident on the graph.

The construction of the interconnector would also allow for the N-2 policy to be relaxed, allowing GEL to reduce their annual maintenance costs. We have calculated the impact of replacing this with either N-1 (Figure B11) or N (Figure B12) policy.

The wider economic benefit ratio is less than that of utility-scale solar PV and the offshore wind farm as Guernsey would be replacing fuel imports with electricity imports rather than retaining this money in the island economy.

Direct benefit-cost ratio	£0.71
Direct benefit-cost ratio including shadow price of carbon	£0.80
Benefit-cost ratio including wider economic effects	£1.96
Benefit-cost ratio including wider economic effects including shadow price of carbon	£2.06

Figure B11. Benefit-cost ratios for GF1 interconnector and N-1

Direct benefit-cost ratio	£0.81
Direct benefit-cost ratio including shadow price of carbon	£0.91
Benefit-cost ratio including wider economic effects	£2.43
Benefit-cost ratio including wider economic effects including shadow price of carbon	£2.53

Figure B12. Benefit-cost ratios for GF1 interconnector and N

Once the GF1 interconnector has been built, the annual costs, benefits and greenhouse gas abatement grow gradually each year

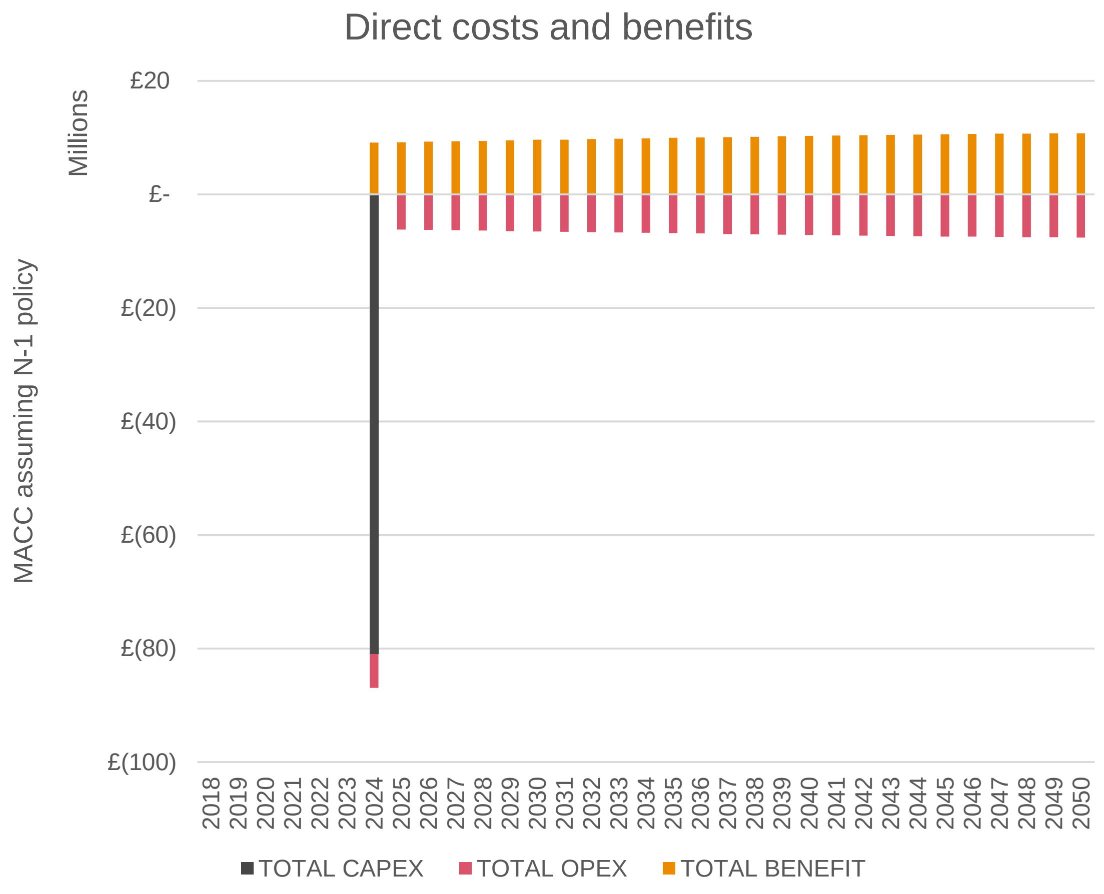


Figure B13. Direct costs and benefits of GF1 interconnector with N-1

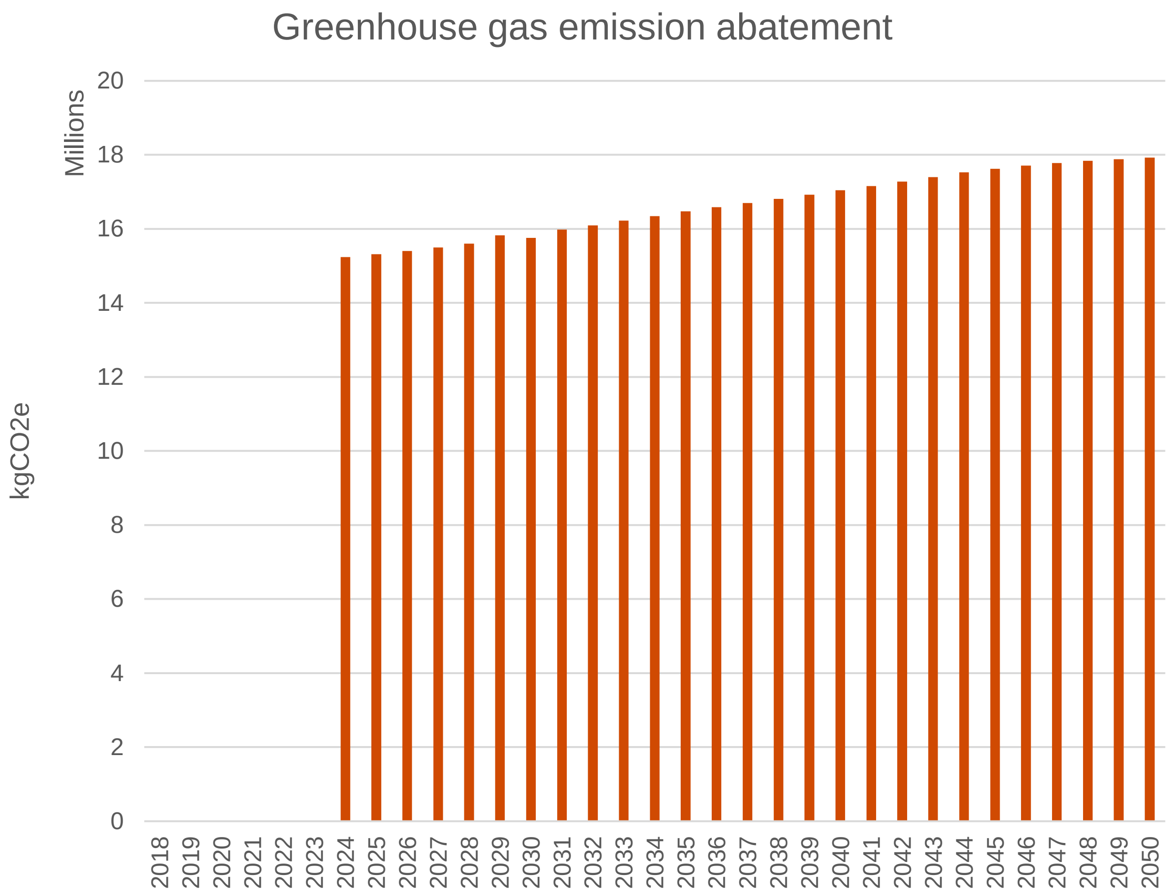


Figure B14. Greenhouse gas emission abatement for GF1 interconnector with N-1

Calculating the direct impact of the GF1 interconnector

GEL has provided data regarding the capacity and performance ratio of the proposed interconnector, along with the capital and operating expenditures associated with such a project. Using this data we are able to calculate the import potential of such an investment as 790.6GWh per year. This capacity is higher than Guernsey's current and forecast electricity demand, therefore in calculating the benefits of such an investment we assume that Guernsey would only import enough electricity to meet its requirements.

The capital cost of the project is the initial constructing cost which has been provided by GEL. Decommissioning costs are not included as this falls outside the time frame of our assessment. Operating costs are the ongoing maintenance costs necessary to ensure the interconnector remains in service and the cost of importing electricity from France, which we assume will rise in line with inflation. We assume the price per GWh is the same as the current price of importing electricity via the GJ1 interconnector.

The benefits of such an investment are the savings for GEL in terms of reduced spending on HFO and gas oil as these are no longer needed for generation. Furthermore, as discussed the construction of a second interconnector would greatly improve Guernsey's energy security. As a result we have estimated the MACC for both N-1 and N level security policies.

If energy security policy were amended to N-1, GEL would be able to reduce annual capex by £1M. If policy were amended even further to N, GEL would be able to reduce annual CAPEX by £2M.

Annual greenhouse gas emission savings can be deduced from the averted HFO and gas oil generation, multiplied by their relative emission factors, compared to the baseline. We do however account for the emissions produced from the electricity generation in France using the emission factor provided by GEL. Greenhouse gas abatement varies over the period due to changing electricity demand in the baseline scenario.

Source: PwC analysis

The GF1 interconnector could have a large wider economic impact on Guernsey, however if left unused and maintained as spare capacity not all of this impact would be realised

Economic benefits	2018	2030	2050
Fuel saving	-	8,055,054	10,106,981
Capital cost	-	-	-
Operational cost	-	6,976,750	7,986,268
Net position	-	15,031,804	18,093,249

Direct benefit-cost ratio	£0.71
Direct benefit-cost ratio including cost of carbon	£0.80
Benefit-cost ratio including wider economic impact	£1.96
Benefit-cost ratio including wider economic impact and cost of carbon	£2.06

Figure B15. Wider economic impact for GF1 interconnector with N-1

Reducing energy security policy to N level slightly increases the wider economic impact

Economic benefits	2018	2030	2050
Fuel saving	-	8,055,054	10,106,981
Capital cost	-	-	-
Operational cost	-	8,377,382	9,556,914
Net position	-	16,432,436	19,663,895

Direct benefit-cost ratio	£0.81
Direct benefit-cost ratio including cost of carbon	£0.91
Benefit-cost ratio including wider economic impact	£2.43
Benefit-cost ratio including wider economic impact and cost of carbon	£2.53

Figure B16. Wider economic impact for GF1 interconnector with N

7

Solar PV microgeneration

Domestic installation of solar PV generates a direct net benefit which is reinforced by the wider economic impact

We model the increased capacity for solar generation using the average growth path of the National Grid's Future Energy Scenarios for solar generation capacity.

Capital costs rise as the speed of uptake increases then fall as uptake slows. These costs then increase again from 2044 as solar technology installed in 2019 arrives at end of life and is replaced. However, installation costs for the last 25 years of the period modelled are scaled down to reflect the number of years of their lifetime that the benefit they generate is captured in the model. Operating costs rise gradually over the years as the installed capacity of solar PV increases.

Benefits and greenhouse gas emission abatement grow in line with the uptake of the technology. The slope then increases slightly from 2044 as old technology is replaced by new, higher performing technology.

Direct benefit-cost ratio	£3.36
Direct benefit-cost ratio including shadow price of carbon	£3.36
Benefit-cost ratio including wider economic effects	£5.60
Benefit-cost ratio including wider economic effects including shadow price of carbon	£5.60

Figure B17. Benefit-cost ratios for solar PV microgeneration

Costs, benefits and greenhouse gas abatement grow as installed capacity increases, additional costs are incurred as technology requires replacement

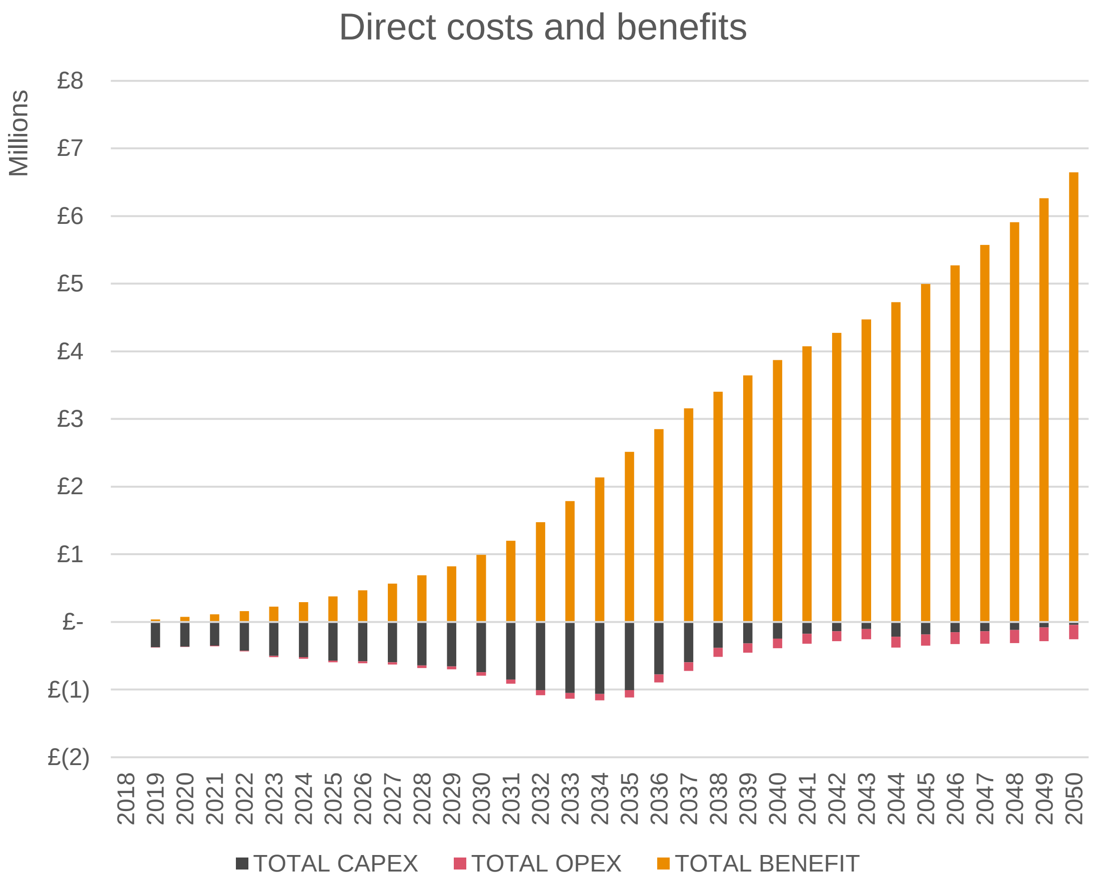


Figure B18. Direct costs and benefits of solar PV microgeneration

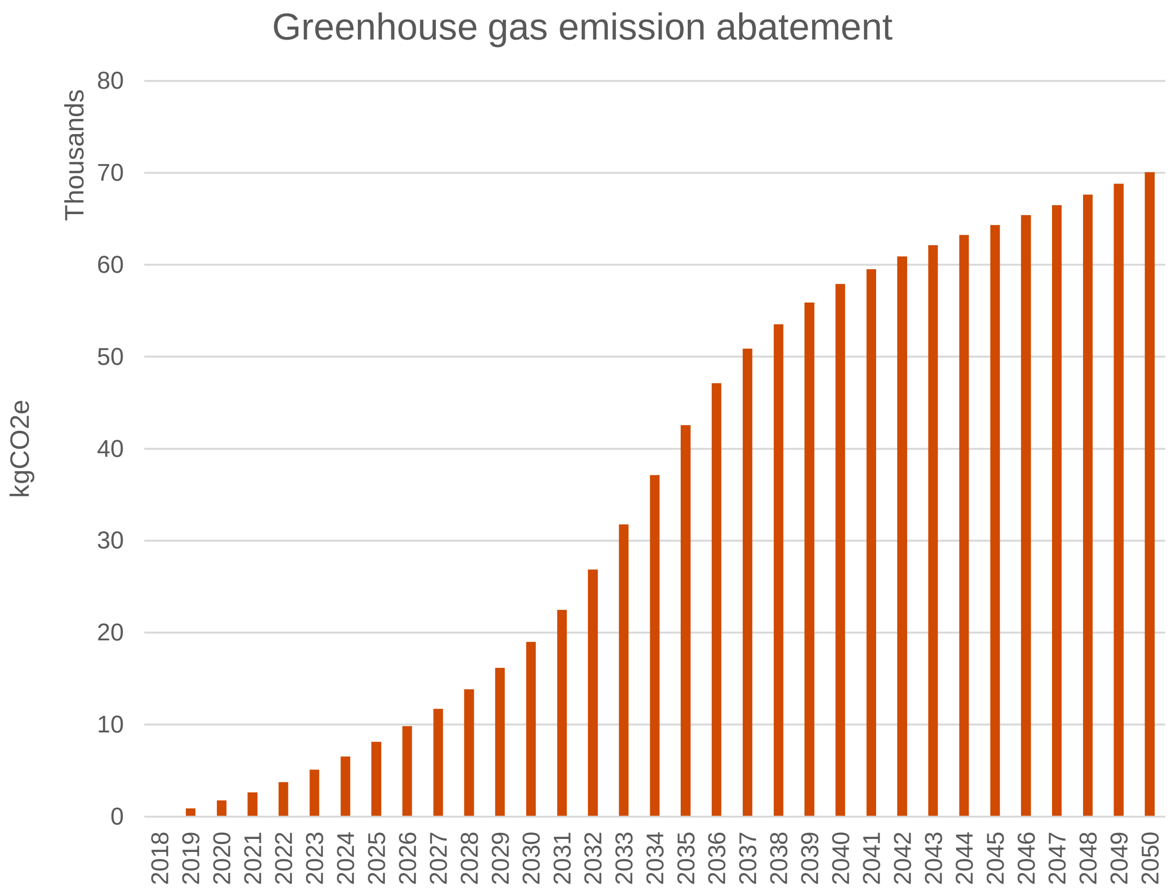


Figure B19. Greenhouse gas emission abatement for solar PV microgeneration

Calculating the direct impact of the uptake of solar PV microgeneration

Currently Guernsey has 500kW (est.) of small-scale solar PV installed. GEL has provided us with capital costs which we have broken down into “hard” and “soft” costs with a 40-60 split. Given continuing advancements in the technology, we take Bloomberg New Energy Finance’s projections of a 71% fall in “hard” costs by 2050 and apply this to today’s cost, assuming costs will fall linearly over this period. We assume that soft costs (i.e. labour and installation costs) rise in line with inflation. For the last 25 years of the model this cost is scaled down to reflect the number of years of the infrastructure’s lifetime for which the benefit is captured by the model. Operating costs are calculated as a proportion of capital costs. We take the average of the National Grid’s Future Energy Scenarios to predict the growth path of solar capacity and apply this to Guernsey, assuming the island will reach 10MW capacity in 2050. Figure B20 shows this rate of uptake.

The benefits come from the reduction in electricity bills for households, which is the electricity generated by the new solar PV multiplied by the price of electricity. We calculate electricity generation using performance ratio data supplied by GEL.

We calculate the greenhouse gas emissions saved by taking the reduced imported electricity and generation using fossil fuels and multiplying by the relevant emission factors. We assume GEL will reduce their electricity generation while maintaining the generation mix of 85% import 15% fossil fuel. We also account for emissions generated by solar panels, using the emission factor provided by GEL.

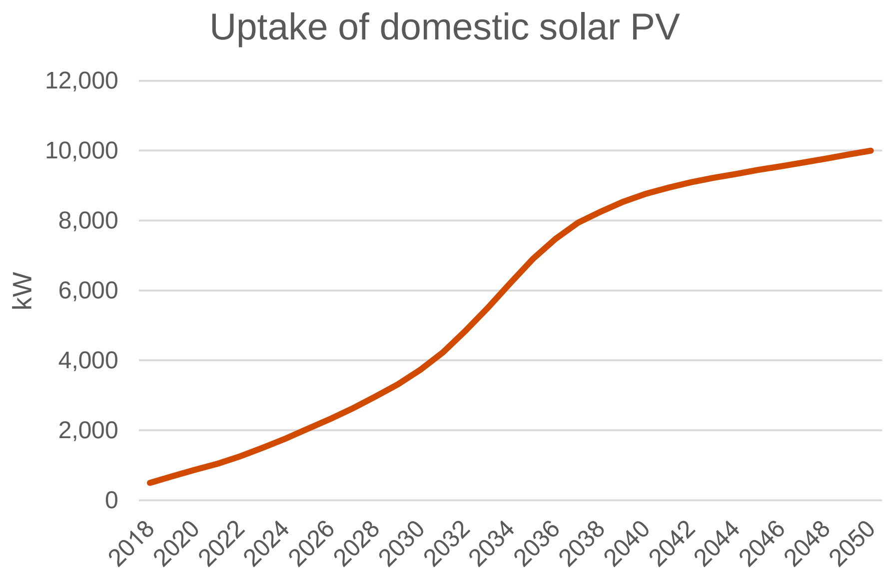


Figure B20. Installed capacity of domestic solar PV

Solar PV microgeneration has a substantial wider economic impact as households save on their energy bills and engage local suppliers to install and maintain the technology

Economic benefits	2018	2030	2050
Fuel saving	-	1,388,531	10,437,802
Capital cost	-	507,831	28,777
Operational cost	-	9,513	42,528
Net position	-	1,905,875	10,509,107

Direct benefit-cost ratio	£3.36
Direct benefit-cost ratio including cost of carbon	£3.36
Benefit-cost ratio including wider economic impact	£5.60
Benefit-cost ratio including wider economic impact and cost of carbon	£5.60

Figure B21. Wider economic impact of solar PV microgeneration

8 Electric vehicles

The direct net benefit of electric vehicles will be greater if fuel duty remains in place due to the higher price of fuels, but regardless of this policy the wider impact is substantial

We model the transition from ICE vehicles to electric vehicles using the Future Energy Scenarios developed by the UK National Grid.

The capital costs decline from 2019 to 2026 as the decline in the price premium for electric vehicles outweighs the cost of installing public and domestic charge points. Meanwhile operating costs grow continuously as the number of charging points in need of servicing increases.

Benefits are the net saving to drivers' bills, the saving on petrol and diesel and the increase in consumption of electricity. Given that electricity is cheaper, particularly during off-peak times, this amounts to a large saving for drivers. The greenhouse gas emission abatement increases in a similar manner due to the reduction in petrol and diesel consumption. Emissions from additional electricity generation are accounted for, but these are low especially for off-peak electricity demand which can be imported from France.

Due to current uncertainties surrounding the future of fuel duty in Guernsey, we calculate the impact of electric vehicle uptake assuming that fuel duty will continue at the current rate (Figure B22) and a separate version assuming fuel duty will be abolished (Figure B23).

Direct benefit-cost ratio	£3.48
Direct benefit-cost ratio including shadow price of carbon	£3.74
Benefit-cost ratio including wider economic effects	£6.19
Benefit-cost ratio including wider economic effects including shadow price of carbon	£6.45

Figure B22. Benefit-cost ratios for electric vehicles with fuel duty

Direct benefit-cost ratio	£1.98
Direct benefit-cost ratio including shadow price of carbon	£2.24
Benefit-cost ratio including wider economic effects	£3.94
Benefit-cost ratio including wider economic effects including shadow price of carbon	£4.20

Figure B23. Benefit-cost ratios for electric vehicles without fuel duty

As the transition to electric vehicles gets underway, the annual cost, benefit and greenhouse gas abatement grow

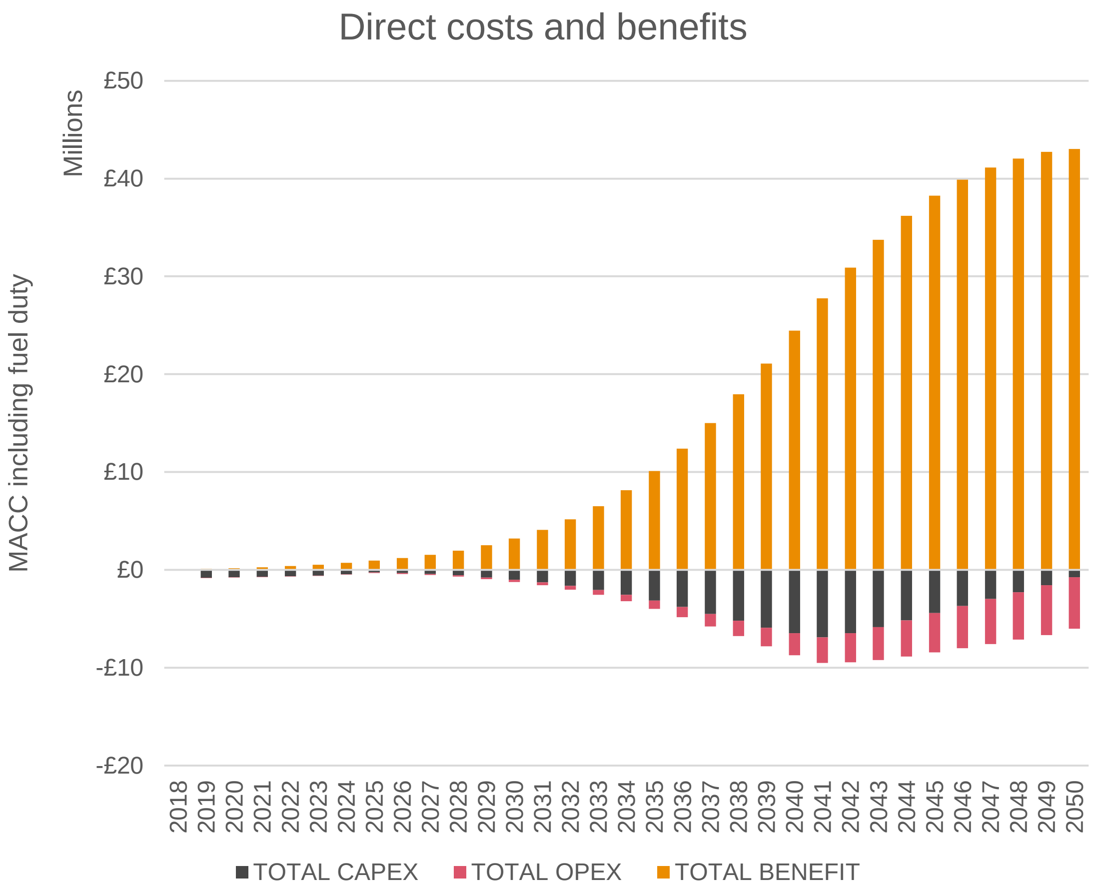


Figure B24. Direct costs and benefits of electric vehicle uptake with fuel duty

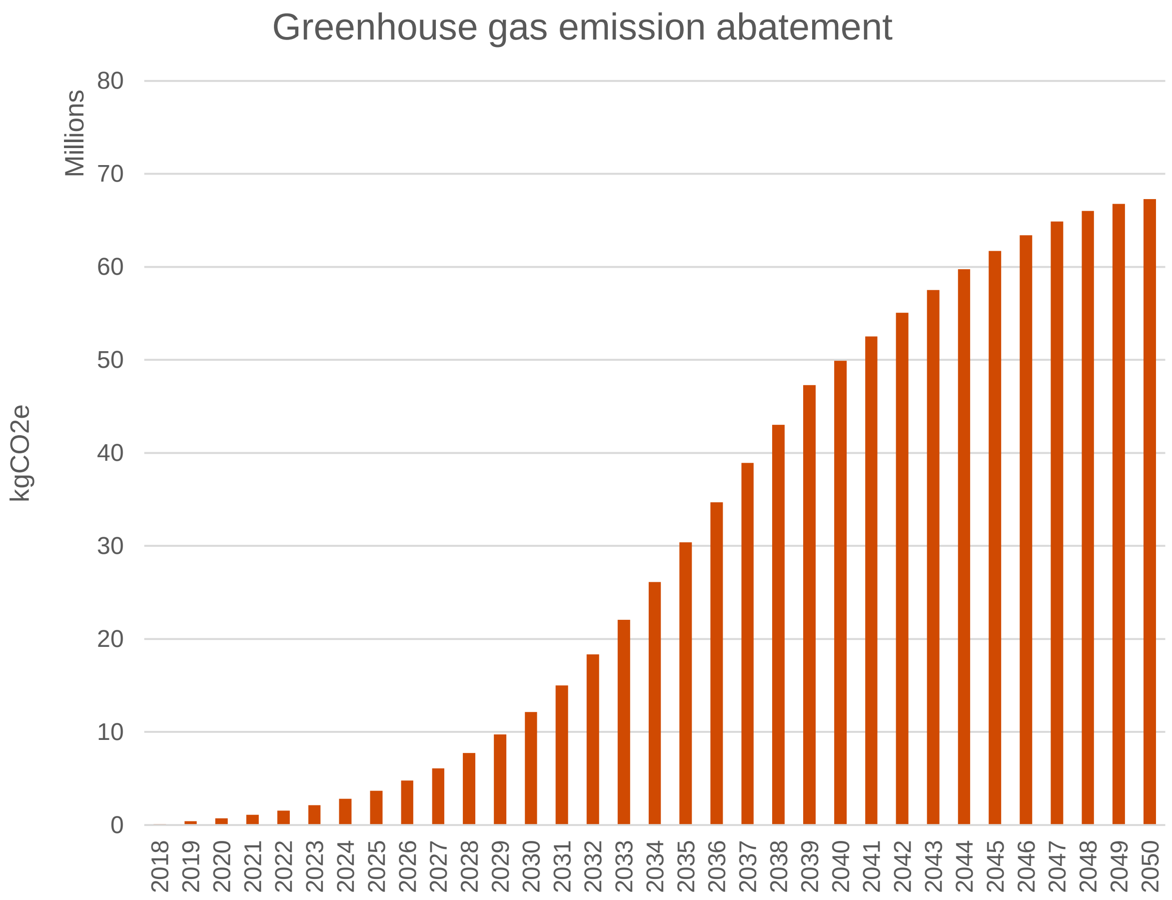


Figure B25. Greenhouse gas emission abatement of electric vehicles with fuel duty

If fuel duty is abolished, the benefit of replacing an ICE vehicle with an electric vehicle is less pronounced

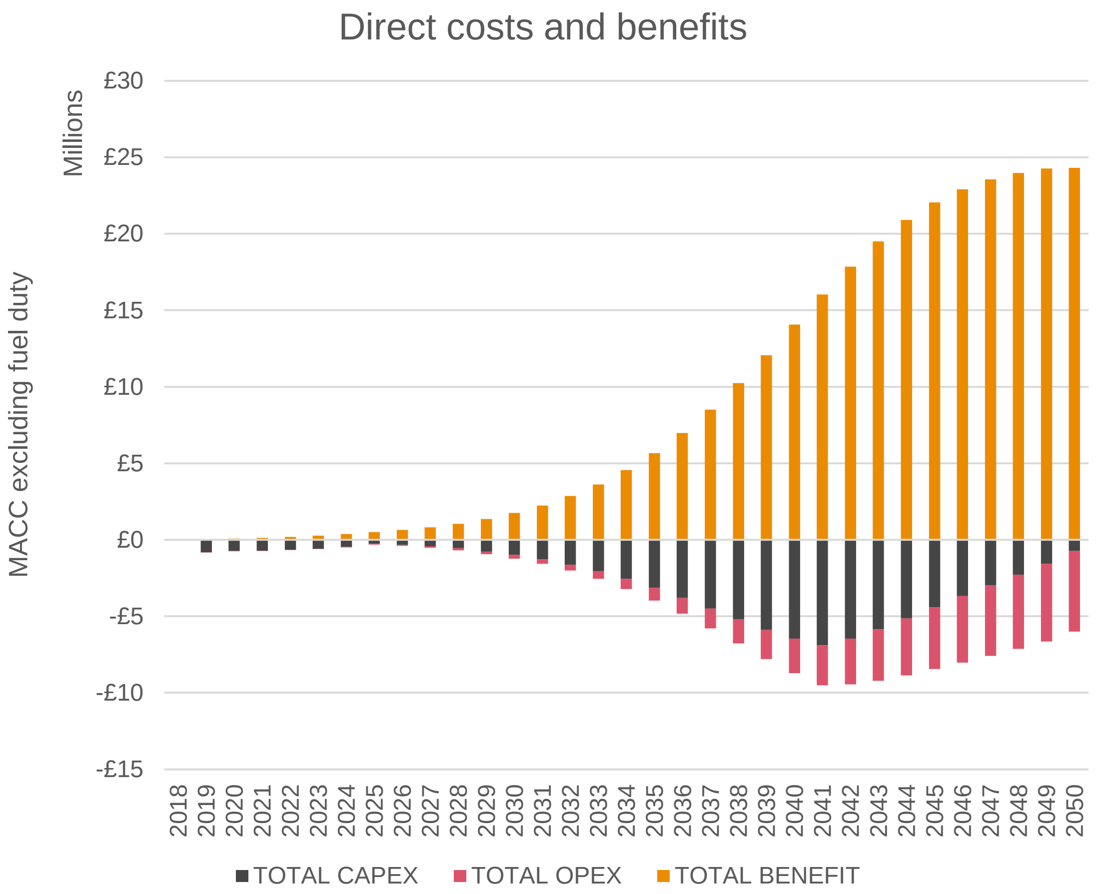


Figure B26. Direct costs and benefits of electric vehicle uptake without fuel duty

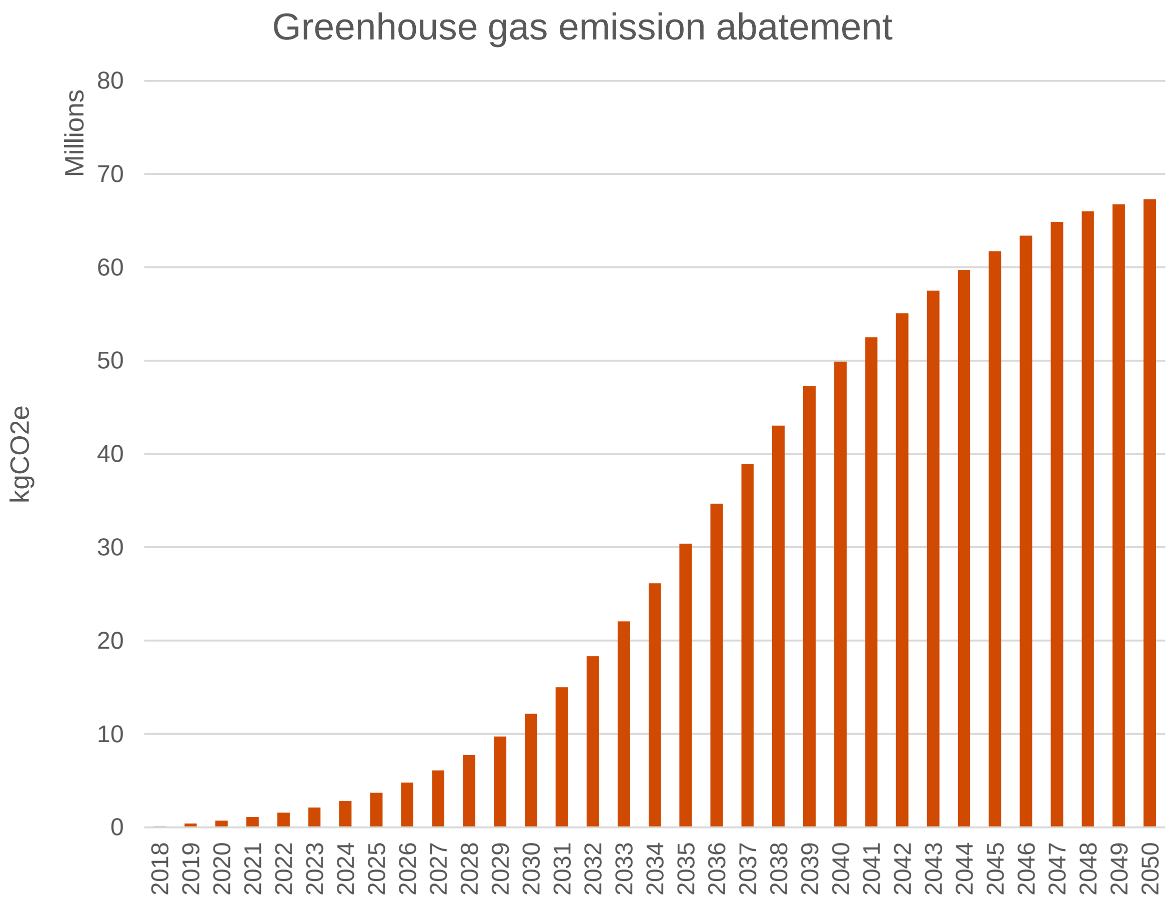


Figure B27. Greenhouse gas emission abatement of electric vehicle uptake without fuel duty

Calculating the direct impact of electric vehicle uptake (1/3)

The first step is to model the changing numbers of each type of vehicle in Guernsey until 2050. We start with the breakdown of the current vehicle fleet provided by the States of Guernsey. As the energy demand forecast has used the average of the two more conservative Future Energy Scenarios developed by the National Grid to predict the transition away from ICE vehicles, we too take this approach and apply this rate of transition to the Guernsey vehicle fleet. We also assume that the numbers of cars per head remains constant to ensure that Guernsey's growing population is accounted for in the total number of cars.

We take into account the fact that Guernsey is further along this transition than the UK but assume that the final composition of the vehicle fleet in 2050 will be the same, due to the eventual market saturation of electric vehicles. This takes the proportion of electric vehicles to 88.5% in 2050 which we use to calculate the annual change in each type of vehicle. The National Grid data treats petrol and diesel vehicles as the same, therefore we must assume that the current ratio of petrol-to-diesel vehicles and electric-to-hybrid vehicles remains constant. This uptake of electric vehicles is shown in Figure B28.

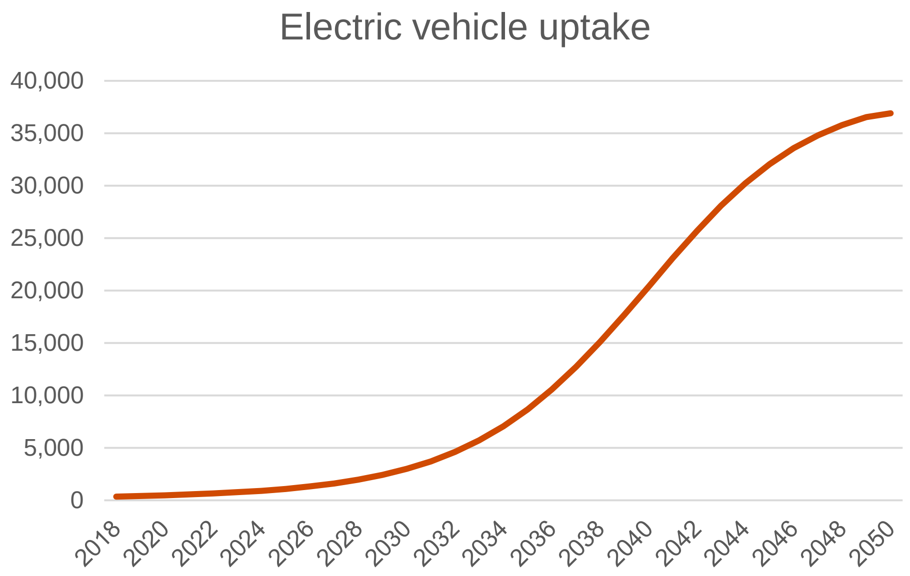


Figure B28. Number of electric vehicles in Guernsey

Calculating the direct impact of electric vehicle uptake (2/3)

The capital cost is the cost of installing charging points on the island both public and private. Using data on the current stock of electric and hybrid vehicles and the number of public charging points on the island we calculate the requirement per vehicle. We multiply this by the forecast increase in these vehicles to estimate future installations. We then apply the cost per charging point of installing the current stock to estimate the necessary capital expenditure, this assumes that the cost will be constant in the future. We also include the annual operating cost of the public charging points, using the current maintenance cost per charging point as provided by the States of Guernsey.

For private charging points, we take the figure from ChargePoint that 80% of charging will take place at home and assume that this proportion of electric vehicle owners will install a charging point at home. [redacted]

For both public and private charging points we assume a lifetime of 10 years, in line with industry predictions. We factor in the cost of these replacements and for the last 10 years of the period modelled we scale down the capital cost to reflect the number of years for which the benefit of this investment will be captured in the model.

Given that electric vehicles are currently substantially more expensive than ICE vehicles, we consider this additional upfront cost to drivers transitioning to electric vehicles. We take the forecast from Bloomberg New Energy Finance (2017) for the falling price of medium-sized battery electric vehicles that predicts parity with ICE vehicles in 2025, and multiply the premium for each year by the number of new electric vehicles being introduced to the vehicle fleet.

We do not account for any investment in electricity grid reinforcements that may be required to deal with increased demand at peak times as residents return home in the evenings and plug in their vehicles.

Calculating the direct impact of electric vehicle uptake (3/3)

In the baseline we assume no further uptake of electric vehicles and use the electricity and transport fuel demand forecasts that exclude them from the calculations. Therefore, to account for the impact of electric vehicles, we use the results from the energy demand forecast that incorporate the impact of electric vehicle uptake to ensure consistency with our findings.

The benefit to consumers is the saving on their overall energy bill as increased spending on electricity is offset by the saving on petrol and diesel. We calculate the extra electricity demand by comparing the demand forecast including and excluding the impact of electric vehicles and assuming again that 80% of charging will be done at home. As home charging is likely to be done overnight and at off-peak times we assume consumers pay a lower rate of 8p/kWh, rising 2.5% per annum. For the remaining 20% we assume this will be done at public charging points and that consumers will pay the standard electricity price.

For reduced spending on petrol and diesel we consider the price of fuels both including and excluding fuel duty and multiply this by the difference in demand in our baseline and scenario.

Further benefits are also accrued to the owners of the public charging points, we use average net income from the existing charge points and apply this to the future installations. We therefore assume that the proportion of charging that is done in public spaces and the cost of that usage will remain constant.

We take a similar approach to calculate the greenhouse gas emission abatement. For the 80% of charging done at home during off-peak times we assume that all extra electricity demand can be met by the interconnector. However for the remaining 20% of charging done at peak times we assume GEL will maintain the generation mix of 85% import 15% fossil fuels. We then subtract the emissions produced from extra electricity generation from those averted from transport fuel consumption

The overall economic benefit of electric vehicles grows as uptake increases as drivers save more on fuel and fuel duty

Economic benefits	2018	2030	2050
Fuel saving	74,598	4,498,041	67,590,778
Capital cost	-	1,252,594	903,380
Operational cost	-	92,540	1,578,055
Net position	74,598	5,843,175	70,072,213

Direct benefit-cost ratio	£3.48
Direct benefit-cost ratio including cost of carbon	£3.74
Benefit-cost ratio including wider economic impact	£6.19
Benefit-cost ratio including wider economic impact and cost of carbon	£6.45

Figure B29. Wider economic impact of electric vehicle uptake with fuel duty

Removing fuel duty in the baseline means drivers save less when switching to an electric vehicle, therefore the wider economic benefit is dampened

Economic benefits	2018	2030	2050
Fuel saving	35,404	2,451,372	38,188,968
Capital cost	-	1,252,594	903,380
Operational cost	-	92,540	1,578,055
Net position	35,404	3,796,506	40,670,403

Direct benefit-cost ratio	£1.98
Direct benefit-cost ratio including cost of carbon	£2.24
Benefit-cost ratio including wider economic impact	£3.94
Benefit-cost ratio including wider economic impact and cost of carbon	£4.20

Figure B30. Wider economic impact of electric vehicle uptake without fuel duty

9

Thermal efficiency improvements

Thermal efficiency improvements allow households to save on their fuel bills, however rapidly rising construction costs mean such upgrades become less beneficial over time

We model improvements in thermal efficiency and the effect on heating demand using UK National Grid Future Energy Scenarios.

The capital cost increases each year as the cost of upgrading the thermal efficiency of a dwelling rises in line with Guernsey construction costs. We foresee no operating costs as once the technology is installed and improvements have been made then there will be no difference in cost in comparison to the baseline. Due to the long lifetime of measures such as cavity wall insulation, we scale down the capital costs by the number of years left in our model at the time of installation for which benefits can be accrued. This is to prevent installation costs from the last few years of the model lowering the benefit-cost ratio simply because the benefits this investment will generate will occur in years not captured by the model.

The benefits rise as the number of houses that have been upgraded increases, therefore the total saving on energy bills grows steadily each year. Meanwhile the rate at which greenhouse gas emission abatement grows slows over the years as the transition towards electricity for heating occurs in the baseline, therefore the saving on energy bills moves away from heating oil, which produces high levels of emissions when burnt, and towards electricity, whose generation is a much greener process.

Direct benefit-cost ratio	£2.15
Direct benefit-cost ratio including shadow price of carbon	£2.23
Benefit-cost ratio including wider economic effects	£3.92
Benefit-cost ratio including wider economic effects including shadow price of carbon	£4.01

Figure B31. Benefit-cost ratios for thermal efficiency improvements

As more households upgrade the thermal efficiency of their dwelling, the direct costs, benefits and greenhouse gas abatement grow

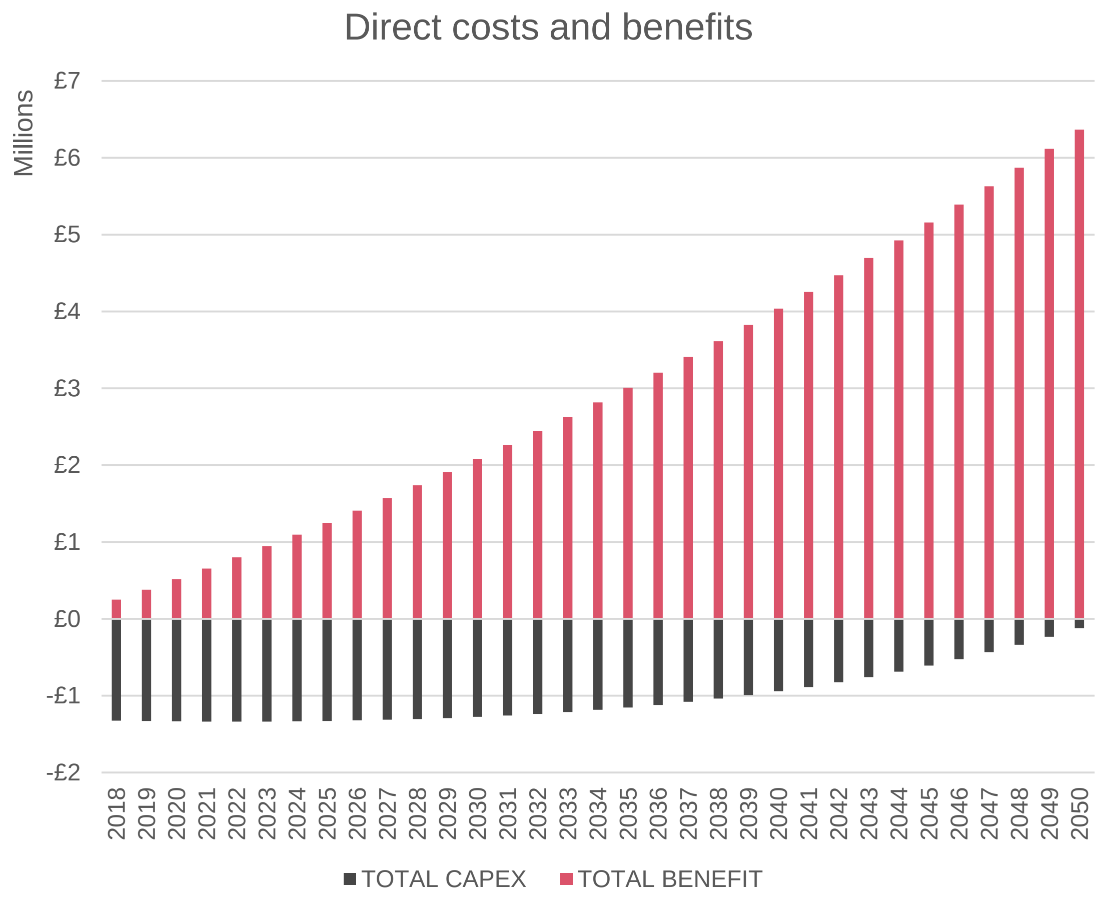


Figure B32. Direct costs and benefits of thermal efficiency improvements

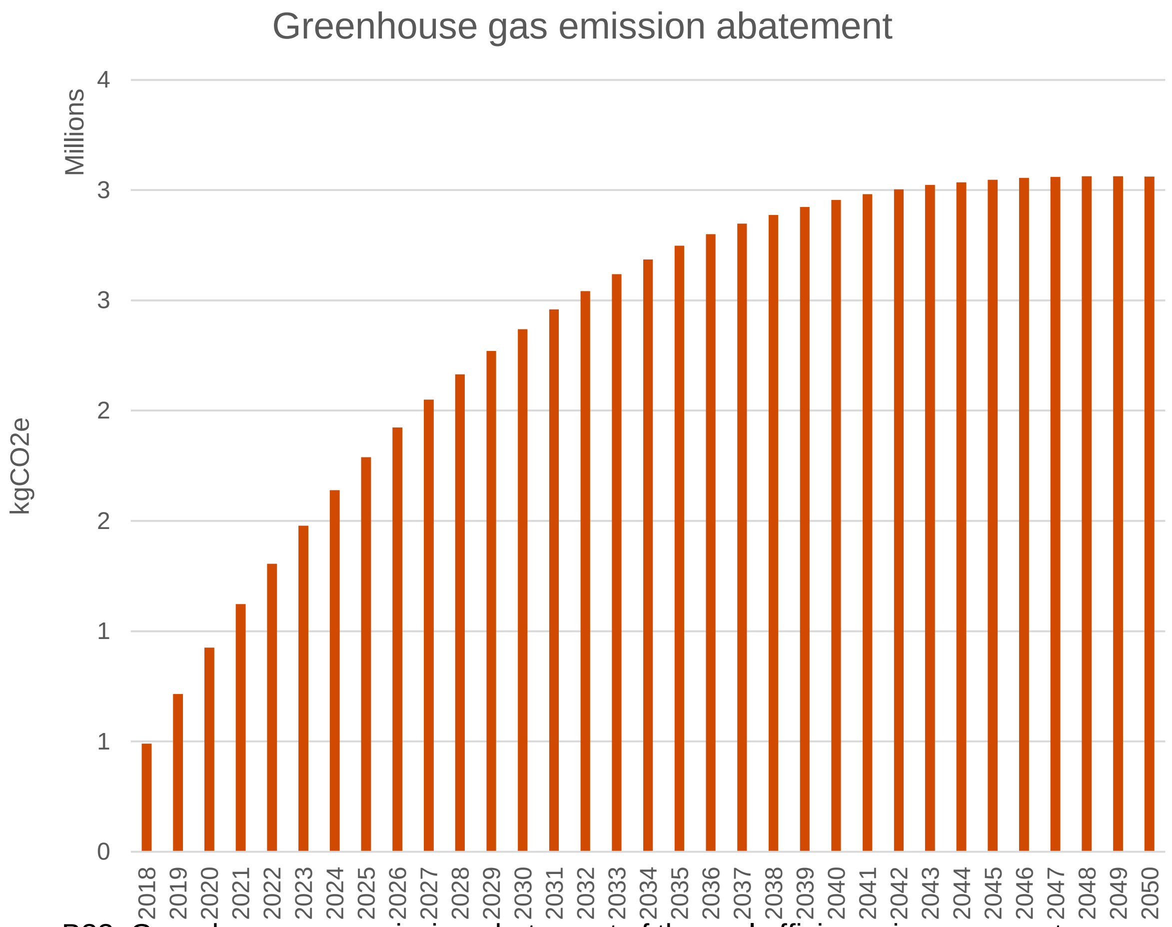


Figure B33. Greenhouse gas emission abatement of thermal efficiency improvements

Calculating the direct impact of thermal efficiency improvements (1/2)

We take the energy demand forecast for all sources of heating as our baseline. This baseline uses the UK National Grid's Future Energy Scenarios predictions for the transition in EPC housing rating and smooths it to achieve a steady movement towards thermal efficiency. The baseline is calculated using the average of the Isle of Wight's EPC ratings and estimates for Guernsey EPC ratings based on the age of buildings. For our scenario, we apply the same methodology but using the average of the estimated Guernsey EPC ratings and the National Grid's prediction that assumes compliance with the 2050 target. This assumes that Guernsey implements a similar policy to the UK in order to encourage improvements in domestic thermal efficiency.

To calculate the capital cost of improving thermal efficiency we start with calculating the number of dwellings which would be improved in the baseline and in the scenario. We use the growth rates of the different EPC rating categories over each time period and apply this to the total housing stock of Guernsey for both the compliant and non-compliant scenario. We then look at the change in the size of each category between 2017 and 2050 to estimate how many dwellings would be upgraded in both of the National Grid's scenarios. Calculating the difference between these forecasts gives the number of upgrades that take place in our scenario above and beyond those upgrades undertaken in the baseline.

Average of Isle of Wight and Guernsey

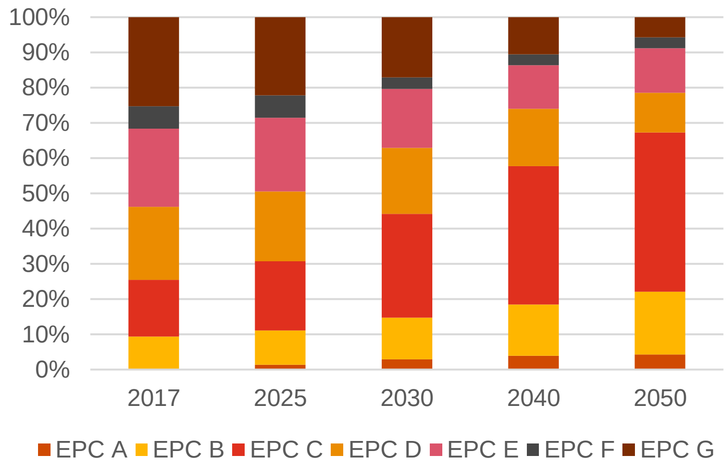


Figure B34. Source: National Grid

Average of UK 2050 compliant and Guernsey

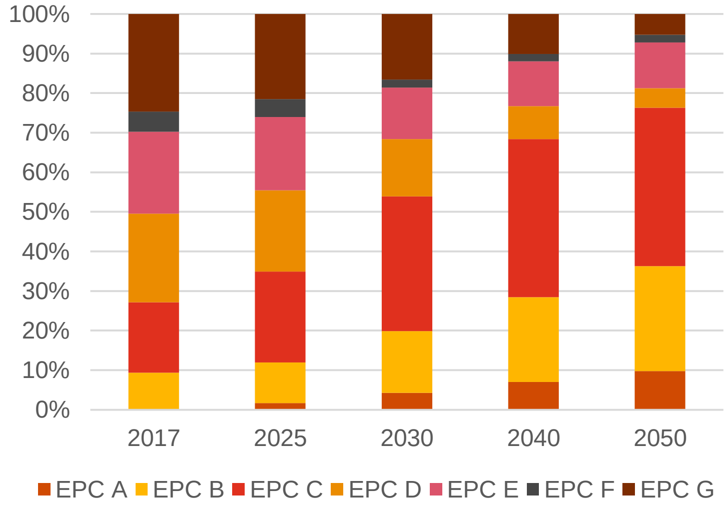


Figure B35. Source: National Grid

Calculating the direct impact of thermal efficiency improvements (2/2)

To calculate the cost of each upgrade we take cost figures from the UK Department for Business, Energy & Industrial Strategy for the cost of retrofitting different categories of dwellings, the types of improvement we consider are listed below. To reflect the higher cost of living in Guernsey, we increase these costs by 40%. We then apply each cost to the proportion of each type of dwelling in Guernsey. To assess the proportion of dwellings that are eligible for each type of upgrade we take data from the Energy Efficiency Study (2007) undertaken by KEMA for the States of Jersey and assume these will be the same for Guernsey. Therefore we are able to multiply the cost of each of the measures by the likelihood of a dwelling being eligible for this upgrade to get the total as the cost of upgrading a dwelling. We increase costs by 3.5% per annum, in line with standard building costs in Guernsey. For each year we multiply the number of houses to be upgraded by the average upgrade cost.

The benefits in this scenario are the cost savings to consumers from reduced heating bills. We multiply the reduction in each fuel used by its price to calculate the benefits. For the price of heating oil and gas oil, we take the current 55p per litre price and for LPG we take the 13.88p per kWh price, both provided by GEL at time of writing. We assume these prices will rise 2.5% per annum.

We use this projection of heating fuel demand to calculate the greenhouse gas abatement potential by multiplying by the UK emission factor for each heating fuel and each source of electricity generation. In doing so, we assume that GEL will scale back electricity generation while maintaining the generation mix of 85% import 15% fossil fuel.

- Hot water insulation
- Cavity wall insulation
- Loft insulation
- Improved heating controls
- Draught proofing
- Solid wall insulation
- Boiler replacement
- Double glazing

Thermal efficiency improvements are a highly efficient intervention, generating substantial economic benefits through local employment

Economic benefits	2018	2030	2050
Fuel saving	318,396	2,916,740	9,996,866
Capital cost	1,093,690	978,011	76,404
Operational cost	-	-	-
Net position	1,412,086	3,894,751	10,073,270

Direct benefit-cost ratio	£2.15
Direct benefit-cost ratio including cost of carbon	£2.23
Benefit-cost ratio including wider economic impact	£3.92
Benefit-cost ratio including wider economic impact and cost of carbon	£4.01

Figure B36. Wider economic impact of thermal efficiency improvements

Thank you

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