The Productivity Institute

Driving zero-carbon transitions and productivity growth

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clarity from complexity

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Executive Summary

This study sets out to explore the potential impacts of decarbonisation on the productivity of the economy of the United Kingdom. To highlight the different impacts at the macro and sectoral levels under different decarbonisation scenarios, we applied the global macroeconomic model, E3ME, integrated with a suite of technology transition (FTT) models. Impacts under the four scenarios based on key policies featured in the 2020 Ten Point Plan and the 2021 Energy Security Strategy were measured relative to the E3ME baseline. The four scenarios include two levels of domestic policy ambition (Policy and Policy+) under two alternative versions of the wider world; one in which other major economies do not decarbonise beyond current plans, and one where they do. The policy choices in these scenarios impact the take-up of four key technologies: offshore wind power generation, solar PV power generation, electric vehicles for private passenger use, and heat pumps for domestic dwellings.

Offshore wind uptake is increased for all scenarios, driven by a government mandate to build 50GW capacity by 2030. However, unless gas generation is regulated, the share of gas generation could increase after the mandate is removed, with growth in the deployment rate of offshore wind slowing dramatically.

Due to the higher up-front costs of renewable energy sources, there is a temporary, short-term rise in electricity prices as the role of offshore wind grows. However, despite a decline in load factors (reflecting the fact that the optimal deployment sites are filled up and secondary sites have to start being used), higher capacity needs and storage costs, in the medium and long-run these effects are still outweighed by the overall lower cost of renewables relative to fossil fuels, meaning that electricity is cheaper as a result of more ambitious decarbonisation policy in the power sector.

The £450m boiler upgrade scheme has a limited effect in ensuring heat pumps are more widely adopted. Uptake is significantly increased when other major economies decarbonise, as a result of costs being driven down from learning by doing effects, but to achieve the full decarbonisation of the household heating sector a phase-out of all fossil fuel boilers is necessary. As a result of the increased efficiency of renewables and the reduction in heat demand due to building renovations that the Policy + scenario entails, as well as the phase-out of fossil fuel boilers, consumer electricity and gas demand falls significantly. These savings mean that, compared to the baseline, consumers have money available to spend on other goods and services, which stimulates demand in other areas of the UK economy.

Consumers also benefit from lower private passenger transport costs due to the increased uptake of electric vehicles (EVs) in all scenarios, driven by the phase out of cars which run on fossil fuels and the falling purchase and running costs of EVs.

Total employment increases in all scenarios, predominantly due to the increased household consumption that the energy savings enable. The services sector has the largest employment gain in all scenarios, as energy-related consumer expenditure is lower, and spending is reallocated towards in particular consumer services such as retailing, hotels and catering. There is a substantial increase in employment in the transport services sector following similar consumer expenditure increases in the industry. There is a smaller but non-negligible decrease in the mining and utilities sector which is mainly offset by higher employment in the electricity sector in the Policy + scenarios.

When labour productivity in the electricity industry is defined as value added at factor costs in real terms divided by industry employment, the more employment-intensive nature of renewables causes labour productivity to fall in the short-run. However, as the shift towards renewables reduces more substantially intermediate demand for fossil fuels, value added per unit of output increases, with labour productivity eventually moving above baseline levels even in the less ambitious Policy scenario.

Looking at the economy as a whole, within-sector productivity affects are generally positive, and more positive in the Policy + scenarios. Agriculture for instance sees productivity increase by up to 2.4% above baseline levels, likely due to economies of scale brought about by slight increases (c2%) in consumer expenditure on food. However, the compositional shifts in employment (i.e. greater employment gains in some sectors than others, as part of the net increase in UK-wide employment) lead to an increase in the representation of lower-productivity sectors in the economy overall in the Policy + scenarios (e.g., services), outweighing within-sector effects and overall reducing economy-wide productivity (while increasing the overall size of the economy).

Decarbonisation has a negative effect on the trade balance, as imports in the machinery and electrical equipment sector increase significantly due to the need to import key components of low-carbon technologies. Nevertheless, the larger negative change in balance of trade in the Policy + scenarios in the long term has less of an influence on GDP than the long-term increase in consumption, so the overall GDP effects remain positive in most scenarios. Full decarbonisation of household heating and other cost-saving measures are key in this area, as these reduce costs faced by households and facilitate increased consumer spending on other goods and services with greater domestic content, leading to positive multiplier effects.

UK-wide CO2 emissions are reduced by up to 50% compared to the current day in the Policy scenario, and 66% in the Policy + scenario, by 2050, so it is clear that the decarbonisation of household heating, private passenger road transport and power generation allow for a significant reduction in emissions. To close the gap and reach net zero, decarbonisation of other energy users such as the manufacturing and aviation industries is required.

This study highlights how immature and emerging technologies have the potential to lead to productivity benefits for the UK economy through their greater efficiency and lower costs. However, realising the full potential of these effects hinges on savings being spent in productive sectors, and highlights the importance of innovation throughout the UK economy, with new products and services as well as new industries likely playing an important role.

1 Introduction

1.1 Motivation for the project

Removing greenhouse gas emissions (a 'zero-carbon transition') from the UK economy involves substantial changes to the economy. These will include both the structure and the technologies used; impacts will therefore be seen at both the micro (within firms, and within economic sectors) and macro level. The deployment of new technologies will change how specific sectors operate – notably, shifting from the combustion of fossil fuels to direct use of electricity offers the potential for substantial efficiency gains in the use of energy – while also changing the costs of outputs, leading to impacts which reverberate through supply chains and household budgets.

In 2020, the Climate Change Committee calculated that the UK zero-carbon transition will require substantial increases in upfront capital investments (CAPEX) in low-carbon electricity, building retrofit, and electric vehicles plus recharging infrastructure, but that operational cost savings (due to cheaper electricity, lower motoring and building heating costs) will be greater than the additional capital investments required from the mid 2030s onwards (CCC 2020). This view is mirrored by the UK Treasury.

> The transition to net zero will create new opportunities for economic growth and job creation across the country. The demand for low-carbon goods and services will encourage new industries to emerge, with the potential to boost investment levels and productivity growth.
>
> (HM Treasury 2020)

Renewable technologies are not dependent on a continuous flow of fossil fuels as inputs. As such, variable costs for technologies such as wind and solar power are eliminated, leaving only the cost of up-front investment and the cost of fixed operation and maintenance (Steckel and Hirth 2016). Cost reductions from learning-by-doing have the potential to further reduce these components, making renewable energy cheaper, cleaner, and more productive.

The potential productivity gains in the power sector are therefore driven by large reductions in intermediate demand (for fossil fuels), as well as the increased efficiency of technologies - specifically reduced CAPEX and lower non-fuel components of OPEX. For technologies which rely on electricity as an input, such as heat pumps and electric vehicles, increased energy efficiency and reduced electricity prices also have the potential to lead to economic gains.

In the wider economy, a reduced reliance on imports due to transitioning away from fossil fuels has the potential to further boost the economy.

In order to explore the economic effects of zero-carbon transitions in the UK, we simulate UK decarbonisation scenarios in E3ME, a global macro-econometric simulation model. E3ME is integrated with bottom-up evolutionary simulations of technological diffusion, implemented in FTT (Future Technology Transformation) models, which allow the impact of different decarbonisation pathways both within individual sectors, and across the economy as a whole, to be compared.

We examine policies which drive technological change in three key sectors: power generation, household heating, and private passenger transport. The analysis then explores how these policies affect productivity within the affected sectors in a holistic manner, as well as at the whole-economy level.

1.2 Defining productivity

In a macroeconomic framework such as the E3ME-FTT model, it is possible to see the impact of the policy scenarios on the traditional measures of labour productivity – value added per employed person. However, this framework combines within-sector changes with broader impacts on the economy (for example, rebound effects mean that consumers spend any money saved on energy on other goods and services), which can have contrasting impacts on economy-wide labour productivity.

As such, the analysis starts with a consideration of sector-specific dynamics. To do this, we look at conventional productivity measures (value added per person directly employed in a given sector) within sectors, as well as alternative measures of productivity or efficiency, including;

- Average reductions in the levelised cost of household heating
- Energy efficiency savings (percentage change in consumer expenditure on electricity and gas)
- Average reductions in the levelised cost of private passenger transport.

These measures can provide indications of more cost efficient consumer spending, achieving the same level of use of energy but at a lower cost freeing up consumer spending for other goods and services, as a result of the take-up of new technologies.

As the FTT models for heat and mobility are consumer facing, structural changes in manufacturing and employment related to the uptake of heat pumps and electric vehicles are not explicitly captured, as they are in the FTT model of the power sector (FTT: Power). However, changes in consumer demand will result in changes in the output of different industries within E3ME.

In order to assess the wider implications for the UK economy, alongside economy-wide productivity we also examine changes in imports and exports, GDP, fuel use and fuel prices, and emissions.

The conceptual framework

Figure 1.1 shows how the shift to low carbon technologies and the reduced use of fossil fuels can lead to changes in the UK economy. The figure splits these impacts into those on the supply side (the top half of the figure) and those on demand (the bottom half).

Starting on the supply side, the impacts which arise from the deployment of nascent low carbon technologies can be characterised as;

- Through learning by doing effects, the cost of these technologies falls (noting that this is a largely global, rather than UK dynamic – i.e. that cost reductions depend on global deployments, not just those in the UK)
- Looking specifically within the power sector, the cost of renewable technologies will continue to fall as these mature, and will (if they are

not already) provide cheaper electricity into the economy than the status quo fossil fuel-focussed grid

- Electric technologies (such as electric heat pumps and electric vehicles) are typically more energy efficient than their fossil fuel equivalents, meaning that fewer inputs are required to achieve the same output
- Within the affected sectors, the cost of production inputs (capital, energy) falls, and the relative productivity of labour therefore increases.

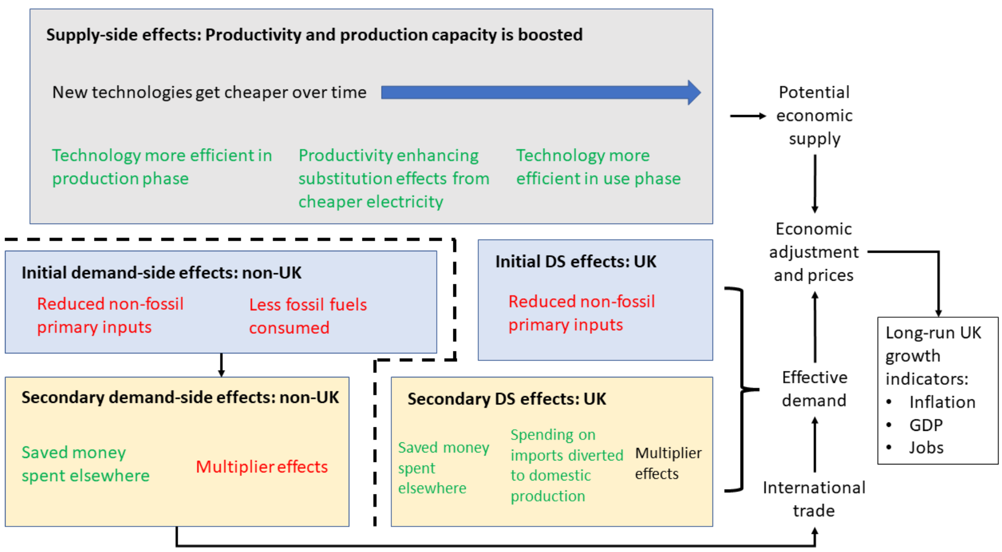
On the demand side;

- Reduced consumer demand for fossil fuels, as a result of the shift towards electricity-based technologies (such as heat pumps and electric vehicles), reduces imports (thereby boosting GDP), and an increase in demand for (largely domestically generated) electricity
- Lower costs of goods and services increases real consumer spending power, and thereby creates additional demand for (primarily) consumer goods and services and their supply chains
- Induced multiplier effects linked to these two demand-side impacts; whereby greater demand for electricity and consumer goods and services creates additional employment in these sectors, leading to higher aggregate wages across the economy and therefore higher real consumer spending in a virtuous cycle.

Note that while the supply side impacts would be expected to have a positive impact on productivity (both within sector and at the economy-wide level), the demand-side impacts have the potential to *reduce* economy-wide productivity; since additional jobs and output are especially being created in consumer services. Historically, these jobs have had low rates of productivity (e.g. the hotels and catering sector), so creating additional economic activity in these sectors can reduce the *average* level of labour productivity across the economy, even though in aggregate the economy is larger. This is why it is important to consider within-sector productivity, as well as aggregate productivity, in the analysis.

We assess whether each of these mechanisms have been captured in the modelling and the impact they have on the results in Section 3.

Figure 1.1: Schematic displaying how decarbonisation can lead to increases in long run growth and productivity



1.3 The E3ME macroeconomic model

E3ME is a computer-based model of the world's economic and energy systems, and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used for policy assessment, forecasting and research purposes.

E3ME has been designed to assess the impacts of climate change mitigation policy on the economy and the labour market. The basic model structure links the economy to the energy system to ensure consistency between economic and physical indicators.

E3ME can provide comprehensive analysis of policies in each of its 71 regions:

- direct impacts, for example reduction in energy demand and emissions, fuel switching and renewable energy
- secondary effects, for example on fuel suppliers, energy prices and competitiveness impacts
- rebound effects of energy and materials consumption from lower prices, spending on energy or other economic activities
- overall macroeconomic impacts: on jobs and the economy at a high level of sectoral detail and (where data allows) household income group.

Theoretical underpinnings

E3ME is designed primarily as an empirical tool. It draws on the Cambridge (UK) tradition of macroeconomics, supplemented by more recent applications of complexity theory to economics. The key properties of the model include recognition of fundamental uncertainty, possible non-rational behaviour and market structures determined by the available data.

The model has been shaped to meet the needs of policy makers, both in terms of the types of scenarios assessed (e.g. a wide range of market-based and regulatory climate policies) and output indicators (e.g. detailed employment, unemployment and measures of inequality) (Mercure, Pollitt, et al. 2018) (Mercure, Knobloch, et al. 2019).

E3ME is often compared to Computable General Equilibrium (CGE) models. In many ways the modelling approaches are similar; they are used to answer similar questions and use similar inputs and outputs. However, there are important underlying differences between the modelling approaches.

In a typical CGE framework, optimising behaviour is assumed, output is determined by supply-side constraints and prices adjust fully so that all the available capacity is used. In E3ME the determination of output comes from the demand side of the economy, and it is possible to have spare economic capacity. It is not assumed that prices always adjust to market clearing levels.

These differences have important practical implications, because they mean that in E3ME, regulation and other policies could potentially lead to increases in output if they are able to draw upon the available spare economic capacity. The role of the financial sector is key[1] (Pollitt and Mercure 2018).

The econometric specification of E3ME gives the model a strong empirical grounding. E3ME uses a system of error correction, allowing short-term

[1] For more information on the E3ME model, including the model manual, please visit www.e3me.com.

dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis (e.g. in Covid-19 recovery).

Basic structure and data used

The structure of E3ME is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. The other econometrically estimated equations cover the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by region and by sector.

E3ME's historical database covers the period 1970-2019 and the model projects forward annually to 2050. Apart from the IEA energy balances and prices, the model's data is based entirely on freely available information from international sources and national statistical agencies. Gaps in the data are estimated using customised software algorithms.

The main dimensions of E3ME are:

- 71 regions – all major world economies, the EU27 and candidate countries plus other countries' economies grouped
- 70 industry sectors, based on standard international classifications
- 28 categories of household expenditure
- 25 different users of 12 different fuel types
- 24 power generation technologies
- 14 types of air-borne emission (where data are available) including the 6 GHG's monitored under the Kyoto Protocol.

Future Technology Transformations

E3ME incorporates bottom-up technology models of four major energy-using sectors (power, personal transportation, steel, and household heating). These models follow the 'S-shaped' diffusion paths of new technologies as they gain market acceptance and incorporate cost reductions through learning rates.

These models are known as FTTs, where FTT stands for Future Technology Transformations. The models estimate the market share of different technologies within the relevant sector; for example, in the power sector, the market shares are estimated for 24 different power generation technologies every year.

The technology mixes in a given year are calculated by simulating investor preferences based on the *levelised cost* of a technology. The characteristic 'S-shaped' diffusion paths are the outcome of this simulation.

Cost reductions due to global learning directly affect both the investment cost and operation and maintenance costs of technologies, allowing the costs to fall as the uptake of the corresponding technology increases. These cost reductions can then lead to changes in investor decision making; investor decisions are probabilistic, and depend on the perceived differences in costs between technologies.

FTT is unique in that it is an evolutionary model of technological change, which allows the technology mix of a particular sector to change slowly with time, and react dynamically to policy changes. It is not cost optimising, and although investors make decisions by comparing costs, they are not perfectly rational agents, and therefore only a subset on investors will make the choice perceived as ‘most rational’[2].

This report includes analysis of policies implemented in FTT: Transport, FTT: Heat and FTT: Power. Changes in the technology mixes for power, personal transportation, and household heating can have significant effects on fuel demand in these sectors, which is a key feedback to E3ME in all FTT models. Currently, feedbacks from FTT: Transport are restricted to fuel only.

FTT: Heat includes feedbacks to consumer expenditure, which are impacted by changes in upfront investment costs for household heating.

FTT: Power has the most advanced feedbacks, which include direct employment in the power sector, electricity prices, and investment at a sectoral level.

All three models will respond to changing fuel prices, which are fed in from E3ME.

1.4 Aims of the work

The motivation for the modelling is to analyse the potential productivity effects of low carbon transitions in the UK based on a wide range of economic impacts, using E3ME-FTT.

Research and development

In order to ensure the productivity impacts of the zero-carbon transition are captured, the first stage of this work involved adding new developments to FTT: Power which improve the feedbacks to the E3ME model and hence allow the productivity effects of the transition to be captured in greater detail:

- Improving the learning rates for operation and maintenance (O&M) and applying the reduction in the cost of O&M to the employment intensity of the relevant power generation technologies.
- Adjusting learning rates applied to capital costs so that distinct learning rates are applied to the portion of investment which goes to ‘hard’ costs, or more generally, equipment, and the portion of investment which goes to ‘soft’ costs, which can include covering project design and installation, permitting, incentive access, financing, and profit margins.
- Improving the investment feedbacks from E3ME, so the sectors benefitting from investment evolve with the change in the balance between hard and soft costs.

Scenario analysis using E3ME-FTT

The second stage of the modelling involved designing and running bespoke decarbonisation scenarios for the UK. The policy choices in these scenarios feature prominently in the 2020 Ten Point Plan for a Green Industrial Revolution and the 2021 Energy Security Strategy and impact four key technologies: offshore wind power generation, solar PV power generation, electric vehicles for private passenger use, and heat pumps for domestic dwellings.

[2] For more information on the FTT models please visit https://www.e3me.com/what/ftt/.

1.5 Structure of this report

This report sets out the methodology and results of the modelling work, and is structured as follows:

- Chapter 2: Methodology
  - 2.1 Scenario design provides information on the benchmark scenario used for comparison of the simulation results, detailed information on the policy documents used for scenario design, and information on how policies are implemented in E3ME-FTT.
  - 2.2 Modelling assumptions explains the implicit and explicit assumptions made during this modelling research project, and the consequent impact on the results. It will also provide information on the limitations of the modelling.
  - 2.3 Research and development explains the changes made to E3ME-FTT and provides sources which informed the new developments and changes to data.
- Chapter 3: The impact of decarbonisation on productivity
  - 3.1 Scenario design sets out the four scenarios which are explored
  - 3.2 Assessing the conceptual framework explains how the results will be interpreted relative to the framework set out in section 1.21.2
  - 3.3 Sectoral supply-side impacts are presented and discussed.
  - 3.4 Demand-side impacts are presented and discussed, linking as relevant back to the supply side impacts.
  - 3.5 Energy and environmental outcomes at a macro level are presented and discussed.
  - 3.6 Macro impacts explains the macroeconomic results arising from the sectoral changes in supply and demand.
- Section 4: Conclusions summarises the main findings of this report.

2 Methodology

2.1 Scenario design

The four scenarios we explore in this work examine current and more ambitious plans for UK decarbonisation, based on key policies featured in the 2020 Ten Point Plan (TPP) and the 2021 Energy Security Strategy (ESS). Two different levels of domestic policy ambition are explored, under two variants; i) in a world which does not decarbonise (beyond current plans), and ii) where other major economies decarbonise at the same time. The four scenarios are therefore:

1) *Current UK Policy:* this scenario captures key polices featured in the TPP and the ESS relevant to power, household heating, and private passenger transport.

2) *Expanded UK Policy:* this scenario features additional policies aiming to accelerate UK decarbonisation, such as a phase out of the use of gas for power generation and household heating, as well as additional support for improving the energy efficiency of UK homes.

3) *Current UK Policy and decarbonisation of major economies:* this scenario implements all policies in the *Current UK Policy* scenario, while also implementing an adapted version of policies contained within CE's global 1.5°C scenario for the US, China, and the EU.

4) *Expanded UK Policy and decarbonisation of major economies:* this scenario implements all policies in the *Expanded UK Policy* scenario, while also implementing an adapted version of policies contained within CE's 1.5°C scenario for the US, China, and the EU.

The impacts in all scenarios are measured relative to the E3ME baseline which reflects policy up to the end of E3ME's historical period only and does not account for the UK Energy Security Strategy (ESS) or the Ten Point Plan. Further details about the E3ME baseline and what is included or assumed can be found in Section 2.2.

Descriptions of the policies included in the different scenarios can be found in Table 1.

Table 1: Scenario design

	FTT	Policy measures
Current UK policy scenario	Power	Coal phase out from 2035. 50GW offshore wind by 2030. Reach up to 24GW by 2050 for nuclear. Up to 70GW of solar by 2035.
	Transport	ICE new sales phase out from 2030. Hybrids new sales phase out from 2035.
	Heat	Support 600,000 heat pump installations a year by 2028 via the £450m boiler upgrade scheme, which supplies £5,000 grants. Adding £1.75bn to Home Upgrade Grant and Social Housing Decarbonisation Fund. Invest £1.425bn in Public Sector Decarbonisation Scheme. VAT cuts for insulation and heat pumps. Exogenous capacity increases to mimic heat pumps in social housing.
Expanded UK policy scenario	Power	Phase out of gas turbines for power generation from 2035.
	Heat	Phase out all new sales of gas and other fossil fuel boilers from 2030. Expand social housing decarbonisation by an extra £1.75bn. Greater exogenous capacity increases to mimic heat pumps in social housing.
Decarbonisation of major economies	Adapted 1.5°C scenario (inc. all FTT models)	The USA, China, and the EU decarbonise at the same time as the UK, following an adapted version of CE’s 1.5°C scenario. A description of this scenario can be found in the appendix.

2.2 Modelling assumptions and notes on implementation

Financing renewable energy

The UK government has set out capacity targets for solar and wind power generation; however, there is limited information available about how these targets will be met, in terms of precise policies to be implemented. We assume these targets are mandated for the purpose of the modelling, and investors are forced to meet the capacity targets. This means all investment is privately funded and no government subsidies are in place. The cost of borrowing within FTT is accounted for in the levelised cost calculations using assumed discount rates. These rates are exogenous and will not reflect recent changes to the cost of borrowing.

Subsidies and taxes

Subsidies and taxes are subject to revenue recycling, which ensures that there is no net change in government spending in the scenarios compared to baseline, by increasing or decreasing taxes accordingly. Taxes and subsidies applied to particular fuels or technologies will influence investor decisions in FTT. Subsidies aimed at improving the energy efficiency of buildings have no direct effect on investor decisions in FTT: Heat, and are introduced in E3ME.

Feedbacks from FTT

Changes in direct employment in the power sector can be captured, as well as changes through manufacturing supply chains where investment in the power sector feeds back to due to a changing technology mix. However, FTT: Heat and FTT: Transport capture consumer investment decisions, and at this time there are no feedbacks to industry. Changes in consumer expenditure are captured for FTT: Heat, but not for FTT: Transport. Employment and investment changes due to switches to heat pumps or EVs are therefore not able to be fully captured.

Electricity pricing

Electricity prices in FTT: Power are determined using a weighted average of the Levelised Cost of Electricity (LCOE) for each technology, which takes into account existing capacity and new additions, and the corresponding capital and operating costs. Recent global increases in oil and gas prices are accounted for in E3ME and affect fuel costs within all parts of the modelling.

Limiting the uptake of solar

The UK Government's plausible 2050 capacity range for solar is 15-120 GW (BEIS 2020). The uptake of solar in the endogenous (i.e. unconstrained) E3ME baseline goes beyond this, and likely reflects an extremely ambitious scenario for the UK. Due to this, the capacity of solar is capped in the baseline and all scenarios to 150GW.

E3ME Baseline

The baseline represents a business-as-usual trajectory in which policies that have been implemented in the past continue to have an effect in future years, however, no additional policy (including stated ambitions and targets and recently announced policies) is introduced.

This version of the baseline was last recalibrated in May 2023. The last year of historical data is 2019 and the first year of simulation is 2022 (with assumptions made for 2019-20 to capture Covid impacts as well as an update to energy prices up to 2022).

The baseline was calibrated to historical data and future growth rates implied by external projections from the following sources:

Economic and demographic indicators

- Long-term EU trends from DG EcFin Ageing report 2021
- Long-term non-EU trends from IEA WEO 2022 Stated Policies scenario

- Short-term assumptions for Covid impacts and recovery from IMF, World Bank, ILO (as of January 2021) and European Commission Autumn 2020 forecast

Final energy demand

- Long-term trends from IEA WEO 2022 Stated Policies scenario
- Short-term assumptions for Covid impacts and recovery from IEA WEO 2022
- Global non-energy commodity prices – World Bank Commodity Price forecasts (2020)
- Global energy commodity prices – IEA WEO 2022 Fossil Fuel Prices under the Stated Policies scenario
- Carbon pricing - EU ETS for power, industry, and aviation only

The policy context is implicitly assumed in the baseline (rather than explicitly considered and modelled). Individual policies are not taken into account, instead they are assumed according to documentation of the external scenario projections used to inform the E3ME baseline, and the direct policy impacts are taken as given.

Some examples of EU policies that are assumed implicitly in the baseline are:

- EU ETS on currently covered sectors in accordance with the 2022 Climate and Energy Package
- Industrial Emissions Directive
- Energy Performance of Buildings Directive 2010
- EcoDesign and Energy Labelling Directive
- Euro 6 emissions and fuel sulphur standards
- Support for renewables
- Biofuel blending mandates and support

An exception to the baseline calibration is FTT sectors (power generation, steel, passenger car transport and household heating) which are endogenous. The trajectories for these sectors and their associated emissions pathways are driven by endogenous resource cost curves and learning-by-doing effects which are independent of new policy implementation.

The main implication of carrying forward the impacts of past policies into the future is that an energy and technology transition does take place in the baseline, however at a much slower pace than needed to achieve stated ambitions (including most NDCs and COP targets, as well as more ambitious net zero and temperature targets).

The baseline is consistent with global warming of around 3°C by 2100.

2.3 Research and Development

Learning and employment in the power sector

Projections of the reduction in operational expenditure (OPEX) costs are vital for analysing productivity in the power sector, as they will not only provide a more accurate depiction of the levelised cost of electricity, but also a more accurate depiction of employment costs and the potential for job creation in the transition.

The potential creation of jobs in the energy sector has been widely discussed in the literature, and direct employment is expected to increase (Ram, et al. 2022, IRENA and ILO 2022) however, the operations and maintenance (O&M) costs of renewable energy technologies are also falling (Steffen et al. 2020). The balance of these two effects will be key for assessing labour productivity in the power sector.

Learning in the power sector is applied to investment costs using the standard formula for experience curves (J.-F. Mercure, FTT: Power : A global model of the power sector with induced technological change and natural resource depletion 2012):

$$C_i(t) = C_i(t_0)\left(\frac{W_i(t)}{W_i(t_0)}\right)^{b_i},$$

where C_i is the cost of CAPEX, W_i is the cumulative number of units produced since an arbitrary start time t_0, and b_i is the (negative) learning exponent. FTT is solved in discrete time steps, and therefore we can approximate the change in cost for a small time step by taking the time derivative of the above and discretising:

$$\frac{dC_i(t)}{dt} = b_i \frac{C_i(t)}{W_i(t)} \frac{dW_i(t)}{dt},$$

$$C_i(t_n) = C_i(t_{n-1}) + b_i \Delta W_i \frac{C_i(t_n)}{W_i(t_n)}.$$

For operation and maintenance costs, the same formula can be applied, however with distinct learning exponents derived from observed reductions in O&M costs.

With each doubling of cumulative experience, cost reductions are found to be between 9.2%-12.8% for onshore wind, and between 15.7%-18.2% for solar photovoltaic (PV) (Steffen et al. 2020).

This cost reduction (known as the experience rate, ER) is linked to the learning exponent using the following formula:

$$ER = 1 - 2^b.$$

Taking the lower bounds for ER from the literature (Steffen et al. 2020), the learning exponents for solar PV and onshore wind can be explicitly calculated. For other technologies, the appropriate learning exponents for O&M are inferred from the learning exponents for investment, based on the ratio of the O&M exponent to the investment exponent. The investment exponents are taken from FTT: Power (J.-F. Mercure, FTT: Power : A global model of the power sector with induced technological change and natural resource depletion 2012):

Table 2: O&M learning exponents for FTT: Power

Technology	Investment Learning Exponents	O&M Learning Exponents
Nuclear	-0.086	-0.063
Oil	-0.014	-0.011
Coal	-0.044	-0.032
Coal + CCS	-0.074	-0.054
IGCC	-0.044	-0.032
IGCC + CCS	-0.074	-0.054
CCGT	-0.059	-0.043
CCGT + CCS	-0.074	-0.054
Solid Biomass	-0.074	-0.054
S Biomass CCS	-0.105	-0.077
BIGCC	-0.074	-0.054
BIGCC + CCS	-0.105	-0.077
Biogas	-0.074	-0.054
Biogas + CCS	-0.105	-0.077
Tidal	-0.020	-0.015
Large Hydro	-0.020	-0.015
Onshore	-0.194	-0.139
Offshore	-0.194	-0.139
Solar PV	-0.319	-0.246
CSP	-0.194	-0.143
Geothermal	-0.074	-0.054
Wave	-0.218	-0.160

Fuel Cells	-0.234	-0.173
CHP	-0.044	-0.032

These new learning rates allow us to better capture the reduction in O&M costs in FTT: Power and have been used for all scenarios presented in this report.

As an additional development, we also applied learning to the employment intensities within FTT: Power, which in turn affects the employment feedbacks to E3ME.

Direct employment in the power sector is based on pre-existing employment rates[3], which supply the number of direct employees required per GW of installed capacity for each type of power generation technology:

Table 3: Employment rates per GW of installed capacity for FTT: Power[3]

Technology	Employees per GW
Fossil fuel technologies	90
Hydro (excl. pumped storage)	510
Nuclear	300
Solar	300
Wind	200
Geothermal	400
Biomass	1500
Tidal and wave	320

Learning is applied to all coefficients, excluding fossil fuel technologies, which allows employment in the power sector to accurately track reductions in O&M costs.

The effect of learning on the different components of investment

For renewable technologies, CAPEX governs the majority of the LCOE due to the low operation and maintenance costs driven by the elimination of fossil fuels (Steckel and Hirth 2016). In turn, a significant portion of these costs are governed by balance-of-system (BoS) costs. For onshore wind power plants, BoS costs account for approximately 30% of costs. For solar power, balance-of-system costs are in general 50% or more of the overall project costs (IRENA and ILO 2022). The components of BoS costs for solar are known to have different dynamics compared to the learning-driven dynamics of PV modules, and include both hard costs (such as cabling, monitoring and safety systems) and soft costs (such as installation, financing, profit margins). Elshurafa et al. (2018) report an average global learning rate of 11% for solar BoS costs (Elshurafa, et al. 2018). Although learning rates for individual world regions vary significantly, data is not widely available for all regions, and as such, global average learning rates for all technologies are currently used in

[3] Employment rates are based on analysis by Cambridge Econometrics and IRENA

FTT: Power. To maintain consistency, we will also use the global average learning rate for BoS costs.

Similar to solar PV, cost reductions in wind power are driven by technological improvements, and not a falling cost of installation (Glenk, Meier and Reichelstein 2021). This diversity in learning between the cost of equipment and installation will significantly change the proportion of CAPEX which goes to the installation of renewables over time. This will mean that over time as learning develops, more of the investment value in renewable technologies will pass to sectors such as construction and professional services responsible for installation, with a smaller proportion of costs being passed through to manufacturing industries which develops the equipment need for renewable technologies.

As learning rates are unavailable for BoS costs for most technologies, we adjust the learning rate for solar power BoS costs by scaling it based on the ratio of the overall learning rate for each technology and the overall learning rate for solar power:

$$b_i^s = \frac{b_i}{b_{solar}} \, b_{solar}^s$$

The ‘hard’ learning rate can then be calculated based on the assumption that the overall learning rate of the CAPEX for each technology must be maintained. The investment cost at time t is given by:

$$C_i(t_n) = C_i(t_{n-1})\left(1 + b_i \frac{\Delta W_i}{W_i(t_{n-1})}\right).$$

In order for the overall change in cost to be preserved when different learning rates, the following must remain true:

$$b_i C_i(t_{n-1}) = b_i^s C_i^s(t_{n-1}) + b_i^h C_i^h(t_{n-1})$$

This can then be rearranged in order to find the ‘hard’ learning rate:

$$b_i^h = \frac{b_i - \epsilon_{in}\, b_i^s}{\epsilon_{eq}}$$

Learning can then be applied separately to the equipment share of CAPEX, and the installation share of CAPEX.

After learning has been applied, the shares of hard and soft costs within CAPEX will have changed, and must be recalculated. This then affects how investment is fed back to E3ME, with ‘hard’ costs fed to manufacturing industries, and ‘soft’ costs fed to industries associated with installation, such as construction and professional services.

Although there may be physical components associated with installation costs, such as cables, we assume these are purchased by the sectors tasked with installation.

This development allows us to capture more accurately how technological change in the power sector affects other sectors in the UK economy. However, these developments rely on global average learning rates being a reasonable approximation. Given most of our analysis is completed for the UK, for which cost reductions are not far from the global average (Elshurafa, et al. 2018), this approximation is appropriate, however care should be taken when analysing results in other world regions.

Furthermore, our analysis relies on the scaling of the BoS learning rates for all technologies based on the learning rates for solar power being a fair assumption. While the overall cost reductions are unchanged, this will affect the feedbacks to the wider economy. As cost reductions in wind power are also driven by the reduction of hard costs, the approximation may be reasonable. Fossil fuel technologies are no longer experiencing significant cost reductions, and therefore the impact of this development is unlikely to be significant in these cases.

3 The impact of decarbonisation on productivity

3.1 Scenario design

To assess the potential impact of decarbonisation on productivity in the UK, we examine four scenarios relative to the E3ME baseline scenario, which assumes no new policy interventions. We examine both UK domestic policy mixes in isolation (i.e. assuming the rest of world follows existing policies only), and in the context of decarbonisation of these other major economies. The policy mixes across the scenarios are summarised in Table 4 below.

Table 4 Summary of policies included in the different scenarios

Scenario	UK policy	US, China and EU policy
UK Policy	2020 Ten Point Plan + 2021 Energy Security Strategy	Current policies
UK Policy+	2020 TPP + 2021 ESS + gas phase out in power generation + gas phase out in household heating + support for household energy efficiency	Current policies
UK Policy w/ other major economies decarbonising	2020 Ten Point Plan + 2021 Energy Security Strategy	Policies consistent with 1.5°C
UK Policy+ with other major economies decarbonising	2020 TPP + 2021 ESS + gas phase out in power generation + gas phase out in household heating + support for household energy efficiency	Policies consistent with 1.5°C

3.2 Assessing the conceptual framework for economic impacts using the modelling results

In section 1.2, we set out a conceptual framework for understanding how the low carbon transition can be expected to impact upon the UK economy, and specifically upon productivity, both within sectors and at the aggregate level of the UK economy as a whole.

There is no simple way to link each of these individual dynamics to the final observed model results; since the E3ME-FTT model is an integrated model which solves simultaneously for both supply and demand, and for all parts of the economy; as such, we cannot isolate supply versus demand impacts, or direct versus indirect versus induced. Instead, our analysis in the rest of this chapter will use specific outcomes observed from the final model results to provide analysis of the extent to which the different channels can be observed in those results, and provide explanation and commentary on why these impacts occur in this fashion.

3.3 Sectoral supply-side impacts

The take-up of low carbon technologies

Figure 3.1 to Figure 3.5 show how the total power generated within the UK evolves over time in the baseline and each scenario.

Offshore wind uptake is increased for all scenarios, and is driven by the government mandate to build 50GW by 2030. The sharp rise in offshore wind power generation resulting from the rapid building of offshore wind farms required to meet this policy target is the reason for the sharp decline in fossil fuel use up to 2030. Once this target is no longer in place, the model suggests that gas (CCGT) generation will increase if not regulated. Note that solar power is regulated in all scenarios to not exceed 150GW of capacity to ensure a more realistic picture of UK power generation is achieved; the UK Government’s own plausible 2050 capacity range for solar is 15-120GW (BEIS 2020).

The Policy + scenarios see increased generation from onshore wind compared to all other scenarios, with the phase out of gas leaving a gap that onshore wind fills. When major economies decarbonise, we see an increased amount of offshore wind and solid biomass, however the differences between scenarios remain relatively small. While learning-by-doing effects are likely to be more pronounced when major economies decarbonise, leading to lower costs of low-carbon generation technologies, the impact of these are relatively small: solar remains the lowest cost option, and onshore wind the most expensive, in all scenarios, however when major economies decarbonise solar and offshore costs move closer to each other.

Figure 3.1 Electricity Generation by Technology (GWh/y) for the baseline scenario.

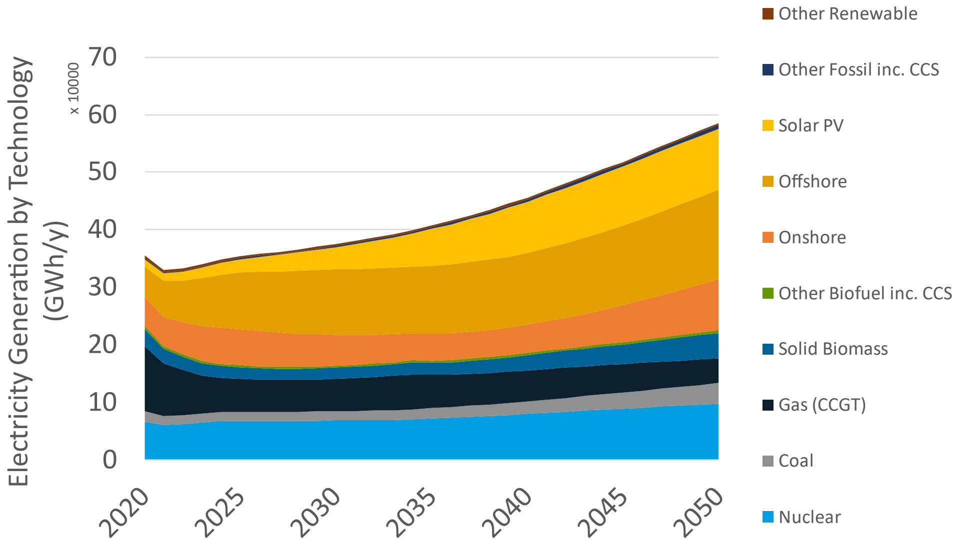


Figure 3.2 Electricity Generation by Technology (GWh/y) for the UK Policy scenario.

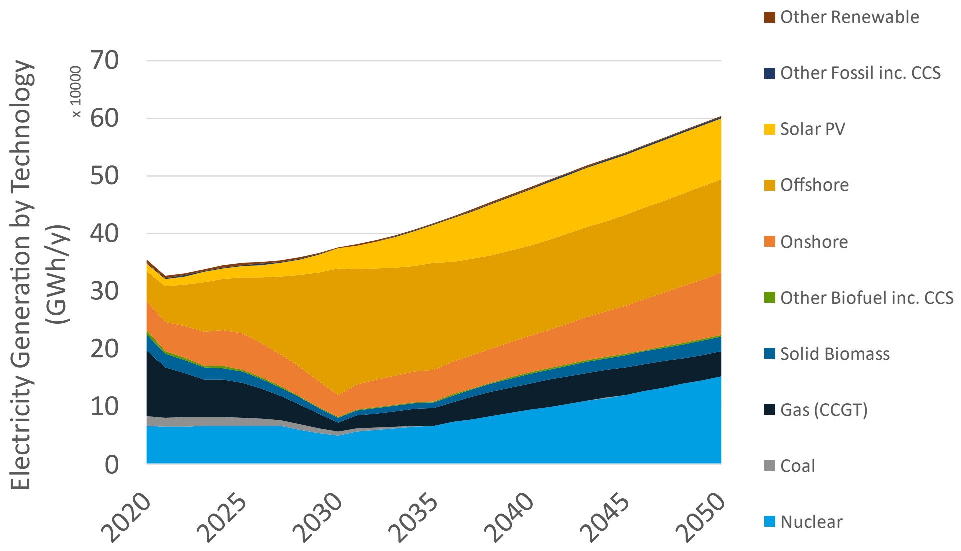


Figure 3.3 Electricity Generation by Technology (GWh/y) for the UK Policy scenario when major economies decarbonise.

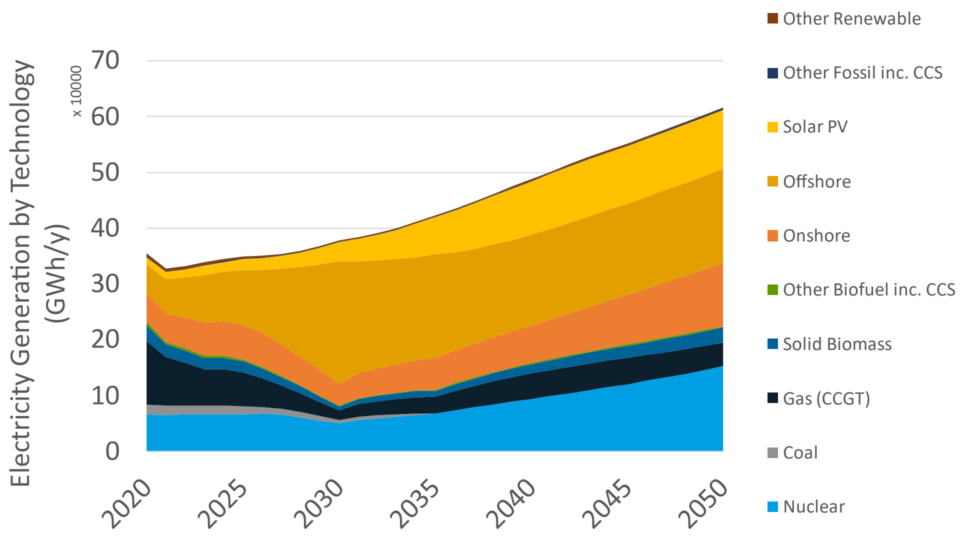


Figure 3.4 Electricity Generation by Technology (GWh/y) for the UK Policy + scenario.

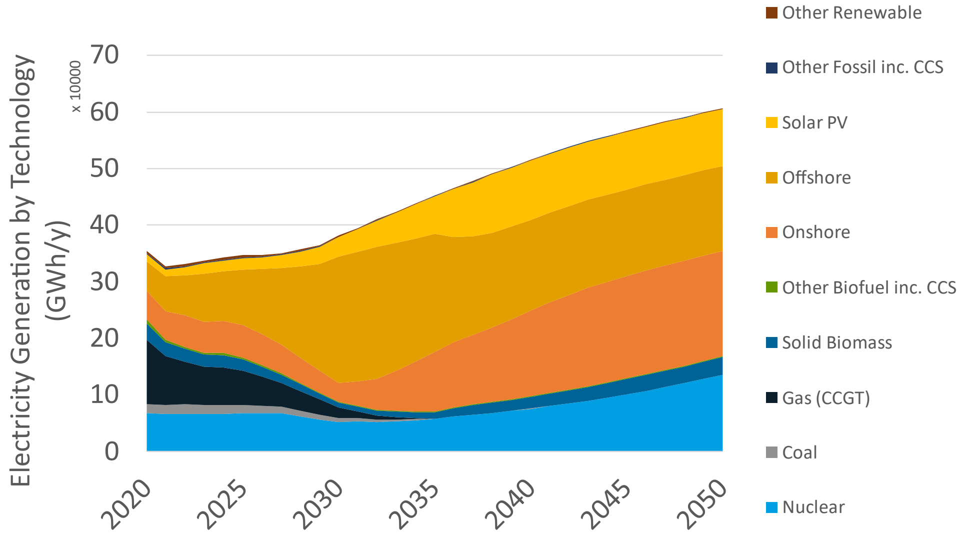


Figure 3.5 Electricity Generation by Technology (GWh/y) for the UK Policy + scenario when major economies decarbonise.

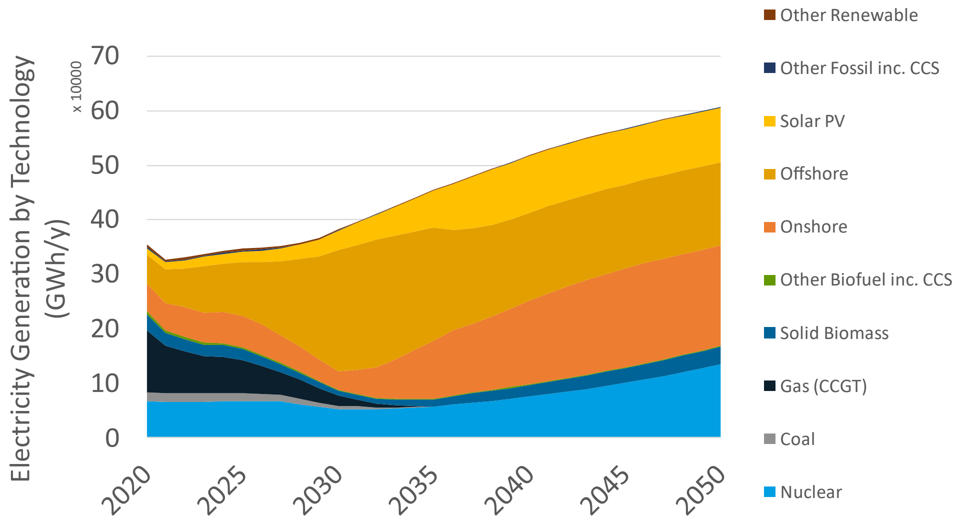


Figure 3.5 to Figure 3.9 show how the technology mix for household heating evolves over time for all scenarios. From comparing and we can see that the £450m boiler upgrade scheme has a limited effect in ensuring heat pumps are widely adopted, even with a kickstart to heat pump uptake from social housing decarbonisation. Heat pump uptake is significantly increased when other major economies decarbonise as a result of costs being driven down by learning, as seen in Figure 3.8. Nevertheless, the phase out of all fossil fuel boilers as seen in the Policy + scenarios ensures the household heating sector is fully decarbonised.

Figure 3.5 Useful Heat Demand by Technology (GWh/y) in the baseline

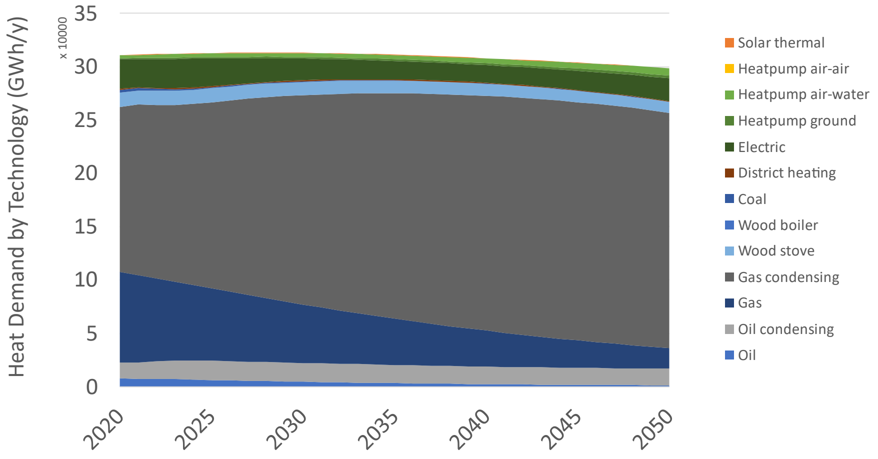


Figure 3.6 Useful Heat Demand by Technology (GWh/y) in the UK Policy scenario

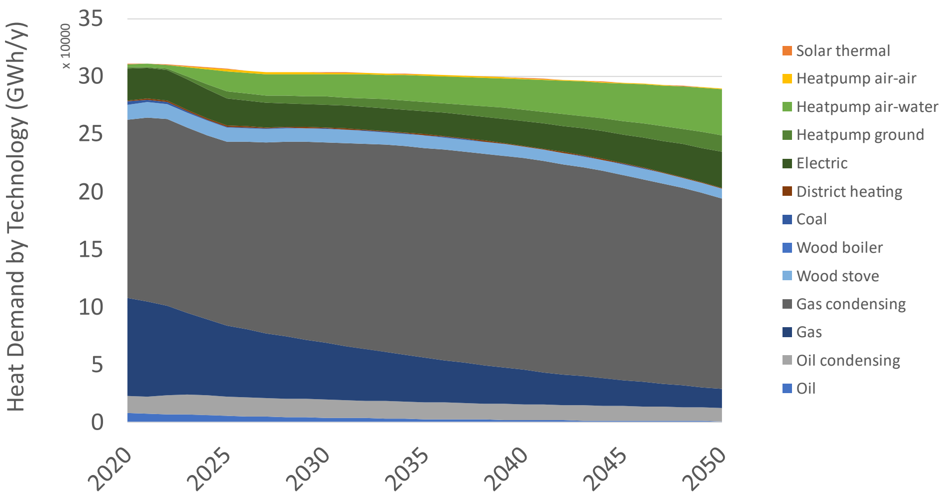


Figure 3.7 Useful Heat Demand by Technology (GWh/y) in the UK Policy + scenario

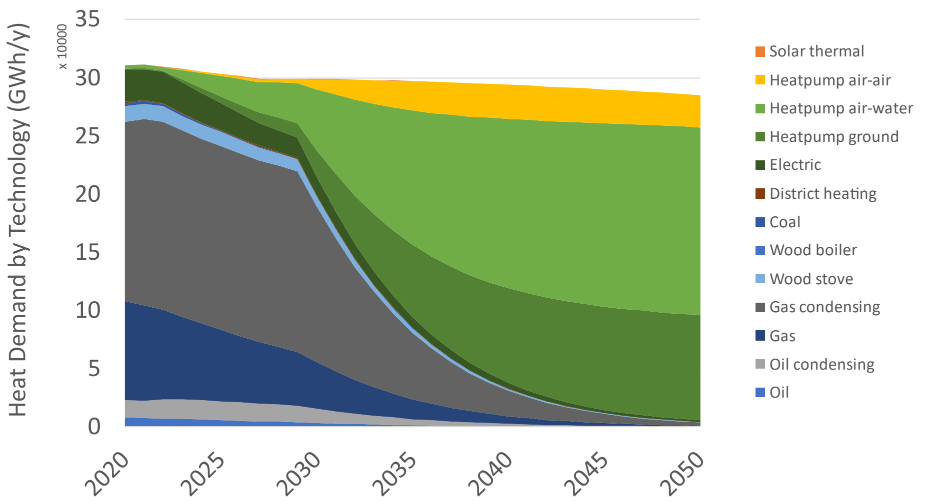


Figure 3.8 Useful Heat Demand by Technology (GWh/y) in the UK Policy when major economies decarbonise scenario

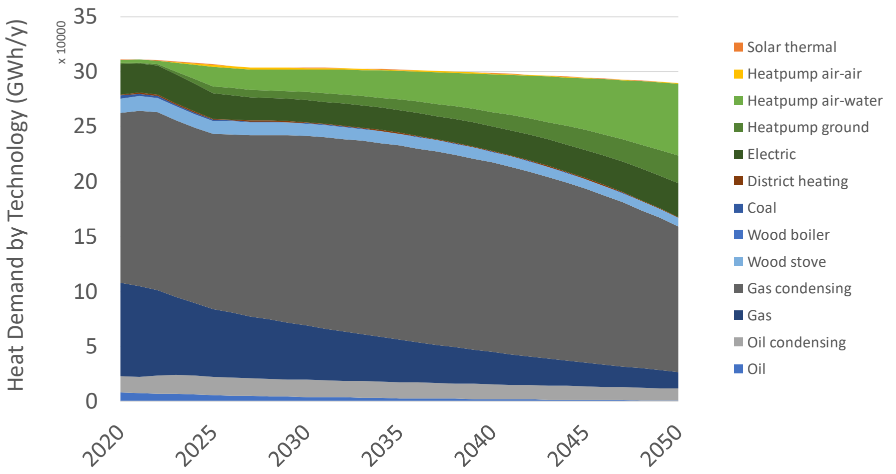
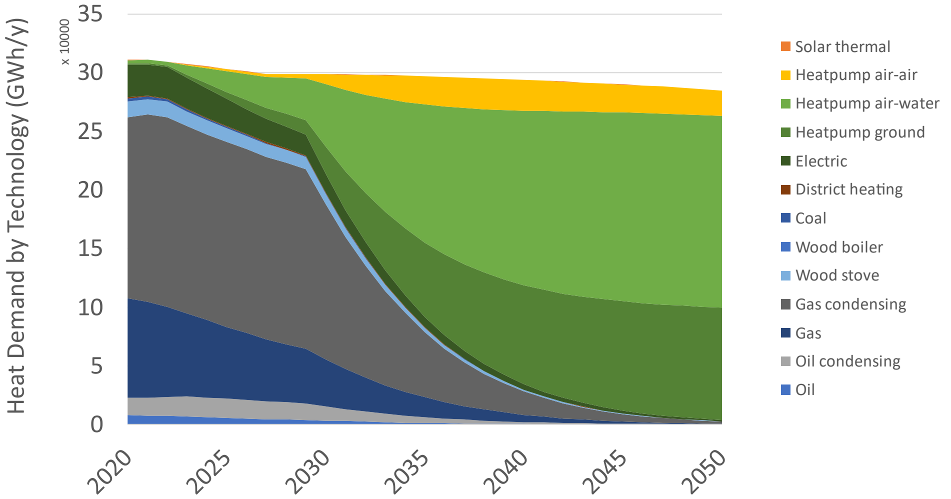


Figure 3.9 Useful Heat Demand by Technology (GWh/y) in the UK Policy + when major economies decarbonise scenario



Air-to-water heat pumps are expected to be the most popular in the UK, as they can provide both household heating and hot water (Energy Saving Trust n.d.). Ground source heat pumps are only viable for certain properties, and air-to-air heat pumps are not commonly found in larger homes (Energy Saving Trust n.d.).

The change in transport demand by technology can be seen in Figure 3.10 to Figure 3.12. As there is no difference between the Policy and Policy + scenarios for the transport sector, only the UK Policy and UK Policy with major economies decarbonising scenarios are displayed.

Figure 3.10 Private Road Transport Demand (million km/y) by technology in the baseline

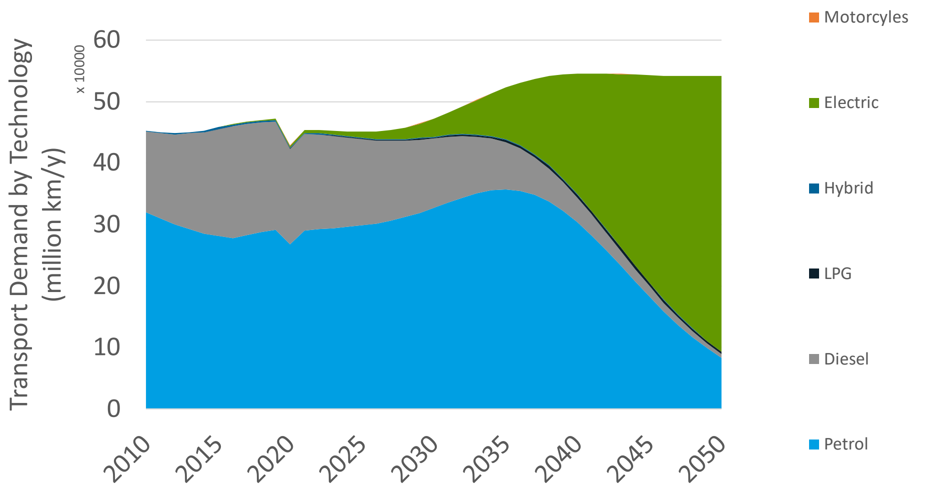


Figure 3.11 Private Road Transport Demand (million km/y) by technology in the UK Policy scenario

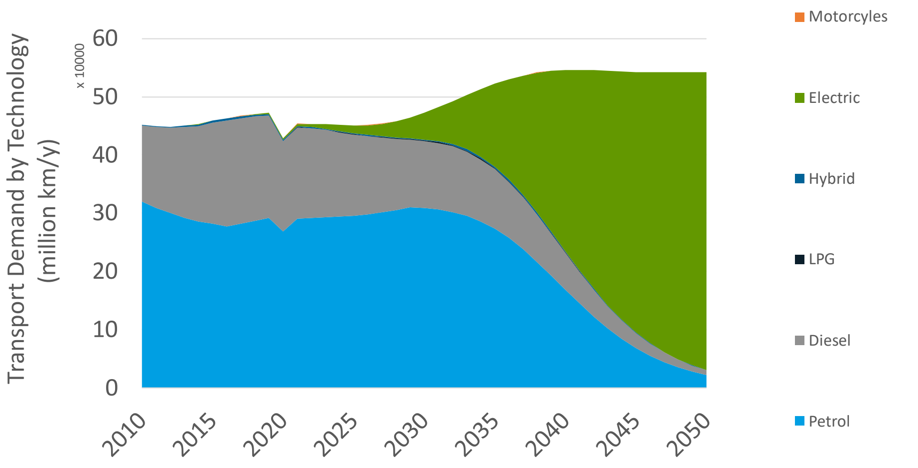
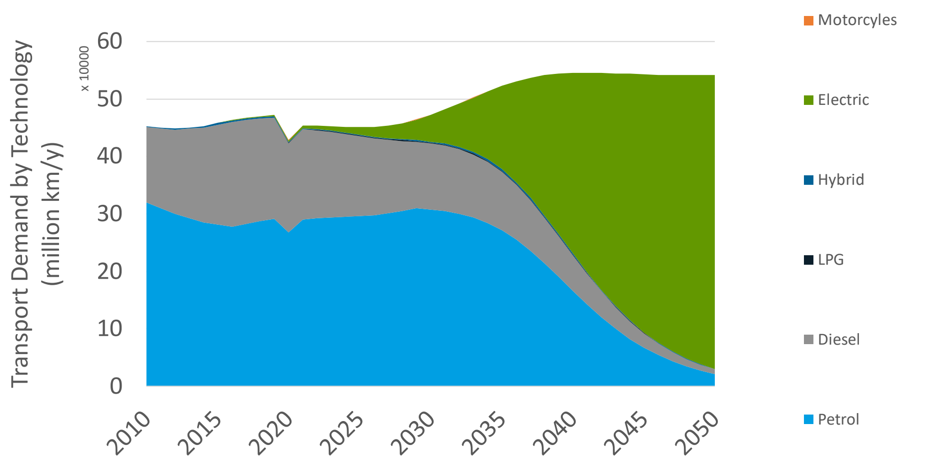


Figure 3.12 Private Road Transport Demand (million km/y) by technology in the UK Policy when major economies decarbonise scenario



Technology costs

Figure 3.13 shows how the levelised cost of different electricity-generating technologies differs in 2050 in each scenario, in terms of percentage changes from the baseline. Although the Policy + scenarios include greater learning-by-doing effects (and therefore lower levelized costs), when looking at the final levelized cost including grid integration costs, intermittent onshore and offshore wind actually end up being more expensive, as at higher levels of penetration the per-unit costs of storage are substantially higher. This is because storage costs do not increase linearly, with the amount of storage required being higher the greater proportion of intermittent generation there is on the grid – to such an extent that this outweighs decreasing unit costs of both renewables and storage. This is true even when learning-by-doing effects are further boosted by greater global take-up of these technologies, as in the UK Policy + with major economies decarbonising scenario.

Figure 3.13 Levelised Cost of Electricity as seen by investors within FTT: Power for selected technologies in 2050, as a percentage change from the baseline scenario.

Figure 3.14 displays the average cost of household heating in the UK as a percentage change from the baseline scenario. The decarbonisation of major economies leads to lower household heating costs due to greater cost reductions from accelerated learning-by-doing in the use of heat pumps. Once the gas boilers are phased out (in the Policy + scenarios), long-term costs are also lower due to lower variable costs (electricity is relatively cheaper compared to natural gas). When the phase out of fossil fuel boilers is combined with the decarbonisation of major economies, costs fall by approximately 45% for consumers in 2050. Following the logic set out in Figure 1.1, these savings will be spent elsewhere in the UK economy, leading to changes in effective demand and the potential for positive long-term economic impacts.

Figure 3.14 The average reduction in household heating costs compared to the baseline

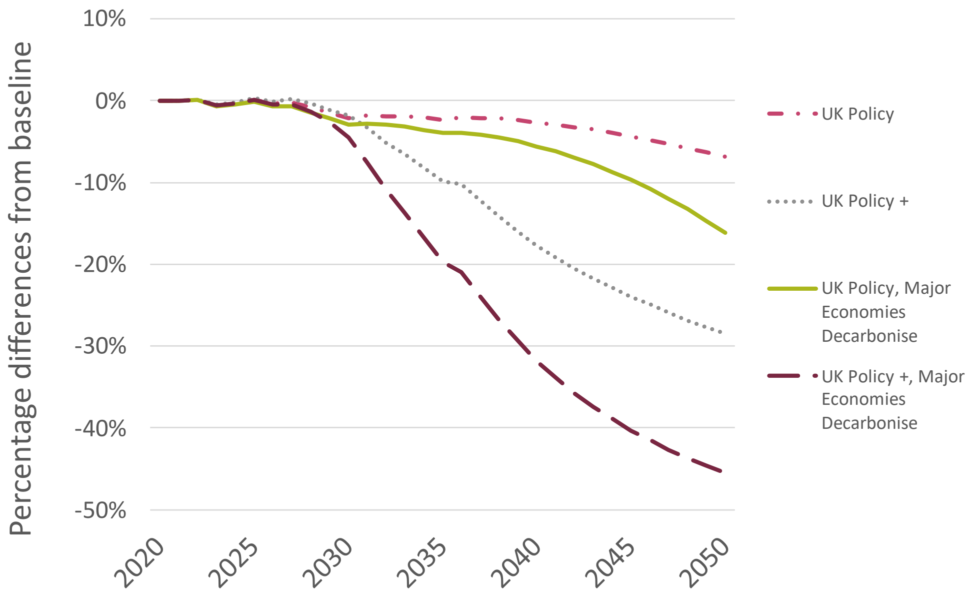
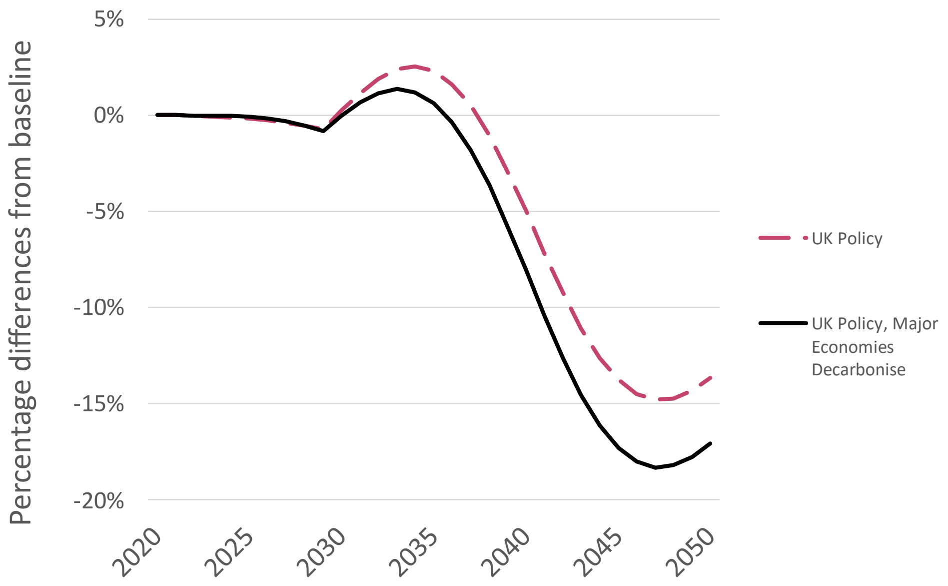


Figure 3.15 shows how the average cost of private passenger transport declines in the UK Policy and the UK Policy, Major Economies Decarbonise scenarios. The rebound in the curves seen in this figure are due to baseline costs also declining towards 2050, which narrows the difference in costs between the scenario and the baseline. Reduced running costs of cars and motorbikes due to falling electricity prices (see Figure 3.16) are expected to further contribute to changes in long-run economic growth, as described in Figure 1.1.

Figure 3.15 The average cost of private passenger road transport (cars and motorbikes) in terms of percentage changes from the baseline scenario.



Electricity prices

There is a temporary, short-term rise in electricity prices due to the higher up-front costs of renewable energy sources. In the medium- and long-run, however, this is offset by lower CAPEX (due to learning-by-doing and economies of scale) and by the lower variable costs compared to fossil fuel-powered generation.

Despite a decline in load factors as the best sites for renewables are filled, which means that more capacity has to be built to deliver increased generation, driving electricity prices higher, and higher storage costs as more renewables are built (to facilitate the greater penetration of intermittent generation sources), these effects are still outweighed by the overall lower cost of renewables relative to fossil fuels and as such the price of electricity for businesses and consumers declines in real terms for all scenarios, as seen in Figure 3.16.

More ambitious policies as well as global cooperation will lead to the greatest reduction in prices, and will allow consumer spending to shift to other areas of the economy due to the money saved on electricity.

Figure 3.16 Changes in the price of electricity in local currency, compared to the E3ME-FTT baseline scenario.

Labour productivity of the power sector

Figure 3.17 displays the change in labour productivity within the electricity industry for each scenario. Here, labour productivity is defined as value added at factor costs in real terms (in E3ME-FTT, this is calculated at a constant price of millions of 2010 euros) divided by industry employment in thousands of people.

Figure 3.17 Change in labour productivity within the electricity industry in the United Kingdom.

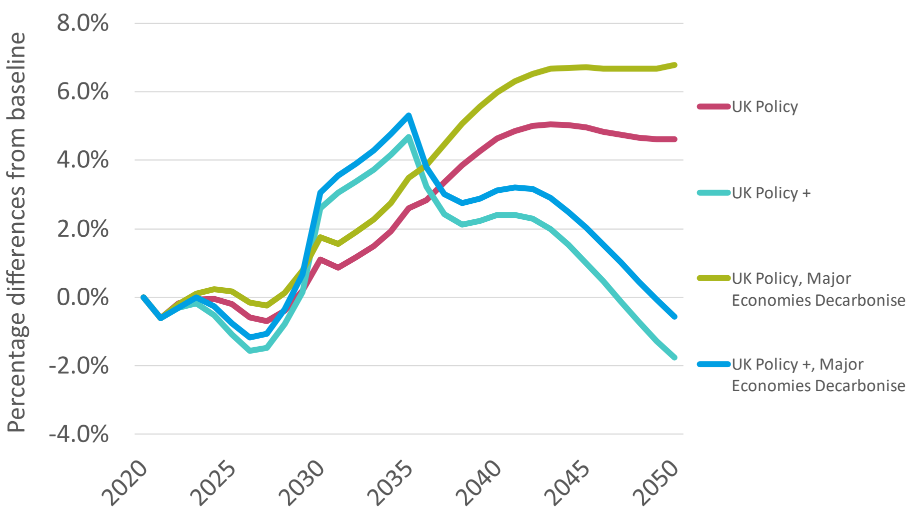
Notable years in the power sector are 2030, when 50GW of offshore wind capacity is reached and the mandate policy to build 50GW of offshore wind by 2030 is removed, and 2035, when coal and gas (Policy + only) are phased out and 70GW of solar capacity (also mandated to be achieved by 2035) is achieved. As renewables are more employment intensive, these dates are important in understanding the dynamics shown in the figure above: employment increases steeply in the run up to 2030 following the mandate to build offshore wind, and then again after 2035 in the Policy + scenarios following the phase out of gas power generation. It starts to move towards baseline levels after this point in all scenarios. This causes labour productivity to fall, however between 2025 and 2030 the effect is countered by increases to value added, due to the falling intermediate demand for fossil fuels.

This is because the removal of fossil fuel-based technologies reduces input costs; these fuels serve as an input to production and reduce the share of value added in output as compared to renewables. The shift towards renewables therefore increases value added per unit of output and therefore increases labour productivity. Value added remains higher than the baseline scenario in the Policy + scenarios, but is decreased compared to the baseline in the standard Policy scenarios.

Figure 3.18 displays an alternate measure of labour productivity in the electricity sector: GWh of electricity generated per employee. Here, the increased employment intensity of renewables is clearly visible, with increasing decarbonisation of the power sector leading to lower productivity in terms of GWh generated by 2050 in the more ambitious (Policy +) scenarios.. The employment intensity of solar power, onshore, and offshore wind falls over time in line with learning-by-doing effects in all scenarios, including the E3ME baseline. Relative to the baseline, employment per GW of capacity for wind power falls more rapidly when other major economies decarbonise, however as solar power uptake is higher in the baseline, the same is not true for solar power. Nevertheless, renewables remain more employment intensive than fossil fuel technologies.

The total market share of wind and solar in the Policy scenario is only 1% higher than that of the baseline scenario, however, in the Policy + scenarios wind power is more prominent. The load factors for onshore and offshore wind are much higher than for solar PV: this is the ratio of average load to maximum demand. Therefore, wind generation is much better at meeting demand, and this means that a higher share of wind power relative to solar makes the power sector more productive: we have the same share of renewables, but the differing renewable mix means we require fewer employees. Wind power is more employment intensive in terms of installed capacity (GW), however the higher load factors, or more efficient electrical energy usage, means it is not more employment intensive in terms of generation. This leads to higher productivity in terms of generation between 2030 and 2035, as seen in Figure 3.18.

Figure 3.18 Change in labour productivity (GWh of power generated within the electricity industry per employee) in the UK.



The downturn in 2035 in productivity in the Policy + scenarios follows from employment increasing while generation begins to plateau relative to the baseline; this plateau is reached in 2040, and then generation moves towards baseline levels. Employment remains higher than the baseline due to the larger dependence on renewables, which leads to lower productivity. In the Policy scenarios, employment remains close to baseline levels, but generation increases due to increasing demand from the decarbonisation of heat and transport, implying more employment is not needed to meet demand with the technology mix found in the Policy scenarios.

The composition of labour productivity

Examining labour productivity by broad sector reveals most sectors see an increase in productivity in 2050, with more progressive decarbonisation policies having a positive effect on productivity outcomes[4]. The productivity of

[4] Note that shifts in the value chains for household heating and private passenger transport due to the uptake of heat pumps and electric vehicles are not explored as part of this analysis, and therefore changes in productivity due to changing compositions of these value chains are unable to be captured in full.

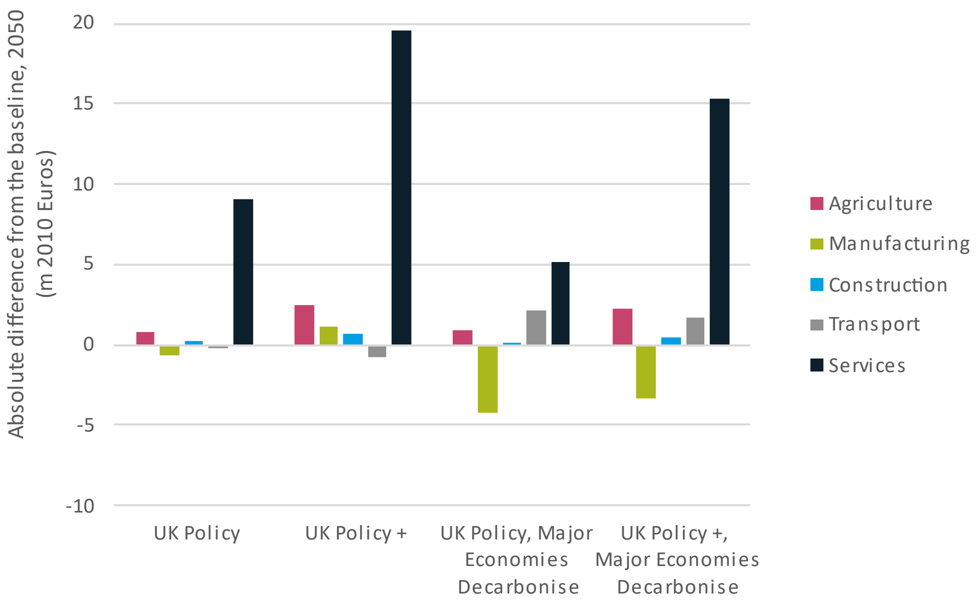
the Mining and Utilities broad sector is excluded due to fossil fuel supply productivity increasing dramatically as employment approaches zero.

The increases in productivity in the agriculture sector are due to increased consumer expenditure on food (up to 2%); consumer expenditure and productivity in this sector are both further increased in the Policy + scenarios. This suggests that the effect is due to economies of scale. In absolute terms, however, these changes are small. Changes to output and employment (the drivers of observed changes to productivity) are the greatest in absolute terms in the services sector as seen in Figure 3.19, however because both output and employment are increasing the impact in percentage terms is small.

The results for manufacturing are also skewed by employment in manufactured fuels approaching zero, so it has been excluded. There are otherwise minimal changes to productivity in manufacturing sectors. Despite increased demand for manufacturing in the Policy + scenarios, there is no economies-of-scale effect seen in Figure 3.19. This is likely due to the reliance on imports as seen in Figure 3.21, which is discussed in the next section.

Changes to productivity in transport, services, and construction remain small.

Figure 3.19 Absolute changes in sector-specific labour productivity in each scenario in 2050, excluding Mining and Utilities.

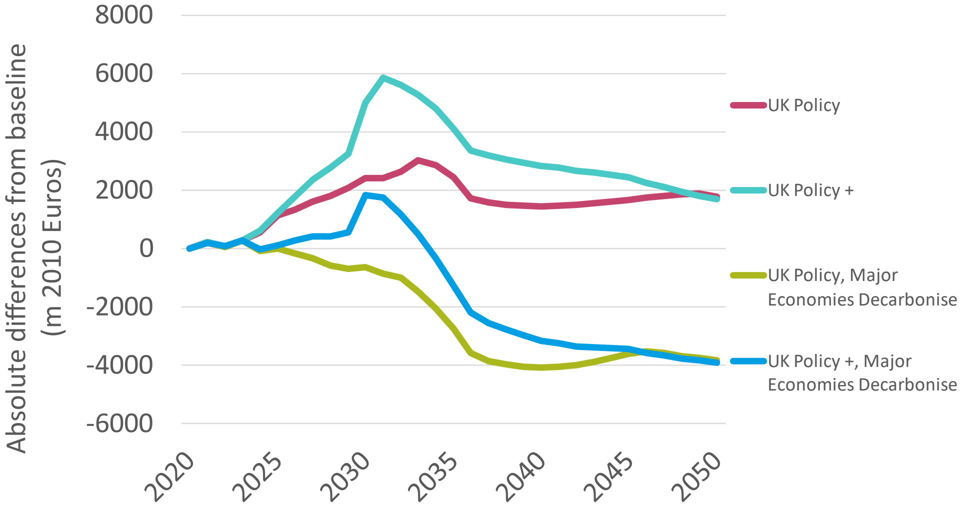


3.4 Demand-side impacts

Fossil fuel imports

For coal, oil, and gas, the balance of trade shifts towards exports in the short term, except in the UK Policy, Major Economies Decarbonise scenario. In this scenario, UK decarbonisation is less aggressive which results in a shift towards fossil fuel imports. In the long term, there is a clear difference in the balance of trade for coal, oil, and gas between the scenarios. In the UK Policy scenarios (where the UK is a first mover in decarbonisation), the fossil fuel trade balance remains positive as fossil fuel imports decrease, while other economies do not decarbonise as rapidly, and the UK can export its fossil fuels. But in the other two scenarios, when major economies also decarbonise, the balance of trade is negative in the long term, because there are fewer countries to export to. This is shown in Figure 3.20.

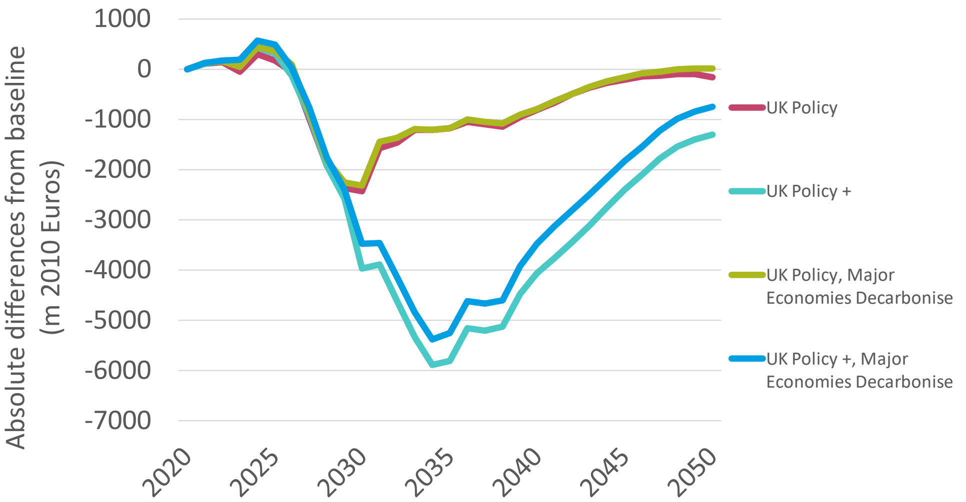
Figure 3.20 Trade balance (exports - imports) of coal, oil, and gas, displayed in absolute differences from the baseline scenario, in real terms (2010 million euros).



Machinery and equipment imports

The demand for machinery and equipment is significantly increased between 2020 and 2050 in the Policy + scenarios due to the increased uptake of renewable technologies, and the materials needed. Since the UK limitedly produces these technologies and materials, this results in increased imports. This can be seen in Figure 3.21.

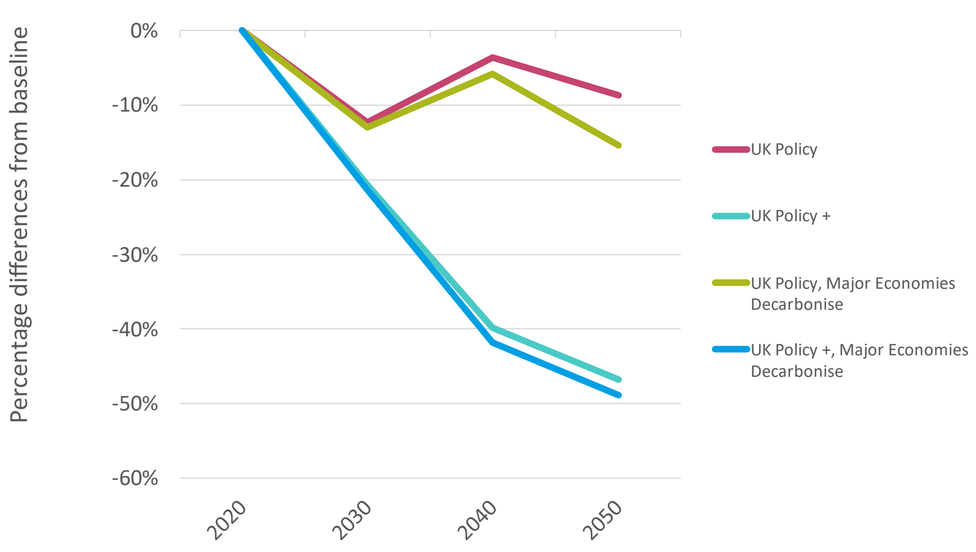
Figure 3.21 Trade balance (exports - imports) of machinery and equipment, displayed in absolute differences from the baseline scenario, in real terms (2010 million euros).



Consumer expenditure

Consumer electricity and gas demand falls by 2050 across all scenarios. This is due to the increased efficiency of renewables such as heat pumps, electric vehicles, and the reduction of demand due to building renovations. Electricity prices remain low in 2050, and as such consumers continue to benefit from the transition in the long term. This can be seen in Figure 3.22, which shows the reduction in consumer spending on electricity and gas in real terms for each scenario. The more ambitious Policy + scenarios show greater savings.

Figure 3.22 Changes in consumer spending on gas and electricity in the United Kingdom.



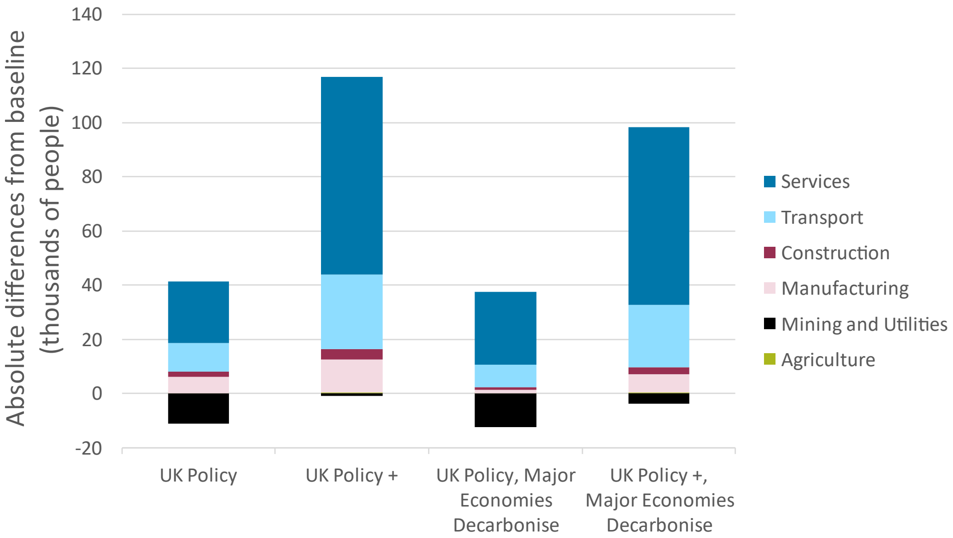
These savings illustrate the importance of building renovation and heat pump installation in the household heating sector: there is a clear difference in consumer savings when fossil fuel boilers are phased out and building renovations are increased, as consumers do not need as much energy and electricity prices fall. Note that the private transport sector is decarbonised in all scenarios, so differences between scenarios are primarily driven by the household heating sector and changes in electricity prices. These savings mean consumers are free to spend this money on other goods and services, which stimulates demand in other areas of the UK economy. This effect is depicted in Figure 1.1.

Employment in consumer-focussed sectors

Total employment increases in all scenarios, while on sectoral level, there are some winners and losers (Figure 3.23). There is a decrease in the mining and utilities sector, particularly in the Policy scenarios (11-12,000 fewer full time equivalents (FTEs)). This is the result of lower demand for fossil fuels. However, in the case of the Policy + scenarios, this negative impact is mainly offset by higher employment in the electricity sector.

The services sector has the largest employment gain in all scenarios, as energy-related consumer expenditure is lower, and spending is reallocated towards these activities. This impact is even larger in the Policy + scenarios due to increased energy efficiency and lower electricity prices. Employment in the manufacturing sector is higher in the Policy + scenarios due to the increased uptake of renewable technologies, and resultant increased demand for related components. There is a substantial increase in employment in the transport sector (9-24,000 FTEs in 2050), which follows changes in consumer expenditure on transport similar to that seen in services.

Figure 3.23 Change in employment in the United Kingdom by broad sector in 2050.

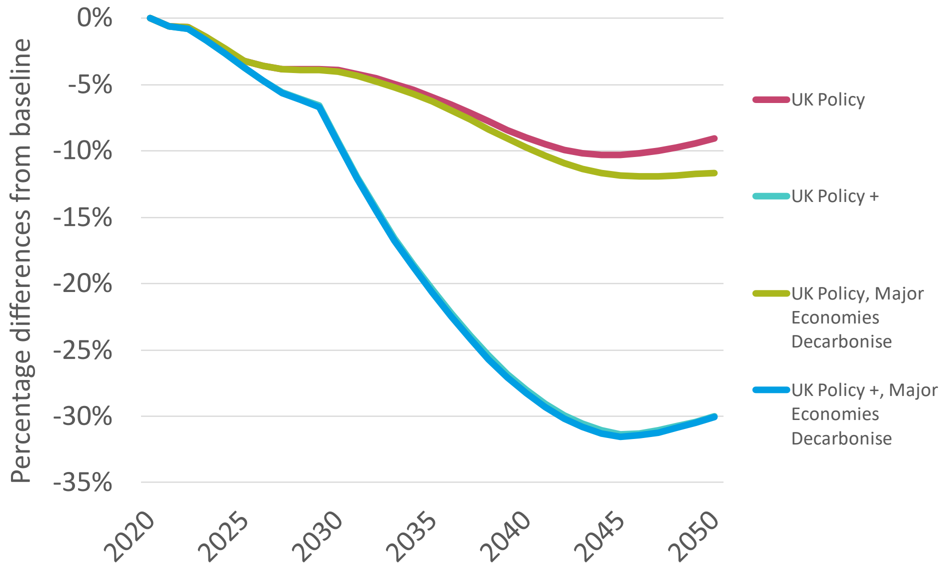


3.5 Energy and environmental outcomes

Final energy demand

The reduction in UK energy demand for each decarbonisation scenario is displayed in Figure 3.24. In every scenario, overall demand falls due to the increased efficiency of technologies such as heat pumps and electric vehicles, as well as building renovations reducing heat demand. UK policy choices are the key driver of demand reduction, with Policy + measures ensuring energy demand falls by approximately 30% by 2050. The phase out of coal and gas for power generation from 2035 as well as the phase out of gas and other fossil fuel boilers in the household heating sector from 2030 play a key role in this outcome because of the much greater efficiency of electrified alternatives.

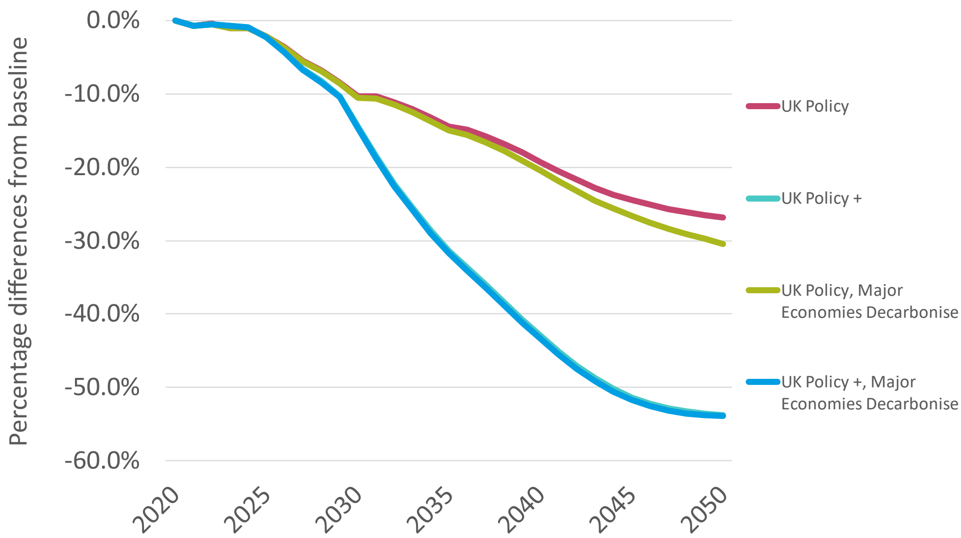
Figure 3.24 Final energy demand as a percentage change from the baseline scenario.



Emissions

Figure 3.25 shows the corresponding change in UK-wide CO_2 emissions, the reduction of which are doubled by 2050 in the Policy + scenarios compared to the less ambitious Policy scenarios. The decarbonisation of household heating, private passenger road transport, and power generation allow for a significant reduction in emissions. However, they would need to be combined with a wider range of industrial decarbonisation policies to ensure net-zero emissions economy-wide by 2050.

Figure 3.25 CO_2 emissions in thousands of tonnes of carbon as a percentage change from the baseline scenario.



The UK Policy scenarios lead to an up to 50% reduction in emissions compared to the current day; however, levels remain close to 50 million tonnes of carbon in 2050. The additional policies seen in the UK Policy +

scenarios bring the UK closer to net zero in 2050, with emissions of CO_2 close to 30 million tonnes of carbon (see Table 5). Given that this study focussed on the power, private passenger road transport, and household heating sectors alone, it shows the potential scale of saving that could be achieved by ambitious climate policy. To close the gap and reach net zero, decarbonisation of other energy users such as the manufacturing and aviation industries would need to be achieved.

Table 5 CO_2 emissions in m tonnes carbon

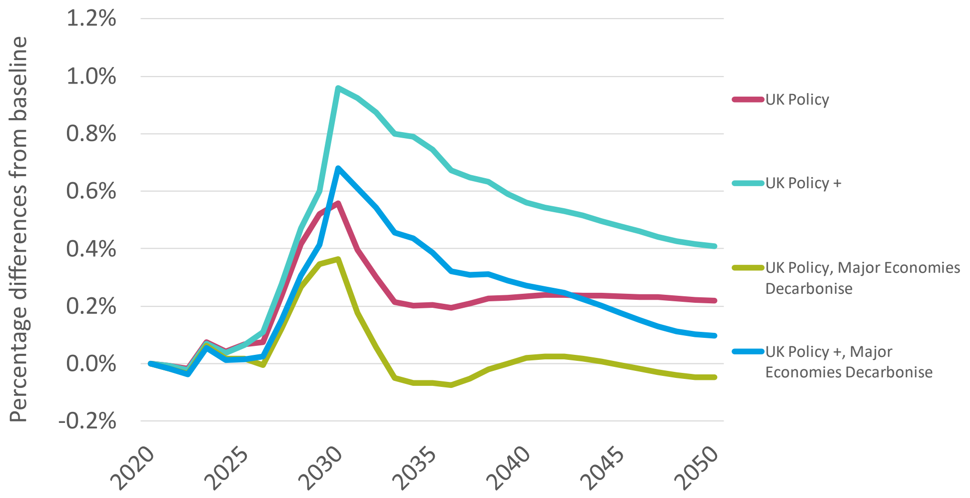
	2023	2050	% Change
UK Policy	95	51	46%
UK Policy +	95	32	66%
UK Policy, Major Economies Decarbonise	95	48	48%
UK Policy +, Major Economies Decarbonise	95	31	66%

3.6 Macro impacts

Economic impacts

In terms of macro-economic impacts, the United Kingdom benefits more from being a first mover, as can be seen in Figure 3.26. The large-scale investment in renewable energy required for the transition will create multiplier effects within the economy, where the money initially spent in the power sector propagates through to other industries and can in turn stimulate additional demand. This will drive short-run changes in GDP, and many other macro indicators, and as such peaks are seen in GDP which track the rapid building of offshore wind up to 2030. In the long run, the decreased cost of renewable technologies will lead to the demand side effects illustrated in Figure 1.1: saved money is spent elsewhere which stimulates the domestic market and creates further multiplier effects.

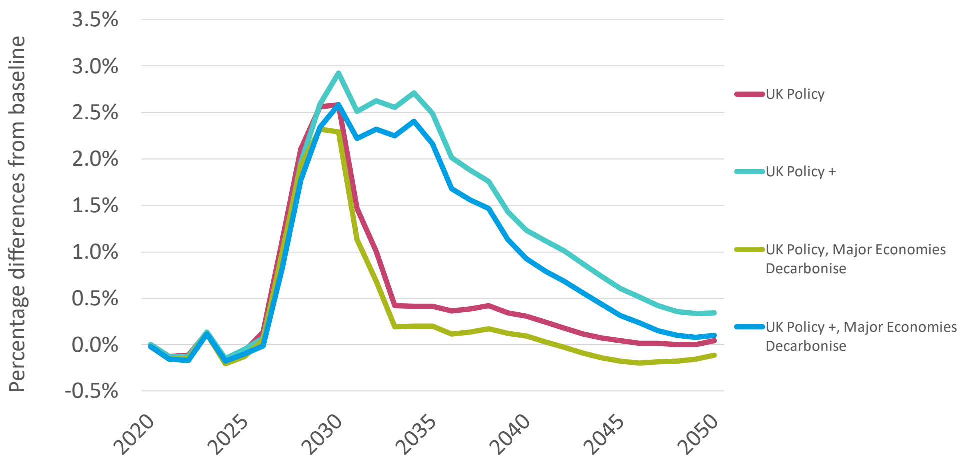
Figure 3.26 Impacts on Gross domestic product (GDP, real terms) in the United Kingdom



Investment, balance of trade, and consumer expenditure are the three main contributors to the trajectory of UK gross domestic product, and can be seen in Figure 3.27, Figure 3.28, and Figure 3.29. Investment is increased more in the Policy + scenarios, which is in line with the increased investment needed within the UK power sector to compensate the phase out of gas with more onshore wind, as seen in Figure 3.27.

It should be noted that the abrupt macro-level changes in the scenarios relate to the modelling inputs and assumptions, in particular the assumption that announced policies end abruptly (e.g. for offshore wind 2030 and solar-PV in 2035). The decline in investment (public and private) post-2035 (Policy) and 2040 (Policy +) is therefore a consequence of these policies coming to an end, and agent behaviour to some extent returning back to 'normal' afterwards. In reality, it's unlikely that there would be such a cliff edge, not least because additional supporting policies would likely be in place.

Figure 3.27 Change in total investment (real terms) in the United Kingdom



Balance of trade (exports – imports) is displayed in Figure 3.28 in terms of absolute differences from the baseline scenario. Changes in the balance of trade in the short term are driven both by the change in investment, where the electricity industry is the largest contributor, as well as changes in fossil fuel imports and exports.

Figure 3.28 Trade balance (exports - imports) of the United Kingdom.

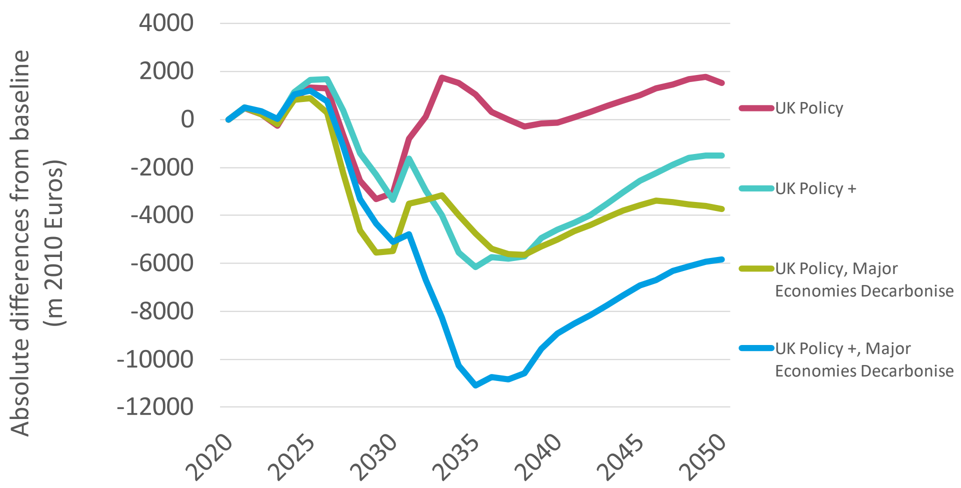
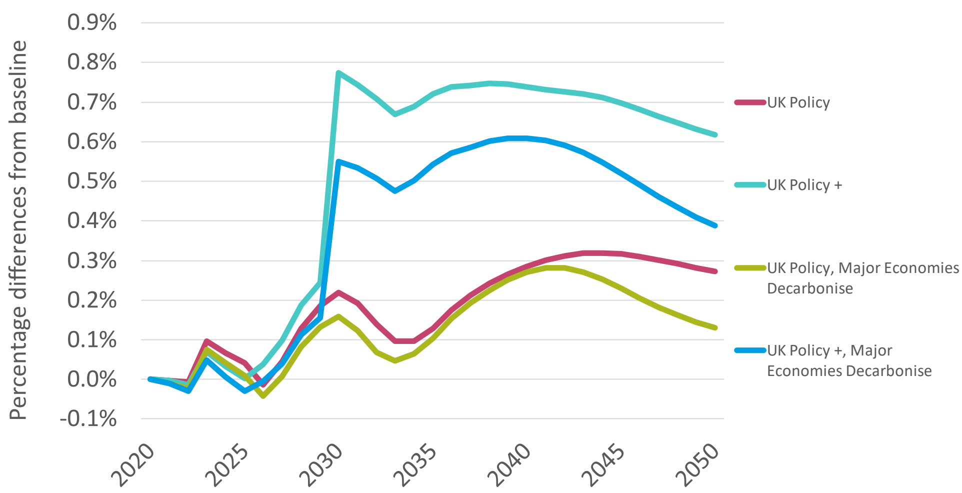


Figure 3.29 shows the trajectory of consumer expenditure in real terms. Initial increases follow the trajectory of investment, however in the long run consumer expenditure does not return to zero in all scenarios. The decarbonisation of household heating in particular leads to large reductions in consumption of fuel in the Policy + scenarios, however consumer expenditure is overall increased with the increased expenditure split between many product categories. This is due to increased consumer spending on other goods and services with greater domestic content leading to multiplier effects, which in turn leads to greater consumer expenditure.

Figure 3.29 Change in consumer expenditure (real terms) in the United Kingdom



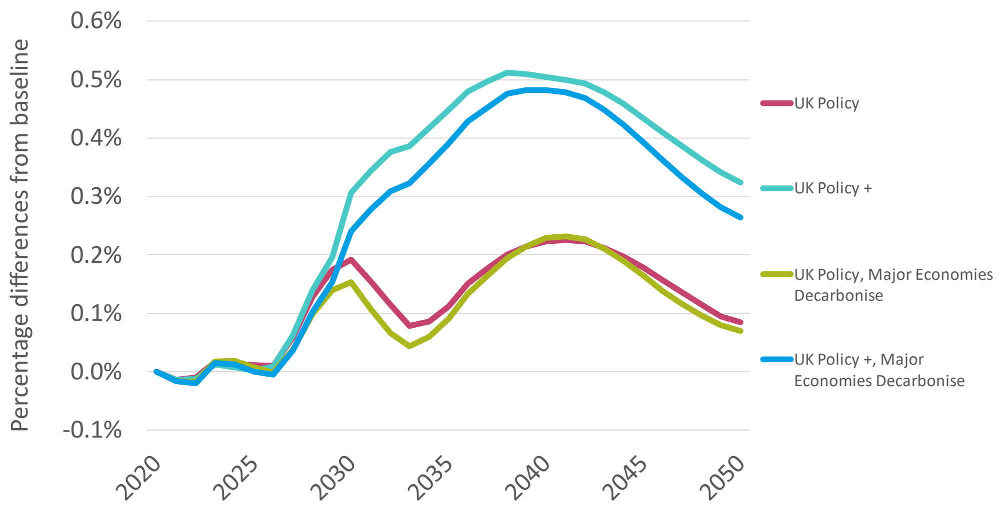
When major economies decarbonise, consumption is decreased (relative to those scenarios where the UK decarbonises alone). In these scenarios, the costs of low carbon technologies are reduced, as are the resultant stimulus effects, which influences the long-term trajectory of consumption.

Returning to GDP (Figure 3.26), it is clear that the increased negative change in balance of trade in the Policy + scenarios in the long term has less of an influence on GDP than long term increased consumption. This is in line with the dynamics described in Figure 1.1, where technology cost savings are diverted to other areas of the economy and can lead to further multiplier effects.

Employment and labour productivity

Employment over time can be seen in Figure 3.30. Employment is increased in all scenarios, however the increase is greater in the Policy + scenarios.

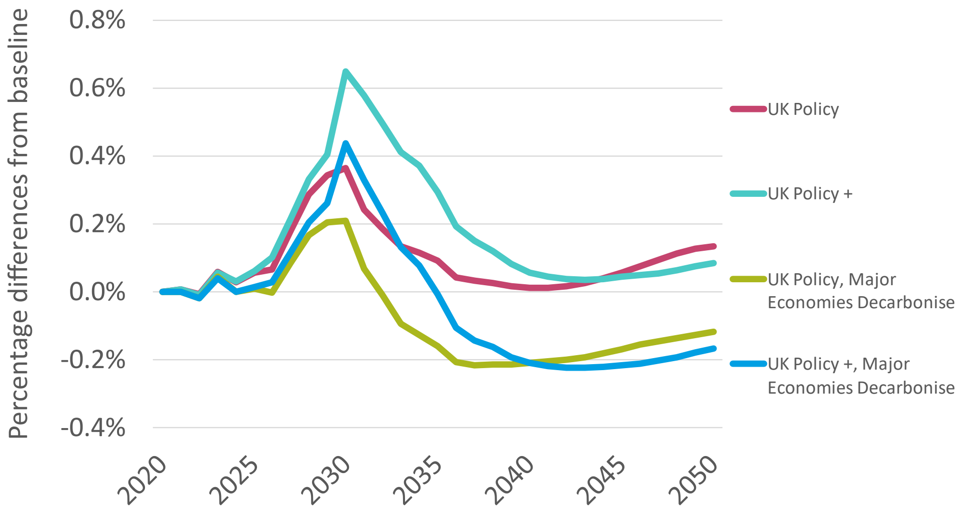
Figure 3.30 Change in employment in the United Kingdom



Labour productivity in terms of GDP per thousands of employed people can be seen in Figure 3.31. More progressive decarbonisation policies pay off to boost productivity, and the UK clearly benefits from being a first mover in terms of productivity (because the results are somewhat less positive in the scenarios where major economies also decarbonise).

In the short term, large increases in capital investment which lead to the short term increases in GDP do not create similar increases in employment at a national level, leading to peaks in labour productivity which track the rapid building of offshore wind up to 2030. However, higher employment from 2030 onwards in the Policy + scenarios means that the long term gains to GDP are not reflected in labour productivity.

Figure 3.31 Change in labour productivity (GDP per thousand people employed) in the United Kingdom



There are no large differences in employment overall when major economies decarbonise, which suggests the negative productivity outcomes in 2050 for these scenarios are not driven by increasing employment.

Sectoral changes in productivity, as seen in Figure 3.19, suggest that within-sector productivity affects are generally positive, and more positive in the Policy + scenarios. However, the compositional shifts in employment, as seen in Figure 3.23, mean there is a greater representation of lower-productivity sectors in the economy overall in the Policy + scenarios.

These two effects counter each other, with the key difference in results in 2050 resting on whether or not major economies also decarbonise. The productivity of the manufacturing sector is significantly affected by the decarbonisation of major economies, and in the less ambitious Policy scenario, the effect on productivity is negative.

4 Conclusions

The decarbonisation of the UK power, household heating, and private road transport sectors has the potential to lead to positive economic and productivity effects through technological innovation. Four scenarios have been analysed, considering current and extended decarbonisation of the above sectors, combined with the assumption that the major economies (US, EU, China) also decarbonise.

We analyse how the reduction in costs for new technologies over time, and the increased energy efficiency of technologies such as heat pumps and electric vehicles, lead to savings which are spent elsewhere in the UK economy which stimulate domestic demand and have the potential to lead to long term growth.

Supply-side impacts

Decarbonisation of the power sector is driven by a range of policies, such as the deployment of 50 GW of offshore wind capacity by 2030. Decarbonisation leads to a fall in electricity prices, which is even more pronounced if gas-fired power stations are phased out from 2035 and replaced mainly by onshore wind capacities (as in the UK Policy+ scenarios).

The £450m boiler upgrade scheme has a limited effect in ensuring that heat pumps are widely adopted, so without further policy action (such as phasing out fossil fuel boilers) the UK housing stock will not be decarbonised by mid-century. The decarbonisation of major economies has a positive impact on the adoption of heat pumps, as costs are driven down by learning-by-doing effects.

There was no significant difference between scenarios in the transport sector, which is already decarbonised in the less ambitious policy scenarios.

The evolution of individual technology costs, and their relative market shares, are the key driver of the levelised cost of electricity (LCOE), and the average LCOE falls in all scenarios, but by more in the Policy + scenarios. This is the result of lower costs of variable renewables relative to fossil fuels, although the costs associated with incremental additions of these technologies increase over time due to the increasing need for battery storage at higher rates of penetration, and the need to utilise less productive sites for renewables.

Faster decarbonisation of the UK power sector leads to a larger reduction in electricity prices due to the falling average LCOE, but prices are between 10 and 18% lower in 2050 in all scenarios relative to baseline. This in turn reduces transportation and heating costs for consumers, as they move to technologies which run on electricity. Savings are in turn increased further due to the increased efficiency of heat pumps and electric vehicles, along with renovations to buildings which reduce heat demand.

Supply-side changes demonstrate labour productivity changes. The increased deployment of renewable energy reduces productivity, as it is more labour-intensive than fossil fuel power generation (noting that much of the more labour-intensive parts of fossil fuel production, such as extraction, occur outside the UK). Comparing the Policy and Policy + scenarios, which have a similar percentage of renewables in the power mix in the medium term, labour productivity per unit of power generated is higher in the medium term in the latter due to the increased role of onshore wind. Onshore wind has a higher load factor and therefore requires less labour per GWh than solar PV. However, in the long term the higher penetration of renewables in the power mix in the Policy + scenarios leads to higher employment compared to the Policy scenarios and the baseline, which means productivity is overall reduced.

Demand-side impacts

Decarbonisation of the power, transport and buildings sectors leads to changes in demand in some sectors. The decarbonisation of other major economies significantly affects the fossil fuel trade balance: if the UK is a first mover, while the major economies do not decarbonise, UK fossil fuels are simply exported rather than consumed domestically, meaning that the trade balance improves. However, when the major economies also decarbonise, the impact is reversed, as foreign demand for fossil fuels disappears. In the machinery and electrical equipment sector, imports increase significantly, particularly in the Policy + scenarios, due to the need to import key components of low-carbon technologies such as renewables.

Savings from the lower cost of ownership of vehicles, electricity prices and heating costs lead to long run increases in consumption in real terms, and hence long run increases in GDP. However, decarbonisation also leads to a decrease in employment in fossil fuel extraction and increases in employment in other sectors, such as consumer services.

Energy and emissions outcome

Final energy demand decreases in all scenarios, but UK policy choices are the key determinant, with the Policy + scenarios ensuring energy demand falls by approximately 30% by 2050, with the decarbonisation of the US, EU, and China further increasing these changes (since they reduce the costs of more efficient low-carbon technologies and therefore encourage their take-up). This is due to increased efficiency of electricity compared to burning fossil fuels, and by the increased rate of building renovation.

Emissions decline almost twice as fast in the Policy + scenarios as in the current policies (a 55% decrease compared to 30%). This is the result of the stronger decarbonisation in the power and buildings sectors. Although current policies can halve emissions, while extended policies can abate emissions by two thirds (relative to 2023 levels), net zero emissions cannot be achieved in 2050 without decarbonisation of other sectors such as industry or aviation.

Macro impacts

Decarbonisation has a positive impact on GDP and employment. This is driven by three main factors: higher consumer spending, an improved trade balance and substantial investment in the transition. Consumer spending and investment have a positive impact, which counterbalance the negative trade impact. When other major economies decarbonise, the trade balance shifts towards imports, and a greater number of fossil fuel extraction jobs are lost. In the Policy+ scenarios, imports increase further due to the additional need for machinery and electrical equipment used primarily in the electricity sector.

Total employment increases, especially in the Policy+ scenarios, with a significant increase in service industry jobs (due to the induced impacts of energy cost savings), although because these jobs are relatively low productivity they lead to lower economy-wide productivity.

The UK clearly benefits from being a first mover and having stronger decarbonisation policies in terms of productivity. In the early years, the increase in productivity is the result of higher GDP due to increased investment, which does not translate into higher employment. However, higher employment from 2030 onwards in the Policy+ scenarios means that the long-term gains in GDP are not reflected in increases in labour productivity. Nevertheless, all changes in productivity remain relatively small, indicating that a low-carbon transition will not have a highly negative effect on UK productivity in any scenario.

In general, there is a counterbalancing effect between the change in productivity and the sectoral shift in the composition employment. However, the productivity of the manufacturing sector is significantly affected by the decarbonisation of major economies, and in the less ambitious Policy scenario, the effect on productivity is negative.

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6 Appendix

6.1 1.5°C scenario

The 1.5°C scenario is a global policy scenario aimed at achieving 1.5°C of global warming by 2100, by all regions taking rapid and immediate actions to decarbonise. In this scenario, developed countries are expected to reach net zero CO2 emissions in the early 2050s whereas developing countries are expected to reach the same in the late 2050s and early 2060s. Globally, CO2 emissions is projected to reach net zero around 2056, later than a global net zero scenario (although this is sometimes used interchangeably with 1.5°C outside of CE).

This version of the 1.5°C scenario was last updated in August 2022.

A range of policies aimed at energy-related CO2 emissions are modelled in all regions in this scenario. All policies are assumed to start immediately in 2021. The most important policies are:

- Expansion of carbon pricing to all sectors
- Increased energy efficiency investments at above historical rates
- Increased biofuel mandates to 100% by 2050 (of remaining fossil fuels)
- Regulation to force switching from fossil fuels to electricity in heavy industries
- Phase-out of new fossil fuel capacity/sales in power generation, road transport, household heating and steel production
- Subsidies for renewables and low-carbon alternatives in the above sectors
- Kick-start/R&D to bring CCS and hydrogen to commercialisation in power and steel sectors

In this scenario, some stated ambitions are close to be achieved or exceeded. However they are not modelled in detail as explicit targets (nor is any country-level policy or target):

- Reduction of emissions by 55% by 2030 and net zero emissions by 2050 in the EU
- Net zero emissions by 2060 in China
- Net zero emissions by 2070 in India

Other emissions sources including land use and non-CO2 greenhouse gas emissions are not modelled. They are assumed to follow a similar trajectory as CO2 emissions.

Negative emissions technologies such as reforestation, direct air capture, etc. are not modelled. Carbon capture & storage is modelled for the power sector in detail (separating fossil fuels with CCS and biomass with CCS) and assumed for industry sectors (moving in line with the uptake of CCS in power generation).

There is no assumption in this scenario regarding economic restructure (e.g. the creation of new low-carbon industries and commercialisation of new technologies) and behaviour change (e.g. diets, circular economy, material consumption). Past trends are to continue and respond to energy-related policies through price effects and overall impacts on levels of economic activity.

Revenues from carbon pricing are assumed to be recycled so that there is no net impact on fiscal balances relative to the baseline. Carbon revenues are used to fund low-carbon policy costs that are borne by governments including energy efficiency investments, compensation for costs of early closures of coal power plants, and renewable subsidies). Shortfalls in investments are funded by individual governments raising taxes in the same year (through income tax, VAT and employers' social security contributions). Similarly, excess revenues are redistributed by reducing taxes through the same channels. There is no international transfers, which means each region is responsible for maintaining its own fiscal budgets.

6.2 Adaptation for the EU, US, and China

- Emissions permit prices from the 1.5°C scenario are included for the UK, EU, US, and China only.
- All other carbon prices included in the 1.5°C scenario are excluded from this analysis.
- All other policies are included for the EU, US, and China, with the UK following its own, bespoke scenarios.