CUTTING BILLS AND CREATING JOBS

THE ECONOMIC OPPORTUNITIES OF THE CLEAN ENERGY TRANSITION

Full report and modelling – June 2022

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The economic opportunities of the clean energy transition - full report and modelling

This report outlines how an accelerated green transition can alter the rate of economic growth and development of countries across the globe. It begins with a contextual discussion of the green transition, how it affects the economy, the trade-offs it presents, where additional supporting policy may be required, and exploring the wider benefits of going green. Building on this discussion, the first chapter contains a detailed examination of global evidence with a particular focus on a selection of the world's major economies including the United States, Germany, the UK, and the EU as a whole. Chapter two sets out the approach taken in a fresh analysis of the economic effects of accelerating the green transition. The results of this modelling exercise are reported on a country-by-country basis in chapter three. Chapter four concludes.

1. PUTTING THE GREEN TRANSITION IN CONTEXT

How investment supports development and deployment of green technology

The state can play a powerful role in driving the development of new technologies, creating new markets for those technologies, and ultimately driving additional economic growth.[1] This ability is well documented and manifests through several mechanisms. Public investment/spending (i) sends a signal to economic actors, (ii) drives further private-sector investment, and/or (iii) increases demand for goods or services. In each of these ways, public policy refocuses economic activity – encouraging development, deployment and driving down costs as described below.

i. Significant investment or spending by the state sends an important signal to other economic actors. By creating a market and backing it financially, governments are signalling certainty to educators, researchers, developers, financiers, and consumers that they are committed to an initiative over the long term, helping to coordinate the deployment of resources. This signalling effect can greatly increase the overall impact of a policy intervention and be instrumental in encouraging the activity required to bring nascent technologies to market readiness. It can lead to crowding-in of private investment, described in (ii) below.

ii. Public sector investment can have a crowding-in effect whereby an initial injection of capital by the state encourages the private sector to follow suit. The capital put forward by government reduces the overall risk of investment faced by private investors. This reduces the overall cost of capital, enabling firms to develop and deploy new technologies more cheaply.

iii. Being a major procurer of goods, government can greatly influence demand, with the long-term effect of driving unit costs down. As firms scale to meet increased demand, their processes become more efficient through learning by doing. This increased efficiency will be accelerated further as firms compete within the market and are incentivised to invest in research and development with a view to improving their productivity and competitiveness. The scale of government procurement is so large that it can produce non-linear responses, where a tipping point is reached and a major acceleration in the take-up of a technology is achieved across the economy.

1. What is government's role in sparking innovation? | World Economic Forum (weforum.org)

An example of all three of these mechanisms acting together is that of solar power in Germany. The Renewable Energy Act (2000) gave precedence to renewable energy sources and sent a strong signal to the market that Germany was serious about the development and deployment of PV solar panels. Public funding supported research and development, encouraging industry to invest in the accelerated development of PV technology. This, combined with guaranteed remuneration for electricity produced through solar technology for a period of 20 years led to a proliferation of solar panel producers. The deployment of solar panels became widespread across Germany. Between 2008 and 2013, the country's total solar capacity increased from 6GW to 36GW. In achieving such scale in such a short time, the unit cost of solar power was driven down significantly. In 2000, the typical PV unit cost was 5 USD per Watt, compared with 0.2 USD per Watt in 2020.

How green investment stimulates the economy and creates jobs

Green investment can impact economies significantly, in what can be broadly categorised into two channels: direct and indirect. First, investing in technologies such as wind and solar power will directly lead to an increase in economic activity in the sectors concerned. In 2014, 59,000 people (equal to 2.3% of the Danish workforce) were directly employed in the production of green technologies, producing the equivalent of 7% of total Danish exports. The extent of this effect will depend on how much of the supply chain for these technologies is located within the country concerned. For example, a country with the ability to produce, install and maintain wind turbines would, all else being equal, see greater economic gains from investment in wind power than a country lacking wind turbine production capabilities. However, it is likely that even in the absence of firms capable of producing said technologies locally, local firms would be involved in the operation and maintenance of deployed technologies. Beyond this, economies would also experience secondary effects as firms in the affected sectors procure additional goods and services to support their own operations.

The second, indirect, channel through which green investment can impact the economy is through reducing costs. Green energy technologies typically lead to lower unit energy costs over the long run, which will represent real savings for consumers. Furthermore, investment in demand side interventions, including home renovation will, all else equal, permanently reduce energy demand – delivering significant savings for consumers. These savings will inevitably be invested or fund greater consumption, which will increase GDP and create jobs. For example, a household could reduce its home heating demand through renovation. That heat demand could then be met more efficiently using renewable heating sources, such as a heat-pump. Such a household would have significantly lower home heating bills and the money that they save may well be spent on hospitality and entertainment within the local economy.

Trade-offs influence the effects of the green transition

The specific effects of each policy intervention will depend on several factors, which will vary by country. Economies with indigenous fossil fuel industries will face a trade-off as they wind down fossil fuel extraction and refinement in favour of investment in renewable technologies. For example, a country with a large coal industry would experience job losses and a fall in output in that sector and its supply chain. Even within a country, these trade-offs may not be equally pronounced. Fossil fuel industries tend to be concentrated in specific locations due to the source of fossil fuels along with the presence of skilled labour and necessary transport infrastructure such as ports. Despite the challenges for fossil fuel producing countries, a head in the sand approach will not be fruitful – as the rest of the world makes the green transition, the opportunities to export fossil fuels will fall away, so diversification away from these industries should be a major focus for such economies. Furthermore, where major economies do not invest in the development of green technologies, they will fail to seize the opportunity to export those technologies. While challenges will exist, policy interventions can be designed to reduce the

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2. Solar power in Germany – output, business & perspectives

3. Evolution of solar PV module cost by data source, 1970-2020 – Charts – Data & Statistics - IEA

4. Green Growth in Denmark | Energistyrelsen (ens.dk)

5. The Renovation Wave can cut EU gas imports and reduce consumer bills - Cambridge Econometrics (camecon.com)

negative economic effects experienced in traditional energy sectors, as discussed in the next section.

Countries that import most of their energy by way of fossil fuels will see greater net economic benefits from the transition to green energy sources. Even where a country imports green technology, money that would have been spent on imports of fossil fuels will be diverted to the import of green capital, with greater economic returns associated with such capital rather than ongoing fuel imports. Installation, operations, and maintenance jobs associated with green technologies are more likely to be distributed across a country in line with distribution of its population.

While electricity from renewable sources is typically cheaper than fossil fuel-based alternatives over the long run, in the short term as demand for electricity increases and investment in generation and transmission is required, electricity prices may increase. However, with fossil fuel prices to continue to rise in the coming decades – as supply dries up – investment in renewable energy sources now will protect consumers from very high energy costs in the future. Regardless of the adoption of green technology, many countries face the need to upgrade their aging electricity grids and transmission networks to meet the demands of the modern economy and protect living standards. That investment, combined with energy efficiency measures, and the deployment of green technology, will deliver not only significant economic benefits as discussed above, but will also bring about significant wider benefits to society, the environment, and national interests.

Effective policy can maximise the net economic benefits of going green

The workers currently employed in traditional sectors are a key concern for world leaders in the transition to a net zero world. The ability of people employed in those sectors to navigate the transition is affected by both the pace of change and the geographical concentration of these workers. Delaying the move to net zero will necessitate a much faster transition, which will make it more difficult for affected workers to adapt. Geographical concentration is an issue because it influences the ability of a community to respond to a shock. In regions where the primary industry is the extraction and refinement of oil, for example, many other jobs will depend on the consumption of those employed within the oil sector. For this reason, policy interventions that include reskilling of workers, incentives to attract new industries, or enable labour mobility, are essential. A failure to ease the transition and protect people from large shocks will increase the political capital required to achieve net zero emissions.Policy, and in particular regulation and standard setting, is also essential to the transition, helping to establish a marketplace for new technologies. Coupled with research and development support, this will help new industries and services to develop and thrive, whether in the manufacture, installation or maintenance of new technologies or green interventions. Clear emissions and energy targets, with evidence of adherence to them, will instil further investor confidence – driving innovation and stimulating the economy.

> " Delaying the move to net zero will necessitate a much faster transition, which will make it more difficult for affected workers to adapt.

The green transition, if well designed, can also be a catalyst for rural and regional development. With green technologies being more location independent than their fossil fuel predecessors, as described above, and potentially more widely distributed between and within countries, their manufacture need not be so concentrated. Furthermore, as many of these technologies, such as solar panels and heat pumps, will be in demand by households, local firms will be established to supply, install, and maintain those systems and may be distributed much like the general population. Building renovation will follow a similar pattern, supporting local jobs in construction and building materials.

Going green has wider social, environmental, and geopolitical benefits

There are wider benefits, beyond the direct economic payback of the green transition. The adoption of green technologies will reduce water and air pollution, with significant improvements in human health as a result. Reforestation will provide environments for habitat regeneration. Homes that are easier and cheaper to heat will improve the quality of life of their inhabitants. This is particularly true for low-income households, who are often unable to afford to sufficiently heat their homes. As is often the case in times of rapid change, such as the industrial revolution or the advent of the internet, reskilling and retooling of the economy may drive a new wave of innovation, creating jobs in industries that do not exist at present. The unequal distribution of and demand for fossil fuels means that at present, energy security is a geopolitical concern. The green transition offers countries a route towards energy independence with significant implications for geopolitical dynamics.

United States

The spectre of climate change weighs heavily on the US economy. The Congressional Budget Office estimates that the total accumulated effects of weather damages could reduce real GDP by 1% per year by 2050.[6] This finding is far from an outlier. The Bank of England finds similarly negative consequences for the US, with its worse-than-expected warming scenario predicting that US GDP is 11% lower by 2050.[7] The Network for Greening the Financial System predicts that climate change related damages are expected to reduce US GDP by 2.7% compared to baseline over the next 25 years.8 It is worth noting that these findings focus on the direct impact of damage caused by climate change. Other linked factors such as rising energy prices have the potential to cause further damage to the US economy.

These effects are not limited to the US economy. A 2019 study by the International Renewable Energy Agency (IRENA) finds that current trends will lead to severe climate damage, reducing global GDP by 15.5%.[9] As a major exporter of goods and services, the US economy will suffer as the purchasing power of other countries falls. Therefore, considering the significant scale and scope of the threats posed, incorporating the effects of climate change and energy crises into decision and policy making is becoming essential.

In April 2021 the US committed to reducing GHG emissions 50-52% below 2005 levels by 2030, as part of increasing global ambition aimed at limiting global climate change to 1.5°C. At the time of the announcement, the US was on track to reduce emissions by only 17-25% by 2030, leaving a gap of some 1.7-2.3 billion metric tons of emissions reductions to be delivered by further action.[10]

Key to achieving these ambitious targets is ensuring that policy drives investment that will accelerate the green transition. This means using the power of public investment to develop and deploy green technologies, to support energy efficiency upgrades, and to drive the regeneration of the environment and its ecosystems. Two major spending packages were proposed to the US Congress in 2021. The 1 trillion USD infrastructure bill was signed into law in November 2021 and represents the greatest investment in climate action in US history to date. However, the Build Back Better bill has stalled in the Senate, and it is still unclear what precisely will be included in the final package. Globally, such significant investments are required, according to IRENA, who find that total investments of 5.7 trillion USD (around 6% of global GDP) would be required annually to achieve a global transition of energy system to zero emissions.[11] Rhodium Group have estimated that in the case of the US, the 1 USD trillion infrastructure bill and the originally proposed 3.5 trillion USD Build Back Better bill are sufficient to reduce GHG emissions by 45-51% compared to 2005 levels. Meanwhile, Deloitte have found that public

6. CBO's Projection of the Effect of Climate Change on U.S. Economic Output
7. www.bankofengland.co.uk/stress-testing/2021/key-elements-2021-biennial-exploratory-scenario-financial-risks-climate-change
8. NGFS Scenarios Portal
9. Global Energy Transformation: A Roadmap to 2050 (2019 Edition) (irena.org)
10. Rhodium-Group_Pathways-to-Paris-A-Policy-Assessment-of-the-2030-US-Climate-Target.pdf (rhg.com)
11. World Energy Transitions Outlook: 1.5°C Pathway (irena.org)

investment amounting to 0.1% of the national GDP (35 billion USD) per year is enough to put the economy on track, highlighting the sensitivity of these estimates to modelling techniques and underlying assumptions.[12]

As discussed in the opening chapter, investment in the green transition should not be seen as a mere cost but rather as an engine for economic growth. By 2050 global GDP could be 2.5% higher due to investment and policies consistent with the Paris Agreement's goals.[9] The US economy is no exception to this finding. In a report for the We Mean Business Coalition, Cambridge Econometrics find that a Covid recovery package focused on the green transition leads to greater employment and GDP gains than more typical stimulus (a VAT/sales tax decrease). Employment is found to be 0.2-0.7% higher in each year until 2030 with GDP growth 0.2-0.5% higher per annum.[13]

Of course, as with most change, there are winners and losers, and as a major fossil fuel producer, consumer, and exporter the US will experience some losses through the green transition. It is expected that the US will experience losses to GDP amounting to 4.5 trillion USD (2020USD) between 2022 and 2036 (discounted). Of this, 3.5 trillion USD is due to fewer jobs in and less output from the fossil fuel-related sector.[14] However, while losses in some sectors are inevitable, these losses may be outstripped by gains in other sectors. Electrification of the economy implies the almost complete onshoring of energy supply, which will create new jobs in electricity generation. This is true even if components and expertise, such as in offshore wind energy, are imported from places with more established industries, such as Europe. Furthermore, the US already holds substantial expertise in the production of EVs and their underlying battery technology, with significant potential for exports. In the late 2010s more than 1 million people were employed in fossil fuel related industries in the US, while 476,000 were employed in renewable technology related industries.[16] With renewable technologies only accounting for 10% of the energy mix, this suggests strong potential for jobs growth as the sector grows.

A separate study suggests that more jobs are created in the renewable energy sector than lost in the fossil fuel industry. It finds that while there will be 25,000-27,000 and 35,000-46,000 jobs lost in association with electricity generation from coal and natural gas, respectively, this is outweighed by the positive employment effect of the installation renewables capacity.[11] The Rhodium Group finds that in the case of the US, job losses will be the greatest in the coal and natural gas industry, while oil production will only reduce slightly.[10] The lower domestic gasoline consumption due to the uptake of EVs is assumed to be compensated by moderately higher exports. The economic impacts of inaction and the corresponding climate damages are unequal both across industries and regions within the US. Job losses are expected to be largest in the service sectors and manufacturing, especially in the American Southeast.[12] Given these trade-offs, there is a role for supportive policies to play, including the reskilling of workers to enable them to adapt to the new economy.

> **"The economic impacts of inaction and the corresponding climate damages are unequal both across industries and regions within the US.**

Rural development can also be supported by the green transition, and this may help to offset some of the losses in, for example, the fossil fuel industry. The originally proposed 3.5 trillion USD budget reconciliation bill allocated 28 billion USD to assist farmers and forest owners to implement climate-smart practices to reduce greenhouse gas emissions but it remains to be seen whether this measure will be ultimately enacted. In the US, maintenance and the restoration of forests has a value of 3.8 billion USD, giving jobs to 126,000 people.

12 www2.deloitte.com/content/dam/Deloitte/us/Documents/about-deloitte/us-the-turning-point-a-new-economic-climate-in-the-united-states-january-2022.pdf
13.Report CE v3 rev (wemeanbusinesscoalition.org)
14. Reframing incentives for climate policy action | Nature Energy
15. Democrats Add $28 Billion in Conservation Funding to Huge Spending Bill - AG INFORMATION NETWORK OF THE WEST
16 https://www.fb.org/market-intel/reviewing-u.s.-carbon-sequestration

Reforestation can also boost the economy – a good example is in Indonesia, where restoration of an area of 160 million hectares could result in an 84 billion USD gain per year.[16] Carbon sink activities in the US such as forestry management or growing conservation cover crops removed 764 million metric tons of CO2 from the atmosphere in 2018 – 12% of the total US GHG emissions. Nevertheless, the sequestration potential of land and forestry management practices has decreased by approximately 9% since 1990, suggesting significant potential for investment in sequestration.[16]

Beyond the economic benefits of the green transition, the US also stands to gain wider benefits by moving towards net zero emissions. The New Climate Economy finds that an accelerated green transition will lead to 700,000 fewer premature deaths globally by 2030 due to improved air quality. Conversely, continuing in a business-as-usual scenario would result in more than 4.2 million deaths annually, causing 350 billion USD loss per year due to reduced productivity and increased health expenditure.[16]

As intended, the green transition would significantly reduce GHG emissions. Rhodium group carried out an analysis of the transition of US electricity system and found that 332-399 billion USD net new investment in the power system from 2022 to 2031 could drive related emissions down to 66-74% below 2005 levels in 2031.[17] Another substantial source of emissions is the buildings sector, responsible for one tenth of total US emissions. Although decarbonizing the electricity grid reduces emissions of the sector drastically, in 2018 there were still 70 million households and businesses burning fossil fuels for heating.[18] Modelling by the National Renewable Energy Laboratory shows that by switching most households and businesses to electric heating by 2050, emissions could be cut by around 306 million metric tons of CO2.[19] The shift also reduces natural gas consumption by more than 7 trillion cubic feet relative to the reference scenario.

In summary, while the transition to net zero emissions presents a challenge to the US economy, it is also a substantial opportunity. By investing in the green transition, the US state and federal governments can drive innovation, increase economic output, and create jobs all while cutting emissions, improving health and quality of life, and realigning the geopolitics of energy. Trade-offs exist and are unavoidable, but the evidence suggests that by embracing the green transition and supporting it with investment and policy, the net economic benefits will be positive. Two examples reinforce this point. First, by electrifying the economy, thousands of electricity generation jobs will be created within the US as renewable technology will allow for the complete onshoring of the energy supply chain. This is true even where technology and expertise may be imported from other countries. Second, as a leader in the production of EVs and battery technology, the US stands to create many more jobs to meet global demand. Beginning the necessary green transition immediately reduces the risk of economic shocks. It gives the most adjustment time possible to those sectors who may face losses, while allowing people and firms to pivot towards a greener, cleaner economy, and reap its rewards.

“ **By electrifying the economy, thousands of electricity generation jobs will be created within the US as renewable technology will allow for the complete onshoring of the energy supply chain.**

18. https://rmi.org/insight/the-economics-of-electrifying-buildings/
19. https://www.nrel.gov/analysis/electrification-futures.html

European Union

The threat posed by climate change looms large over the EU's economy. As an example of bloc's vulnerability to climate change, in a scenario where GHG emissions continue to rise, it has been estimated that by 2050 the continent could experience damages of €310 billion per year in flooding damage alone, with the flooding affecting three million people directly.[20] Globally, it is predicted that under current trends, the effects of climate change will be severe, and cause a reduction in global GDP of 15.5%.[9] As one of the largest markets in the world, and a major exporter of goods and services globally, the EU's economy is vulnerable to shocks to the purchasing power of other countries.

In early 2022 another crisis appeared on the EU's eastern horizon, with Russia's invasion of Ukraine throwing Europe's energy security into doubt. Rising energy prices are already taking a toll on European economies, placing economic recovery from the COVID-19 pandemic in jeopardy. In early February 2022 (prior to the invasion) the European Central Bank estimated that a 10% fall in energy supply would reduce euro area gross value added by 0.7%.[21] The climate and energy crises are linked beyond occurring at the same time. The combustion of fossil fuels, a significant share of which are imported into Europe from Russia, are a primary source of Europe's GHG emissions. Therefore, while these crises present a challenge to policy makers, this link brings with it a monumental opportunity. By investing in green technologies and energy efficiency, the EU can achieve greater energy independence while also dramatically reducing its GHG emissions.

In July 2021 the European Commission adopted a series of legislative proposals that set out how to achieve net zero emissions within the EU by 2050.[22] As part of the route to net zero, an intermediate target of a 55% net reduction in GHG emissions by 2030 was set. Aside from major regulatory changes, the plan also outlines significant investment under the Green New Deal with a pledge to mobilise at least 1 trillion EUR over the next decade.[23] 30% of the EU's multiannual budget and the NGEU pandemic stimulus have been ringfenced for green investments, while EU Member States must devote at least 37% of their allocation of the 673 billion EUR Recover and Resilience Facility to investments and reforms that support climate objectives. Across the EU, annual investment of 326 to 377 billion EUR is required to cut GHG emissions by 55% by 2030.[24] In the case of decarbonising the Bloc's energy system, it is estimated that on average, annual investment of 11.1 per cent up to 2030 is required. This compares with a total investment requirement of 5.7 trillion USD (around 6% of global GDP) to achieve a global transition of energy systems to net zero emissions, as estimated by IRENA.[11]

As previously discussed, economic growth can be accelerated through investment in the green transition. Investment consistent with that outlined in the Paris Agreement is expected to increase global GDP by 2.5% by 2050.[9] For this reason, it is important to view the investment required across the EU as an opportunity rather than simply as a cost. The investment outlined above would transform the Union's economy, while cutting emissions, improving quality of life, and achieving greater energy independence. Crucially, outcomes must be considered not only against current levels, but against a counterfactual – how the economy might look if policy makers do not act. Analysis using Cambridge Econometrics' E3ME model finds that by 2030, achieving a 55% reduction in GHG emissions would lead to an increase in GDP of 0.2-0.5%, against a potential loss of GDP of 40% in a do-nothing scenario.[29] For completeness, it should be noted that within the same impact analysis but using the JRC-GEM-E3 model, GDP was predicted to be 0.3-0.4% lower by 2030 when emissions are cut by 55%. This slightly more negative outcome can be explained by a difference in assumptions about spare capacity in the economy across each model. As an equilibrium model, JRC-GEM-E3 does not account for the unemployment shock created by COVID-19 pandemic, nor the potential gains in output achievable by ensuring that more resources (labour, capital and financial) are utilised to drive the green transition.

20. COACCH-Sector-Impact-Economic-Cost-Results-22-Nov-2019-Web.pdf
21. Natural gas dependence and risks to euro area activity (europa.eu)
22. 2030 Climate Target Plan (europa.eu)
23. Finance and the Green Deal | European Commission (europa.eu)
24. EUR-Lex - 52020SC0176 - EN - EUR-Lex (europa.eu)

Other analyses support the case that the green transition will lead to economic growth for the EU. Mercure et al (2021), estimate that if the world's major economies reach their climate goals, the EU – as a major importer of fossil fuels and a leader in green technologies – will see its GDP increase by a cumulative 7.7 trillion USD over the period 2022-2036 (discounted).[19] For context, this is equivalent to 50% of the Bloc's GDP in 2021. Furthermore, analysis for the We Mean Business Coalition finds that by 2030, a green transition scenario leads to better economic outcomes than doing nothing and also outperforms traditional economic stimulus (a cut to VAT/sales taxes).[13] Green stimulus would leave GDP 1% higher by 2030, with an additional 1 million people employed. Research commissioned by the European Commission, using Cambridge Econometrics' E3ME model finds that GDP and employment increase in line with investment in energy efficiency.[25] For example, under the most ambitious scenario modelled (where an energy efficiency gain of 40% is achieved when compared to the PRIMES 2016 reference scenario), GDP is expected to increase by between 2.2 and 4.1%, with a reduction in the number of people unemployed by 3 million. Most of these new jobs would be in sectors directly related to the manufacture and installation of energy efficiency measures such as construction and engineering.

While the direct effects of the green transition on economic outcomes have been described above, the indirect effects must also be considered. Energy efficiency investments can substantially reduce overall energy demand for home heating, and this will also place significant downward pressure on fossil fuel prices. For example, analysis by Agora Energiewende finds that by increasing energy efficiency and switching to renewable energy, 1200 THh of gas demand could be saved over the next five years, amounting to a €127-€318 billion reduction in gas consumption.[26] Of course this would require significant investment by both the public and private sectors, meaning that initially households may face increased energy costs through the green transition. However, over the long term, energy efficiency upgrades will continue to insulate households from fossil fuel price increases. The European Commission finds that by 2030, an accelerated green transition could reduce energy imports by a total of 83-133 billion EUR, amounting to 0.1-0.2% of GDP.[29] However, the analysis acknowledges that this would lead to higher energy related expenses, with an accelerated green transition increasing household energy expenses by 28% by 2030. Low-income households would need to be protected from these effects. Revenues from carbon taxes can be used for this purpose as well as to boost other sectors of the economy. Under an accelerated green transition, energy taxes and carbon payments will amount to a 19.5% share of all energy system costs.[29] This will equate to between 1.8 and 2.3% of GDP in 2030 and provides a double dividend: these taxes will disincentivise and reduce carbon intensive activity while making funding available to support the transition. Furthermore, the types of new jobs created by the green transition are likely to have a distributional effect, where households across the distribution are not affected equally, with the result that low- and middle-income jobs experience the greatest wage growth.[27] Typically, increases in the disposable income of low- and middle-income workers leads to greater increases in consumption than income increases for the wealthy, due to their higher propensity to spend income. This increased consumption would have additional benefits for the economy. Analysis for Eurofound finds that service sectors would benefit significantly from the green transition with the business sector seeing an increase in employment of 0.7%, and the non-business services sector experiencing 0.3% higher employment as consumers would have more disposable income and as services are part of the supply chain for renewable technologies.[32]

The green transition will utterly transform Europe's economy. This process will create winners and losers. Policymakers must acknowledge this in how they drive the necessary change and implement policy to ease the negative effects of the transition. The EU imports most of its fossil fuels and so the effects will likely be different to those experienced by the US, which is a major producer of fossil fuels. Another fundamental difference

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25. The Macroeconomic and Other Benefits of Energy Efficiency (europa.eu)
26. 253_Regaining-Europes-Energy-Sovereignty_WEB.pdf (agora-energiewende.de)
27. Energy scenario: employment implications of the Paris Climate Agreement - Cambridge Econometrics (camecon.com)
28. Reviewing the impact of the low-carbon mobility transition on jobs (camecon.com)
29. Renewables Can Help Solve Europe's Energy Crisis | Ørsted (orsted.com)

between the EU and the US, is the EU's role as leader in wind and solar technology. That notwithstanding, certain Member States will experience job losses in particular sectors. For example, it is expected that 65,000 jobs will be lost in Europe's coal sector, which is concentrated in central and easter Europe, and in particular Poland.[29] Another example is the automotive industry, which plays a major role in the economies of Germany, France, and Italy, for example. A study by the Fraunhofer Institut found that the shift to battery electric vehicles would see the labour input required drop by 62 and 66% respectively, when compared to petrol (gasoline) and diesel vehicles.[28] Based on German vehicle production, it predicts 4,000 fewer jobs per million vehicles produced in 2030. However, this effect is not observed when calculated using Cambridge Econometrics' E3ME model, which considers the wider value chain. The E3ME findings suggest that employment across the value chain will increase by net 5,000 employees. While uncertainty about the ultimate extent of the trade-offs of the green transition exists, the case for mitigating policy is concrete. In the case of electric vehicles, the positive value chain effects can be increased through investment in battery research and development, for example. There are already encouraging signs in this regard. Although at present battery cells are largely imported from Asia, large-scale investment in European battery manufacturing has begun, with projects such as the Tesla and LG Chem gigafactories in Germany and Poland respectively. In the case of job losses in the fossil fuel sector, reskilling programmes, and initiatives to attract inward investment are key. Such interventions must be carefully targeted because the negative effects of the green transition will not be evenly distributed. Coal is concentrated in a few pockets of the continent. The same is true for automotive manufacturing.

Aside from the economic and climate impetus behind the green transition, another major motivation is to achieve energy independence. Without major domestic sources of oil and gas, the EU has long been a fossil fuel importer, relying on huge volumes of oil and gas from Russia, Middle East, and the US. This has significant implications for the Bloc's geopolitical and economic security over the long run. The Russian invasion of Ukraine has brought this strategic weakness to the fore of policy makers' minds. Despite its desire to, the Union is unable to fully cut economic ties with Russia, due to its dependence on Russian gas. This gas is fundamental to electricity production, Europe's manufacturing sector, the production of fertiliser for agriculture, and to heating homes across Europe. Agora Energiewende suggest that independence from Russian gas is achievable by 2027 through targeted investment in energy efficiency and renewable generation amounting to 680 billion USD.[31] They estimate that gas savings of 480 TWh could be achieved in buildings, with a further 223 and 500 TWh saved in industry and power generation respectively. This would result in some job losses in the gas industry, but that would be outweighed by the 418,000 new jobs created in solar and wind power generation. Onshoring Europe's power supply will create good quality jobs in Europe and this will be sufficient to offset any jobs lost in the gas industry and to compensate for increased electricity prices up to 2030. A study by Orsted finds that investment of 7-10 billion EUR in wind supply chains is required to achieve an annual deployment rate of 20 GW by 2030.[29] It finds that extra capacity of 30 GW can be put in place by 2030, on top of current targets and that this has the potential to replace 10% of current gas imports from Russia.

The green transition also has the power to dramatically improve the everyday lives of European citizens. In terms of improved human health alone, the impacts are dramatic, with the World Resources Institute predicting that by reducing emissions globally by 20.5% by 2030, European health expenditure would fall by 2.5 billion USD.[30] Furthermore, through the removal of fossil fuel subsidies, health expenditure across Europe would fall by a cumulative 7.2 billion USD by 2030. The European Commission's Fit for 55 impact assessment finds similar results. Achieving a 55% reduction in GHG emissions would correspond to a 60% reduction in air pollutants by 2030 (compared to 2015), leading to a significant reduction in premature deaths.[29] Beyond emissions reductions, wider environmental benefits would also be felt. For example the European Commission's Plastic Strategy would bring about investment of 10-20 billion USD, with the effect that all plastic packaging would be recyclable by 2030.

To summarise, there is little doubt that the green transition presents a challenge to the EU's economy, but it also presents a substantial opportunity. By investing in the green transition, the European Commission and Member State governments can achieve two stated aims – decarbonisation and weaning itself off Russian gas. Moreover, in doing so, it will drive innovation, increasing economic output and employment, with the added benefits of improved health and quality of life. Trade-offs exist and they must be acknowledged, with mitigating policy implemented to reduce any negative effects of the green transition. By embracing the green transition and supporting it with investment and policy, the evidence strongly suggests that the net economic benefits will be positive. This point is reinforced by the example of Europe's indigenous wind energy sector. As a major developer and manufacturer of wind turbines, Europe stands to gain significantly through the export of wind power technology across the globe. By investing in Europe's own green energy transition, the EU can drive innovation in that sector, ensuring that it remains competitive and at the cutting edge of development. Finally, the importance of undertaking the green transition immediately should be acknowledged. Every delay only increases the amount of change required in the future to achieve a net zero emissions by 2050, increasing the size of the shock felt by those affected. Acting now gives those affected the most time to adapt and reap the rewards of a greener, cleaner economy.

> **"By investing in the green transition, the European Commission and Member State governments can achieve two stated aims – decarbonisation and weaning itself off Russian gas.**

Germany

As Europe's largest economy, the implications of climate change for Germany and the German government's policy response to it are far-reaching. A failure by the country to adapt to climate change has been estimated to potentially cost the German economy 2.6 billion EUR per annum up to 2080.[31] This estimate is supported by analysis from Cambridge Econometrics, who find that Germany could experience flood related damages of 2 billion EUR per year, due to its proliferation of infrastructure in areas at risk of flooding.[35] Moreover, as a major exporter of manufactured goods, negative economic shocks experienced by other countries will likely have a detrimental impact on the German economy. Economic motivations are far from the only incentives for Germany to act now on climate change. The real-world effects of climate change have manifested across the country with disturbing consequences. Major rivers, such as the Rhine, have become unnavigable during long spells of dry weather – impacting the transport of essential goods and threatening water supplies. Analysis by Umwelt Bundesamt found that the drought of 2018 resulted in an 18% fall in grain yields, with the extent of the damage estimated at 770 million EUR.[32] At the other extreme, devastating flash flooding has hit parts of the country. In 2021, 134 people died in the Ahr Valley close to Bonn, when the Ahr and other nearby rivers burst their banks. A further consideration is the energy crisis that has impacted Europe since late 2021. This crisis has worsened since the Russian invasion of Ukraine in February 2022, and the supply of fossil oil and gas from Russia to Europe is likely to continue to fall as sanctions increase in intensity and coverage. As the single biggest consumer of Russian gas in the EU, this places further pressure on the German economy and provides further impetus to invest in alternative energy sources. All things considered, as an influential political force within the EU and globally, and as one of the world's largest economies, Germany's response to the dual climate and energy crises will have a significant effect on the world's ability to tackle climate change and achieve energy sustainability.

Estimates of the level of investment required by Germany to achieve a green transition vary. In 2018 BCG estimated that additional investment of the order of 1.5 to 2.3 trillion EUR is required by 2050, which equates to 1.2-1.8% of GDP annually.[33] Included in these figures is a requirement for 120 and 430 billion EUR investment by the industry and power sectors respectively, while investment of 500 and 480 billion will be required in

30. New Climate Economy: unlocking the inclusive growth story of the 21st Century - Cambridge Econometrics (camecon.com)

transport and buildings respectively. Analysis by Lutz et al (2021) estimates that additional annual investment of 38.4-49.8 billion EUR is required between 2020 and 2050, compared to the baseline (2017 policies and historical trends).[34] As a relatively wealthy country, with a large proportion of the population able to afford to take up low-carbon technologies, Germany is well placed to deliver this level of investment and it is widely held that Germany stands to gain economically from the green transition.

Analysis by Cambridge Econometrics finds that a policy scenario which subsidises EVs, phases out fossil fuel boilers, and strengthens emissions standards, would see Germany's GDP 3.2% higher than baseline by 2030, with a 1.2% increase in employment compared to baseline over the same period.[35] The same analysis finds that an alternative scenario, which expands the coverage of the ETS, does not have the same stimulating effect on the economy. Policy which includes investment is key to achieving an economic gain from the green transition. Lutz et al find similar results, with their green scenarios achieving a 1.4-1.7% GDP gain over the baseline scenario by 2030.[39] The size of the gains reduce from 2035-2050 but are still positive, in the range of 0.3-0.6%. The authors find the main driver of this increase in economic output is higher investment, which stimulates demand. They also find that revenue from carbon pricing can positively influence GDP if it is recycled through the economy effectively. More jobs are added to the economy by Lutz and co-authors' estimates, with 158-206 thousand new jobs created in 2030 and this is expected to coincide with a 2.2-3.2% increase in wages. The greatest gains are in construction, public services, and wholesale and retail trade. All of this bodes well for Germany's green transition, and indeed the country has historical precedence that shows the benefits of climate action. In 2010 8.7 billion EUR was provided to households in the form of loans, as part of the Energy-Efficient Rehabilitation Programme. It has been estimated that this intervention supported 953 thousand households and created 342 thousand jobs, all while saving 4.4 million GJ of energy and 300 thousand tonnes of CO2 per annum.[35]

While there is substantial evidence to suggest the green transition will have a net positive effect on Germany, there will inevitably be some downsides. A country with such a large industrial base, with major exports of carbon intensive products such as cars, and with significant demand for foreign fossil fuels, will face trade-offs on the road to net zero. Policy makers should consider those who stand to lose from the green transition and put in place measures to ease the burden and help individuals and firms to adapt. Among those who will experience challenges linked to decarbonisation is Germany's automotive sector. The shift from ICEs to EVs is gathering momentum, with most firms taking steps to replace their existing production lines. This will have a direct implication for jobs in the sector, as EVs have fewer moving parts than more complex ICEs. It will also have knock-on implications for supply chains and services, and further still through changes in induced demand. Analysis by the Fraunhofer Institute estimates that 9,450 workers are required to produce 1 million petrol (gasoline) ICEs, compared with 10,770 workers for 1 million diesel-powered cars.[33] However, to produce an equivalent number of EVs, between 62.1 and 66.8% fewer workers are required. Lutz et al. find that the manufacturing sector stands to lose most, with 40,000 fewer jobs in 2030.[39] The effects of increased carbon pricing will also be felt directly by households, with significant increases in the cost of fossil fuels. Analysis by Cambridge Econometrics finds that, by 2030, the price of gas will be 73% higher than under the baseline scenario.[40] Diesel and petrol (gasoline) prices are expected to increase by 20% above the baseline over the same period. Meanwhile, there are similar findings from Lutz et al. who estimate that final consumer expenditure on electricity, heating, and road traffic will increase in absolute terms but that they will decrease relative to GDP.[39] None of these challenges are insurmountable. Reskilling programmes could enable redundant automotive workers to be employed in the manufacture of new green technologies. Investment in indigenous supply chains will minimise job losses to other markets. The Tesla gigafactory in Brandenburg, which will

31. How Climate Change Is Affecting Germany | Climate Reality (climaterealityproject.org)
32. Field of Action Agriculture | Umweltbundesamt
33. Climate Paths for Germany (bcg.com)
34. Sustainability | Free Full-Text | Socioeconomic Effects of Ambitious Climate Mitigation Policies in Germany (mdpi.com)

produce batteries for electric vehicles, which might otherwise be imported, is an example of this already in action. Subsidies, loans, and grants to bring down the cost of home renovation, will insulate households from increases in energy costs. Investment in public transport, along with supports to help drivers make the move to EVs will protect consumers from increase fossil fuel costs. All in all, with a larger economy resulting from the green transition, Germany should be well equipped to ease the burden on those worst affected.

While the economy is the focus of this analysis, the wider benefits of decarbonisation should not be lost sight of. Firstly, getting the world's largest economies (and emitters) to net zero is essential to limit the devastation caused by rising sea levels and extreme weather events, which Germany has experienced first-hand. Lutz et al. estimate that with additional investments of 38.4-49.8 billion EUR per annum, compared to the baseline, Germany's GHG emissions could be reduced by 85-90% by 2050 compared to 1990 levels.[39] This would coincide with a significant drop in final energy consumption, which will fall by 50% over the same period. A report commissioned by the We Mean Business Coalition finds that the biggest drivers of reduced emissions are renewable energy subsidies and improved energy efficiency.[13] Significant reductions in GHG emissions are attainable in the short term, with Cambridge Econometrics estimating that by getting on track for net zero and the European Commission's Fit for 55 initiative, Germany could reduce its emissions by 23% by 2030 – a bigger reduction than the EU27 average of 12%.[40] A reduction in emissions has benefits beyond slowing global warming.

> **"Getting the world's largest economies (and emitters) to net zero is essential to limit the devastation caused by rising sea levels and extreme weather events, which Germany has experienced first-hand.**

Air quality will be noticeably better, particularly in urban areas, and this will bring significant health benefits. Homes will be warmer, protecting more vulnerable people from long, cold German winters. Society will be better off, too. Improved housing conditions, lower energy demand, and more sustainable energy supply will protect the most vulnerable households. Increased wages, more jobs, and a larger economy will have a particularly positive effect on those on lower and average incomes. Germany's energy security – currently a weak point for the country and the EU – will be assured, freeing the Republic and the Union of geopolitical concerns that currently hinder policy making.

Germany's fate is intertwined with that of the EU. As its largest economy and industrial heartland, Germany's path to net zero emissions will influence the success of decarbonisation across the EU. Through coordinated decarbonisation across the EU, Germany stands to gain from developing, manufacturing, and exporting new green technologies to its trading partners. By investing in the green transition, Germany can dramatically cut its GHG emissions, strengthen its economy, create quality jobs, and reduce its dependence on Russian gas. Wider benefits will also be felt through improved air quality, better health, and a higher quality of life. As an industrial and carbon intensive economy, Germany will face trade-offs on the road to decarbonisation. These trade-offs must be identified, with appropriate mitigating policy implemented to reduce any negative effects. Nonetheless, the evidence is clear that the net benefits to the green transition are overwhelmingly positive for Germany and its citizens. Germany's strong track record on solar and wind power, together with its great strides in the design and manufacture of EVs, are key examples of how Germany can gain significantly through the global export of green technology. Continued and increasing investment will secure Germany's position as a driver of innovation, and lead to the creation of new jobs in new industries. By setting out on the challenge to decarbonise its economy now, Germany can minimise the negative effects felt by those affected. Delays in the implementation of decarbonisation policy will only increase the size of shocks felt by those most vulnerable to change.

35. Exploring the trade-offs in different paths to reduce transport and heating emissions in Europe - Cambridge Econometrics (camecon.com)
36. Key elements of the 2021 Biennial Exploratory Scenario: Financial risks from climate change | Bank of England
37. The ten point plan for a green industrial revolution - GOV.UK (www.gov.uk)
38. The road to Net-Zero Finance (Sixth Carbon Budget Advisory Group) - Climate Change Committee (theccc.org.uk)
39. Green job creation, quality, and skills: A review of the evidence on low carbon energy | UKERC | The UK Energy Research Centre

United Kingdom

The UK is directly exposed to the threat of climate change, with flooding, drought and other extreme weather events becoming more common. According to analysis by the Bank of England, the UK's annual output growth could be 0.4 percentage points lower due to climate inaction when compared to early action on both adaptation and mitigation.[36] As an exporter, the country's economy is highly dependent on the economic success of its trading partners, who are also threatened by climate change. Climate catastrophe in developing countries would likely lead to significant increases in migration around the globe, placing further pressure on the UK's political system, where migration has been a central issue. That said, as a relatively wealthy country, the UK is well placed change its economy to rapidly reduce its emissions and therefore contribution to global climate change. There are already encouraging examples of this. Surrounded by sea, the UK has become a leader in the development of offshore wind and continues to invest in its development, with considerable potential for further deployment domestically and abroad. With some of the world's leading universities and research institutions, and a long history of innovation, there is great potential to develop indigenous industry in new, green technologies. Experience in oil and gas, along with the infrastructure to support it may well give the UK an edge in the nascent area of carbon capture and storage. Other strengths abound but to capitalise on them will require significant investment.

Various investment initiatives have been rolled out, and more will be necessary. Among the announced government measures is the Ten Point Plan, which allocated over 12 billion GBP of public money to support a green recover from the COVID-19 pandemic.[37] This plan is intended to leverage up to three times more private sector investment, leading to much greater capacity for change. Within this funding envelope, 5.2 billion GBP is set aside for flood and coastal defences across six years. This alone will not be sufficient, however. The Climate Change Committee has estimated that in order to achieve net-zero, the UK's extra capital investment will need to increase fivefold from 10 billion GBP in 2020 to 50 billion GBP in 2030, with this level of additional investment required through to 2050.[38]

While this level of public spending is significant, it should not be seen merely as a cost. Appropriately targeted investment can increase innovation, create jobs, and drive economic growth. In the short term there are significant employment benefits to climate change mitigation, as identified by the UK Energy Research Centre, driven by the installation of solar PVs and wind turbines and the renovation of homes.[39] Over the longer term, the economic impacts are found to depend on the extent of labour, the supply chain, and services that are imported. The Energy Research Centre finds that the long-term effects of the energy transition will only be positive where the investment contributes to an economically efficient transition. Analysis for Greenpeace finds that the decarbonisation of the residential sector through the annual installation of 600,000 heat pumps could create 44,000 jobs by 2025 and more than 70,000 by 2030.[40] Most of these jobs would be created in the construction sector, due to the required building renovations associated with heat pump installation. However, there would also be significant employment gains in the manufacturing and services sectors. Interestingly, these findings were found to be positive regardless of whether the investment was financed by the State or privately funded by households.

In a separate analysis Cambridge Econometrics assessed the macroeconomic impacts of meeting the Sixth Carbon Budget recommended by the Climate Change Committee.[41] Specifically, the model considers the impacts of a number of policy measures including the electrification of the power sector through investment in renewables, the development of hydrogen power and necessary infrastructure, and the deployment of carbon capture and storage across industry. Fossil fuel vehicles are phased out by 2030, and the share of biofuels used in aviation is increased. Consumers adopt less carbon intensive diets, while land-based carbon sequestration is scaled up significantly. These changes must be underpinned by significant investment, equivalent to 12% above the baseline investment level in 2030. Given this widescale transformation of the economy and society, substantial positive effects are predicted. In the medium- and long-term GDP increases by 2-3% above the baseline, while employment increases by 1% meaning a net 300,000 additional jobs across the economy.

A further analysis for the Centre for Energy Demand Solutions, using Cambridge Econometrics' E3ME model analyses the effects of a green stimulus package designed to drive the recovery from the COVID-19 pandemic. Focussing efforts on investment in building and industry energy efficiency would yield a 46 billion GBP return by 2040, equivalent to a 1.5% increase relative to baseline GDP.[42] In addition, 215,000 new jobs would be created over the same period. The primary drivers of this of these positive impacts are the decreased demand for gas for home heating and electricity production, which improves the UK's trade balance. Reduced spending on gas and electricity by consumers allows for greater spending on domestic goods and services, increasing aggregate demand. Product prices fall as industrial policy increases efficiency and drives costs of production down. In the medium term, the largest employment gains are experienced by the construction sector due to the emphasis on building renovation. However, over the long term, reduced energy costs to consumers create sustained increased demand for services, with this sector seeing the greatest number of new jobs created.

Although the evidence above is overwhelmingly positive, with significant opportunities open to the UK on the road to net zero emissions, there are also challenges. Some jobs will be lost, particularly in those high carbon sectors which are unable to decarbonise or are rendered obsolete by the widescale adoption of green technologies. The Greenpeace report finds that the shift away from fossil fuels and bioenergy leads to moderate jobs losses in the mining, utilities, and agriculture sectors.[45]

Policy makers should acknowledge these trade-offs and set out clear interventions aimed at minimising the negative consequences of the green transition on those affected. This can include, for example, reskilling workers to work on new, green technologies, or to meet increased demand in other sectors as consumers spend their savings. Agricultural policy is another example of where the State can minimise the negative effects of the required transformation on British farmers, while also achieving wider policy goals such as biodiversity protection and habitat restoration.

Agriculture is responsible for 10%, 68%, and 48% of the UK's total CO2, NOx, and methane emissions, respectively.[43] While this is significant, emissions from agriculture are going in the right direction, with GHG emissions 13% lower in 2019 than in 1990. A Farm Practice survey conducted by the Department for Environment, Food and Rural Affairs in 2021 found that many farmers have already realised the need to reduce the GHG emissions from their activities.[48] 67% of farmers who responded stated that it is important for them to consider the GHG emissions in their decision making, compared to 27% who didn't consider it important. Importantly, 47% of respondents believed that greener business decision making could increase the profitability on their farms. The survey also highlighted some important opportunities for Government, in educating farmers to ease their green transition and allow them to maximise the benefits from it. Some 33% of respondents stated that they lacked information, while 41% noted a lack of clarity around what to do to reduce their emissions. Furthermore, among those who have already taken some action to reduce their emissions, 26% have been constrained by financial barriers. Combined these findings suggest that Government has the potential to drive a reduction in emissions across the agriculture sector by assisting with finance, while guiding farmers in what must be done, and making it clear why it must be done.

Recent changes to the UK's agriculture policy, spurred by the country's departure from the European Union, are encouraging. Under a radically reformed agricultural policy, direct farm payments have been placed on a downward trajectory. Instead, financial supports will primarily be funnelled into the sector by aligning them with incentives aimed at achieving a range of policy goals including environmental and animal welfare outcomes. In 2021/2022 direct farm payments amounted to 68% of all agriculture spending by the State, amounting to 1,664 million GBP.[44] In contrast, in the same period, just 23% of funding provided (562 million GBP) was targeted at environmental measures. By 2045, these shares will switch, with direct payments accounting for 34% of all agricultural supports, and 57% being allocated through environmental and animal welfare initiatives.

40. Economic impacts of decarbonising heating in residential buildings (camecon.com)
41. Economic impacts of the Sixth Carbon Budget (theccc.org.uk)
42. Macro-economic impacts of green policies in the Economic Recovery Package post-Covid (camecon.com)
43. Agri-climate report 2021 - GOV.UK (www.gov.uk)
44. Agricultural Transition Plan 2021 to 2024 - GOV.UK (www.gov.uk)
45. For the purposes of this analysis countries will also refer to the European Union as a whole.

With interventions such as these, policy has the power to utterly transform the agriculture sector, and with-it rural Britain. This has the potential to breath new life into the regions, by placing value on land beyond its food-production capabilities. Measures such as these will be essential to ensuring the buy-in required to achieve a successful green transition.

The UK is undergoing fundamental economic and societal change. Brexit and the Covid-19 pandemic followed hot on the heels of the Global Financial Crisis. Now, rapid economic recovery has been stunted by high energy prices in the wake of Russia's invasion of Ukraine, and persistent supply chain issues. The green transition is an opportunity for the UK to step forward and build a better, more resilient economy and society, free from the constraints of imported fossil fuels. Improved health outcomes through reduced emissions and better air quality would reduce the burden on the National Health Service (NHS). Warmer homes would allow for a better quality of life. The UK's existing success in offshore wind highlights the ability of the country to transform. By investing in green technology and innovation, new well-paying jobs can be created across the country. There will be trade-offs and Government must ensure that policies are put in place to protect the vulnerable. Kicking the can down the road will only increase the shock felt by those most affected by moving to a net zero emission economy. Well-coordinated public investment now will leverage greater private investment and set the UK on course for a green industrial revolution.

> **"The green transition is an opportunity for the UK to step forward and build a better, more resilient economy and society, free from the constraints of imported fossil fuels.**

2. BUILDING ON THE EVIDENCE – MODELLING THE IMPACTS OF DECARBONISATION ON A SAMPLE OF MAJOR ECONOMIES

As is clear from the evidence reviewed in the previous chapter, the green transition is a significant opportunity to develop the economy, increase employment and the quality of employment, protect the environment, improve health outcomes, and increase quality of life. That said, it is also evident that the transition will take different forms in different countries, with each having their own unique characteristics. The transition will not be without its challenges and maximising the net benefits will rely on carefully calibrated policy as well as significant and well targeted public investment. Building on the evidence from the literature, this chapter introduces new analysis of the economic impacts of the green transition for a selection of the world's major economies. The chosen countries are each unique in terms of their starting points, location, natural resources, manufacturing capacity, etc. In comparing the results across the selection of countries, this report aims to highlight the sensitivity of the results to the unique factors affecting each country while also showing that the findings are broadly consistent with the evidence collated previously. The next section briefly describes the modelling methodology before setting out the baseline conditions for the analysis and then describing the scenario that is being tested. The results are reported in the following chapter.

The modelling methodology

This global analysis seeks to evaluate the potential macroeconomic impacts of policies which aim to accelerate the transition to green energy. A selection of the world's major economies is the subject of the analysis: the United States, the European Union (EU 27), the United Kingdom, Canada, India, Indonesia, Japan, and South Africa. The modelling is conducted using Cambridge Econometrics' proprietary E3ME model, which compares an accelerated decarbonisation scenario (the scenario) to a business-as-usual baseline. The economic implications of the policies contained within a given scenario are determined as the differences in outcomes between the scenario and the baseline, which each represent alternative versions of the future. This allows for an internally consistent comparison between the two.

The purpose of the modelling exercise is to determine how the performance of the economy will change due to the changes made in the structural transition, over time, from the high-carbon, business as usual economy that we know today to an economy that is on track to net-zero. GDP is the primary indicator of economic prosperity. However, GDP as a standalone indicator does not present a full picture and so the analysis also determines the implications for other indicators, such as employment and expenditure on energy. Both the scenario and the baseline are described in more detail below. The results for each country are reported and discussed in the next chapter.

The baseline

This baseline represents a business-as-usual case, is calibrated to external socioeconomic and energy projections, and incorporates assumptions for short-term COVID-19 recovery (built on the green recovery modelling previously done for WMB).[46] This assumes policies that have been implemented up to COP26 continue to have an impact and no additional policy is introduced in the future. It does not include NDCs or net zero pledges. It should be noted that it is beyond the scope of this study to consider the effects of climate change on economic prosperity. For this reason, the baseline does not reflect the potentially significant economic costs of inaction on climate change.

The scenario

The modelling is based on an accelerated decarbonisation scenario whereby the subject economies adopt policies to achieve net zero CO2 emissions by the mid-2050s – developed countries reach net zero by 2050, while developing countries reach net zero in the late 2050s to early 2060s. This decarbonisation of the economy is achieved through substantial investments from the public and private sectors, plus behaviour changes which alter underlying demand for energy. The policies are tailored to consider specific measures in the national/regional context (identified from the evidence review and other work recently carried out by Cambridge Econometrics on similar topics). A detailed discussion of the policy assumptions within the scenario, the E3ME model, its theoretical underpinnings, and the data used, is available in Appendix A.

46. Key sources include European Commission, IEA World Energy Outlook and CEDEFOP.

3. RESULTS OF THE MACROECONOMIC MODELLING

As described in the previous chapter, the green transition will be experienced differently by different countries, depending on their unique characteristics. Developing countries will have very different needs to developed countries, along with radically different demographic profiles. Countries with harsh, cold winters wills require significant heating capacity while those in warmer climates may have greater need for cooling technologies. The transition will also require different policy mechanisms depending on whether a country is a fossil fuel importer or exporter, due to the effect that the phasing out of fossil fuels will have on the labour market and he economy.

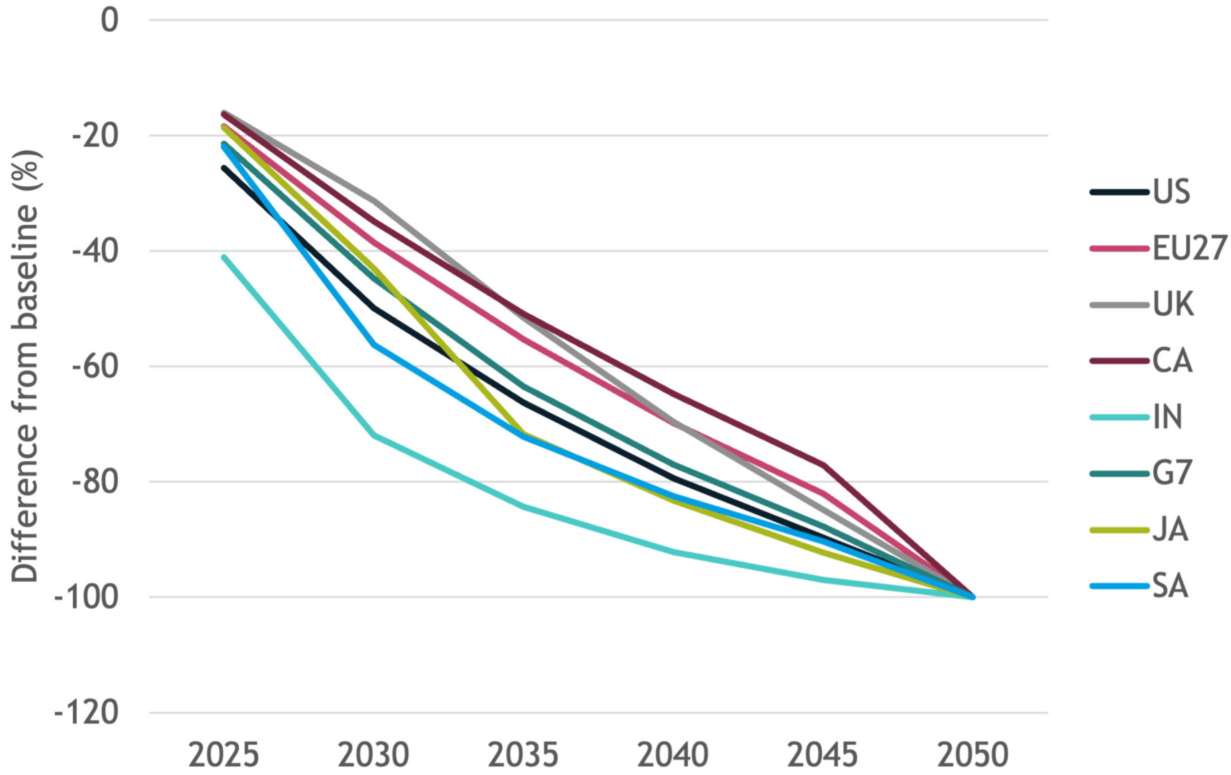

Figure 1: Path to net zero emissions by country

Despite the varied paths to net-zero, the endpoint of the transition will look quite similar for each country, as illustrated in Figure 1, above. In the modelling exercise conducted by Cambridge Econometrics the eight subject countries reach net zero CO2 emissions by 2050. The remaining sections of this report consider, on a country-by-country basis,

i. the level of investment required to make this transition a reality,

ii. the effect of the transition on household expenditure on various energy sources,

iii. the impact of the transition on the economy in terms of GDP and employment.[47]

All results are presented as relative differences from the baseline scenario, in percentage terms. The findings are presented in this way to emphasise an important point: this analysis is not an economic forecast but rather it seeks to highlight the relative effects of a green transition when compared to a baseline scenario. A table of results is included in Appendix B.

47. Note that despite countries reaching net zero by 2050, expenditure on natural gas does not fall to zero. A small share of households continues to use natural gas but the emissions from this are offset through land use change and carbon capture (BECCS).

United States

As the world's leading economy and a major exporter of fossil fuels, ICE vehicles and other carbon intensive goods and services, the effects of the green transition on the US are of particular significance. Furthermore, as a country of global influence, and a major donor to developing countries, the success of the global green transition will depend heavily on outcomes in the US and on the country's continued economic strength.

Figure 2 shows the additional investment required up to 2050, to deliver a green economy for the US. These figures include both public and private sector investment, and the split between these depend on the design of policy and varies by sector. In the case of the US, investment is heavily frontloaded, with additional investment of 11.3% in 2025. Investment then falls back to less than 5% in each subsequent period reported.

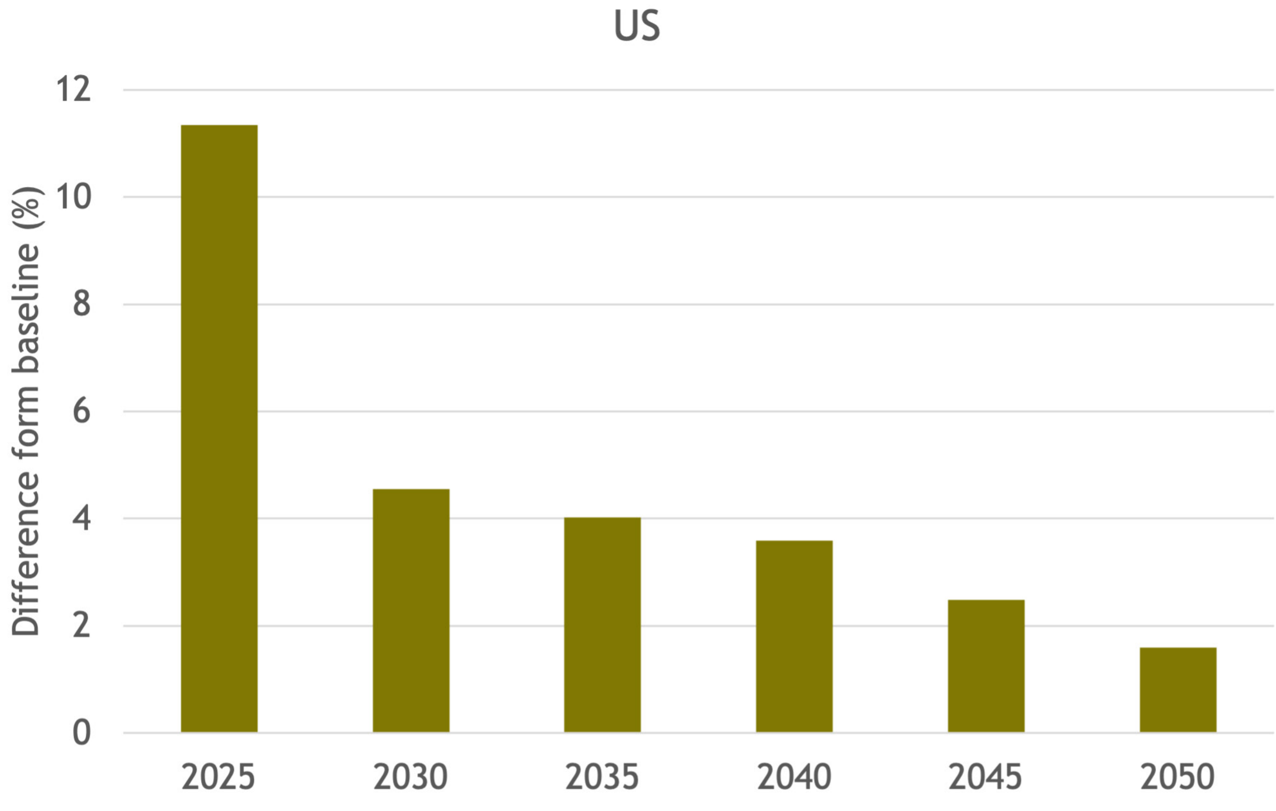

Figure 2: Investment over time, difference from baseline (%)

As an economy with enormous demand for energy, the additional investment noted above must be considered in terms of its effect on energy demand and, ultimately, household expenditure on energy. Figure 3 shows rapid benefits in the greening of the energy system, with expenditure on natural gas 11.7% below baseline and expenditure on petrol (gasoline) and diesel 5.3% below baseline in 2025. From here, household expenditure continues to fall rapidly up to 2050, where spending on petrol (gasoline) and diesel falls to nothing, while expenditure on natural gas is 81.5% below baseline. Over the same period expenditure on electricity increases, to 19.8% above baseline in 2050. This reflects the electrification of the economy, with homes being heated and cooled by heat pumps and drivers switching to EVs. Despite this increase, this still represents a very significant reduction in energy spending across the US economy. The shift to renewable technologies allows for cheap energy, whose price is decoupled from geopolitical events that can trigger fossil fuel supply issues and consequent price hikes. With warmer homes and cheaper transport, lower income households experience a significant and positive disposable income shock, with less money being spent on heating and getting to work.

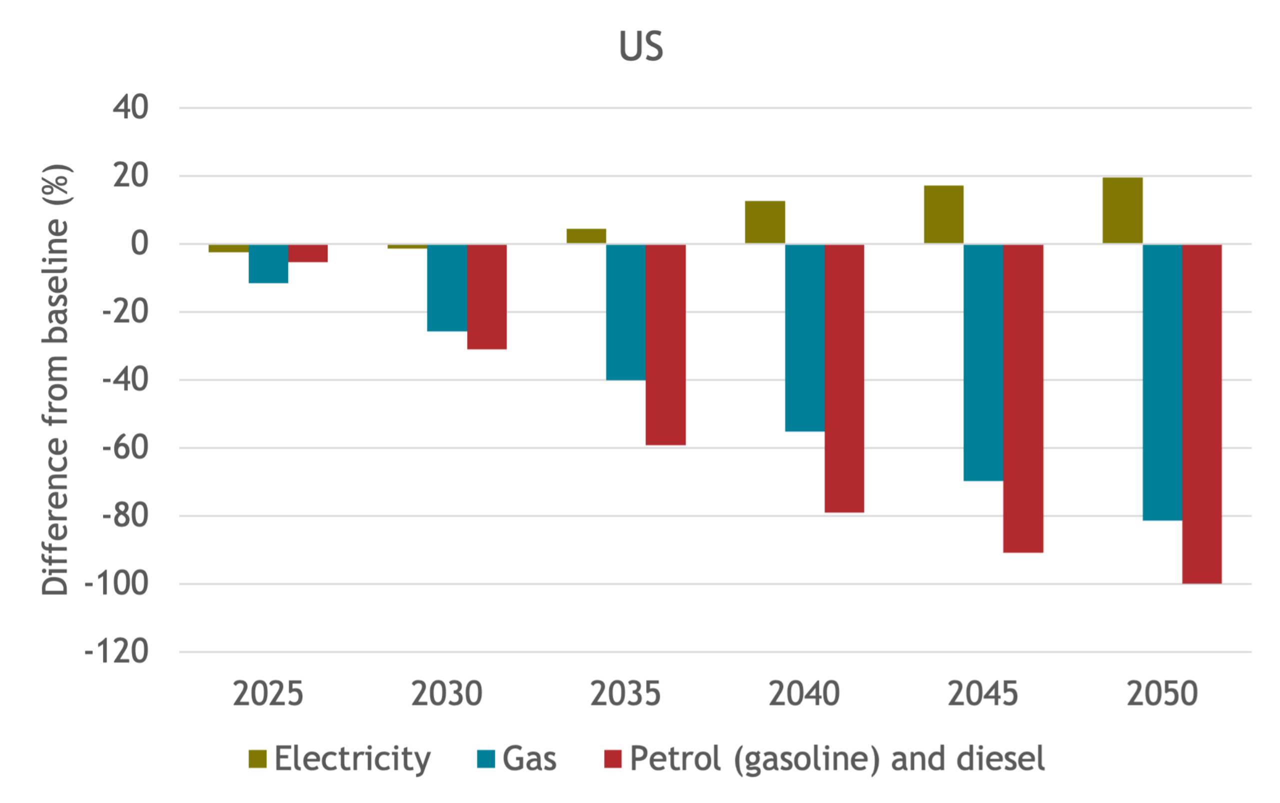

Figure 3: Household expenditure on energy over time, difference from baseline (%)

The impacts of the green transition on the US economy are mixed, with gains relative to the baseline observed in the first half of the analysis period, followed by some losses between 2040 and 2050 but early action could lead to smaller losses. GDP is 1.9% higher than the baseline in 2025, with employment up by 0.6%. This is the result of the major investment made to decarbonise the economy. As a major fossil fuel exporter, it is not particularly surprising that, as 2050 approaches and the countries included in this analysis make the transition to net zero, demand for fossil fuels will fall and exporters will experience a fall in output and employment. Indeed, analysis of changes in total output show clearly that the fossil fuels sector is dominating these results. Given that, in the case of the US, losses relative to the baseline come in the second half of the transition, this allows time to develop the kind of policy interventions that may alleviate such trends. For instance, policies which direct savings in energy expenditure into further investment in the economy could raise productivity and leader to greater economic growth.

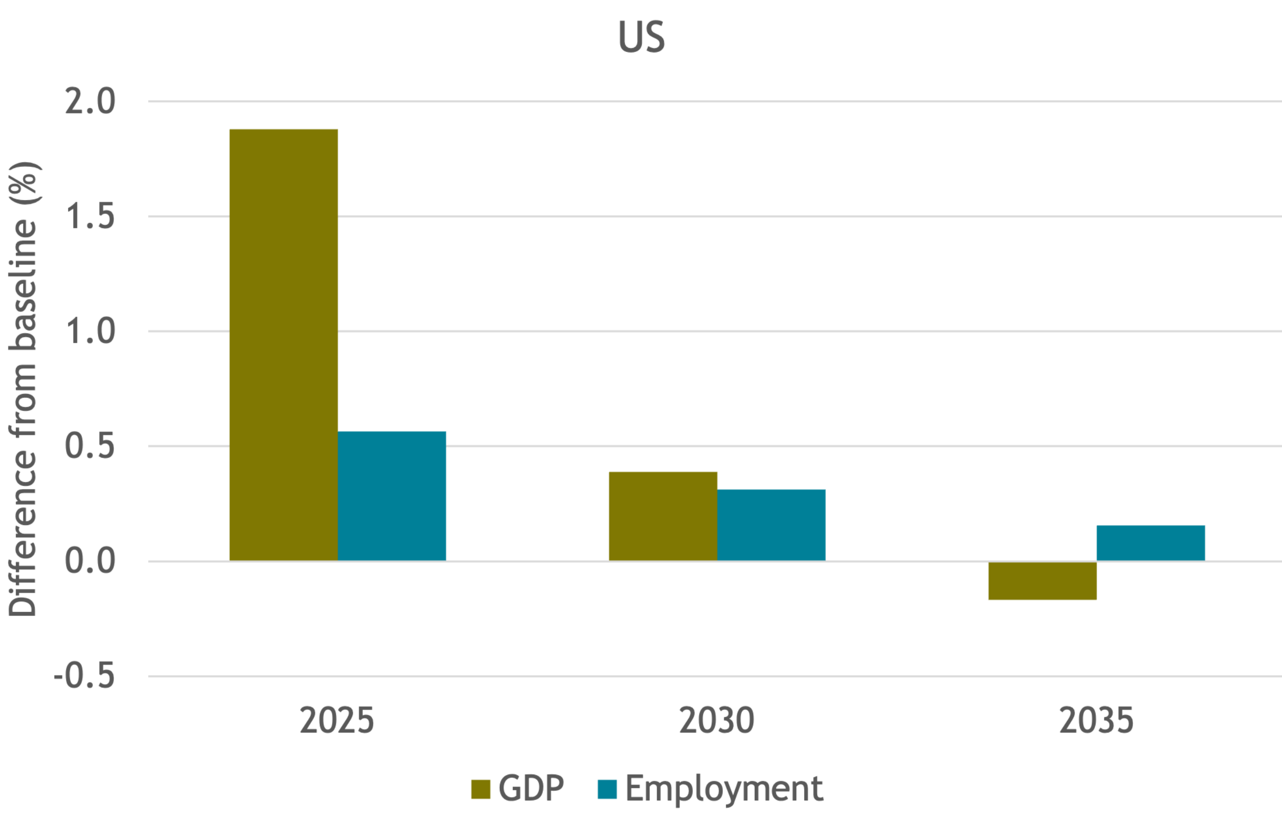

Figure 4: GDP and employment over time, difference from baseline (%)

The US, as the world's biggest and most carbon intensive economy, has an important role to play in getting the world to net zero. Even for such a highly developed economy, the changes required will not be easy, requiring significant investment. Some sectors will lose out but given the ambition across the world to reduce fossil fuel consumption, the market for fossil fuels will shrink regardless of whether the US achieves decarbonisation. Careful policy design can help to alleviate any negative consequences of the transition and encourage investment in new growth areas. Lower energy cost would lead to a greater standard of living among low-income households. Achieving net zero would not only contribute to the fight against climate change, but it would also improve air quality and reduce pollution with dramatic and immediate impacts on the health of the US population.

European Union

As a bloc, the EU has an economy of comparable size to the US but with very different characteristics. Countries within the EU are typically characterised by a large welfare state, relatively extensive public transport, a large share of the population living in apartments, and a dependence on imported fossil fuels. While each country will set out its own path to decarbonisation, some policy is set for the EU as a whole by the European Commission, and collaboration between European states on decarbonisation is likely to continue. The European Commission also coordinates and supports investment in the green transition, in addition to the individual investments made by Member States. Figure 5 shows the profile of additional investment, relative to baseline, required to decarbonise the EU's economy. Additional investment of 6.8% is required in 2025 and this declines gradually over time, to 2.7% in 2050. These requirements will vary by Member State and the EU's institutions have a role to play in redistributing investment to where it is most needed to achieve decarbonisation across the bloc by 2050. The investment will come from both public and private sources and the relative shares will depend on the sectors and their respective capacities to decarbonise without direct public support.

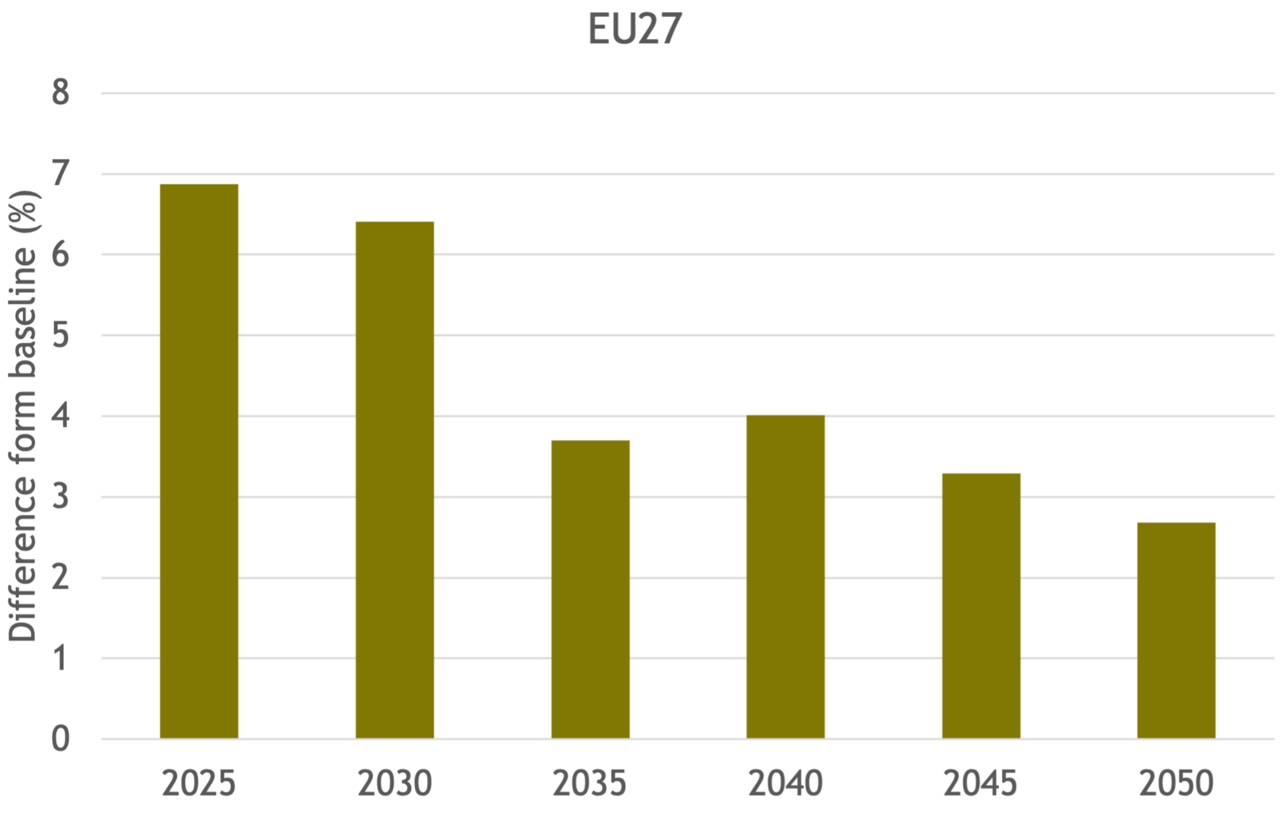

Figure 5: Investment over time, difference from baseline (%)

There is a clear pay-off for this investment, as illustrated in Figure 6, with expenditure on natural gas, petrol (gasoline) and diesel falling dramatically over the period. Indeed, by 2050, expenditure on petrol(gasoline) and diesel falls to zero, with the Union's fleet of ICE vehicles being replaced by EVs. Natural gas expenditure falls 7.5% below the baseline in 2025, and by 2050 it lies 85% below baseline. Given the EU's reliance on imported natural gas from Russia, and the geopolitical challenges that this presents, the benefits of the move away from natural gas are broad and far-reaching. These savings in fossil fuel expenditure are offset partially by increased expenditure on electricity in line with the electrification of the economy. However, overall, this represents a significant net reduction in expenditure on energy across the economy. Cheap renewable energy combined with investment in energy efficiency will greatly improve the lives of Europeans. Not only will homes be easier to heat/cool, and vehicles be cheaper to run, goods such as food, that require significant energy inputs will also likely be cheaper than under the baseline scenario.

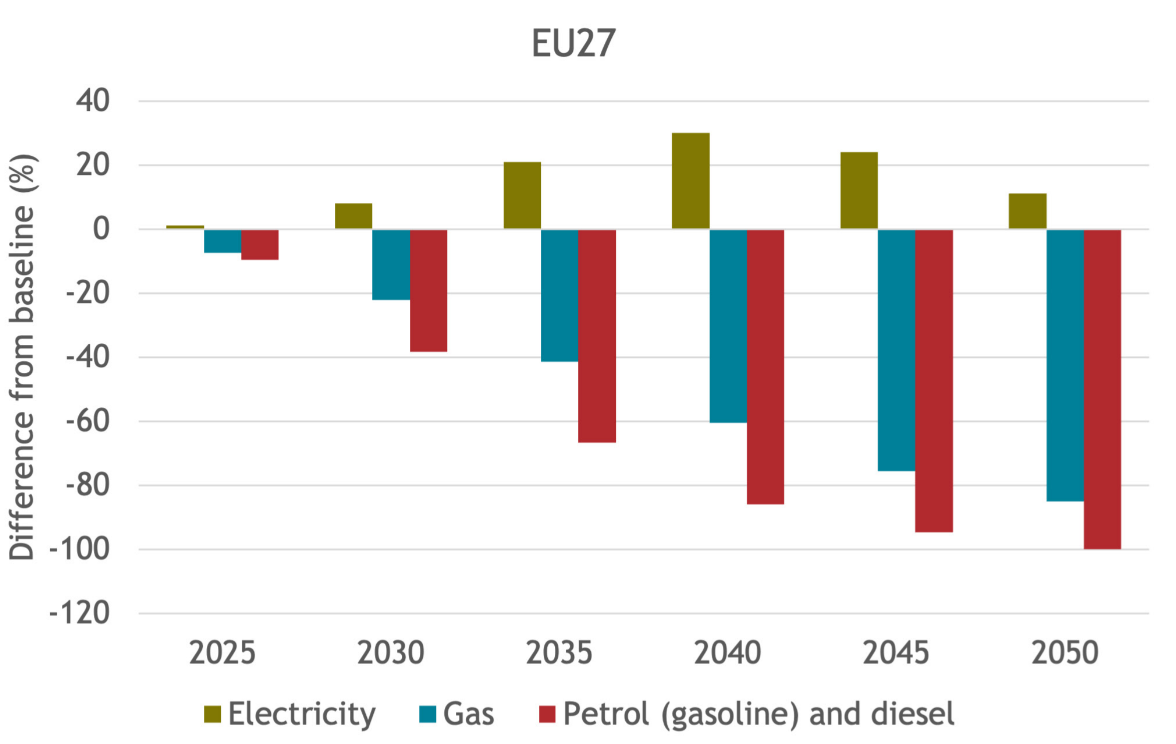

Figure 6: Household expenditure on energy over time, difference from baseline (%)

As a fossil fuel importer, and major producer of green technology, the EU's economy stands to gain substantially from decarbonisation. Our analysis finds that in 2025, GDP will be 1.8% above the baseline with a 0.6 increase in employment, as shown in Figure 7. Similarly positive results are observed across all periods, with a slight downward trend towards 2050. On average, GDP will be 1.3% above the baseline in each period, with employment 0.4% above baseline on average. These results alone make a strong case for decarbonising the EU's economy. However, beyond this - by achieving net zero emissions - Europeans will achieve increased quality of life, better health outcomes, and lower levels of air, soil, and water pollution. Furthermore, by moving away from fossil fuels, the EU will achieve greater energy independence, with the geopolitical freedom that that brings.

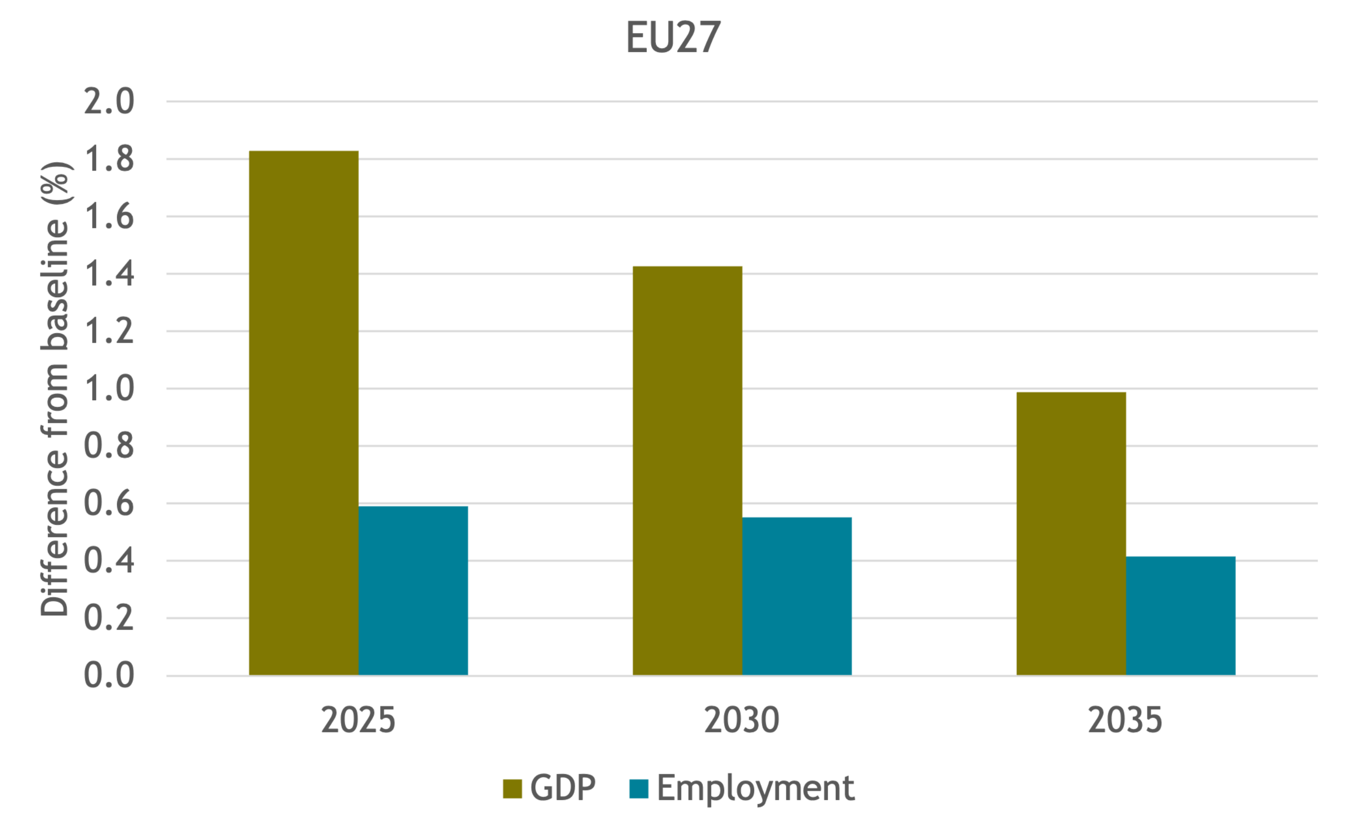

Figure 7: GDP and employment over time, difference from baseline (%)

United Kingdom

Having left the EU, the UK will plot its own course towards net zero. However, given its physical proximity to, and long-established connections with the EU it is likely that decarbonisation will best be achieved through collaboration. As an example, of how such collaboration will be pivotal, consider the electricity market. Electricity interconnectors allow for larger scale energy markets and more efficient use of capacity, which is particularly advantages as the share of renewable energy increases. The UK's strength in offshore wind presents a significant opportunity for the country and its trading partners. Significant investment will be required for the UK to achieve its climate ambitions and to capitalise on the opportunities that the green transition presents. Figure 8 presents the additional investment required across the UK economy up to 2050. The additional investment may come from public and private sources, is relatively consistent over time, and averages 5.4% above the baseline.

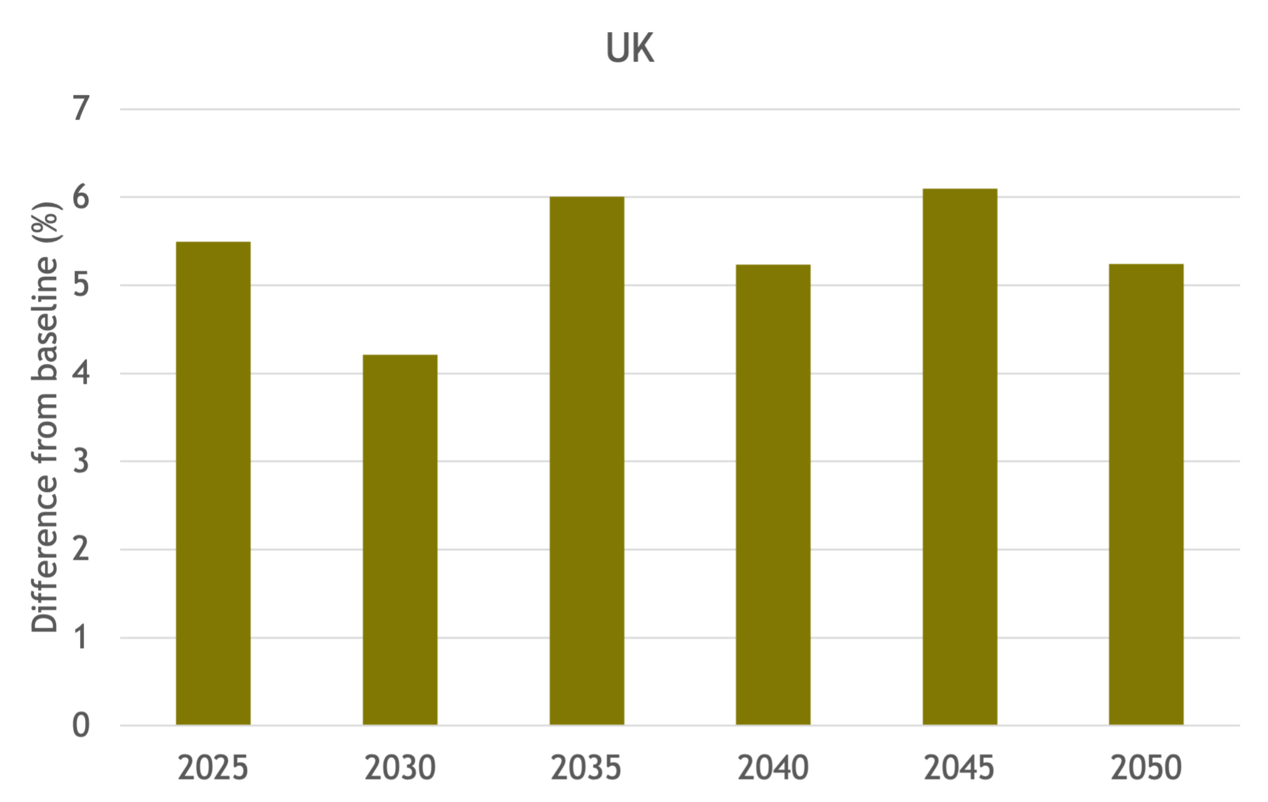

Figure 8: Investment over time, difference from baseline (%)

The investment described above will have a transformational effect on energy expenditure across the UK, as illustrated in Figure 9. Expenditure on natural gas falls 80.1% below baseline by 2050 while expenditure on fossil fuels for vehicles falls to zero over the same period, as the fleet is replaced by EVs. Electricity expenditure increases significantly, in line with the electrification of the economy.

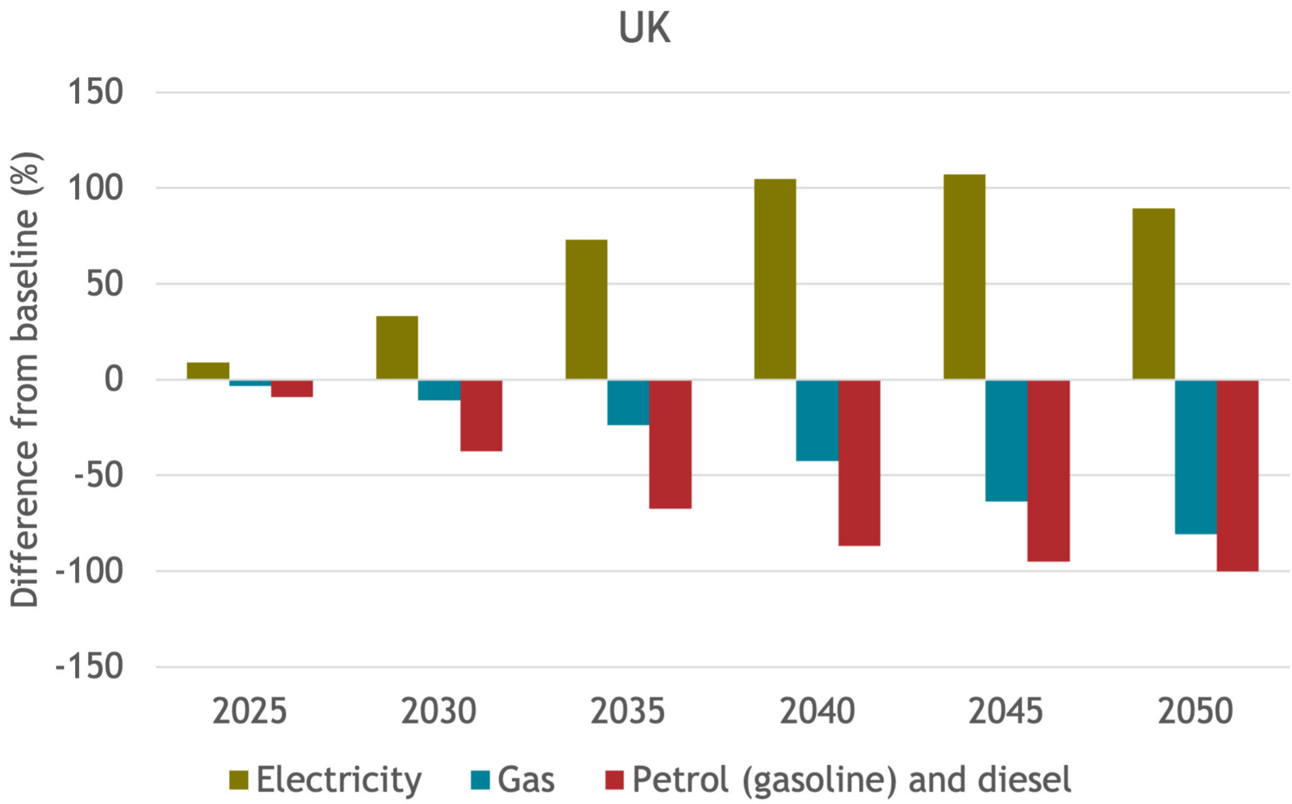

Figure 9: Household expenditure on energy over time, difference from baseline (%)

The UK's economy experiences significant gains from the green transition, as evidenced by Figure 10, below. In 2025, the UK's GDP is 1.1% above the baseline level, and in each period thereafter, the economy is on average 1% bigger than the baseline. This has a major impact on jobs also, with employment figures an average of 0.7% higher than the baseline between 2025 and 2050.

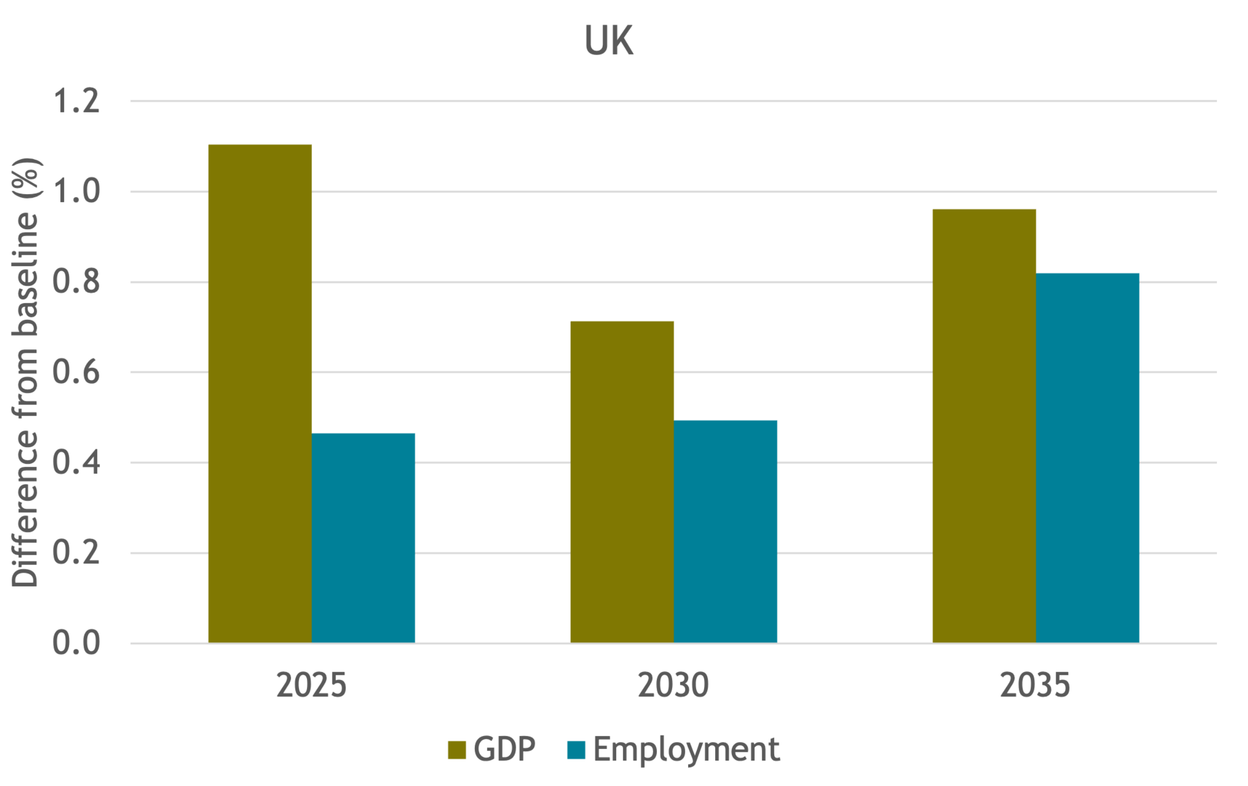

Figure 10: GDP and employment over time, difference from baseline (%)

Canada

Canada has a highly developed economy and is a major exporter of fossil fuels. Its welfare state lies somewhere in the middle of the US and a typical European country in terms of breadth and level of support. Figure 11, below, shows the additional investment required to decarbonise Canada's economy. The additional investment will come from a mix of private and public sources and is frontloaded, with investment an average of 8.3% above baseline up to 2030, and just 4.7% above baseline on average, thereafter, up to 2050. This investment has a significant impact on household expenditure, as discussed below.

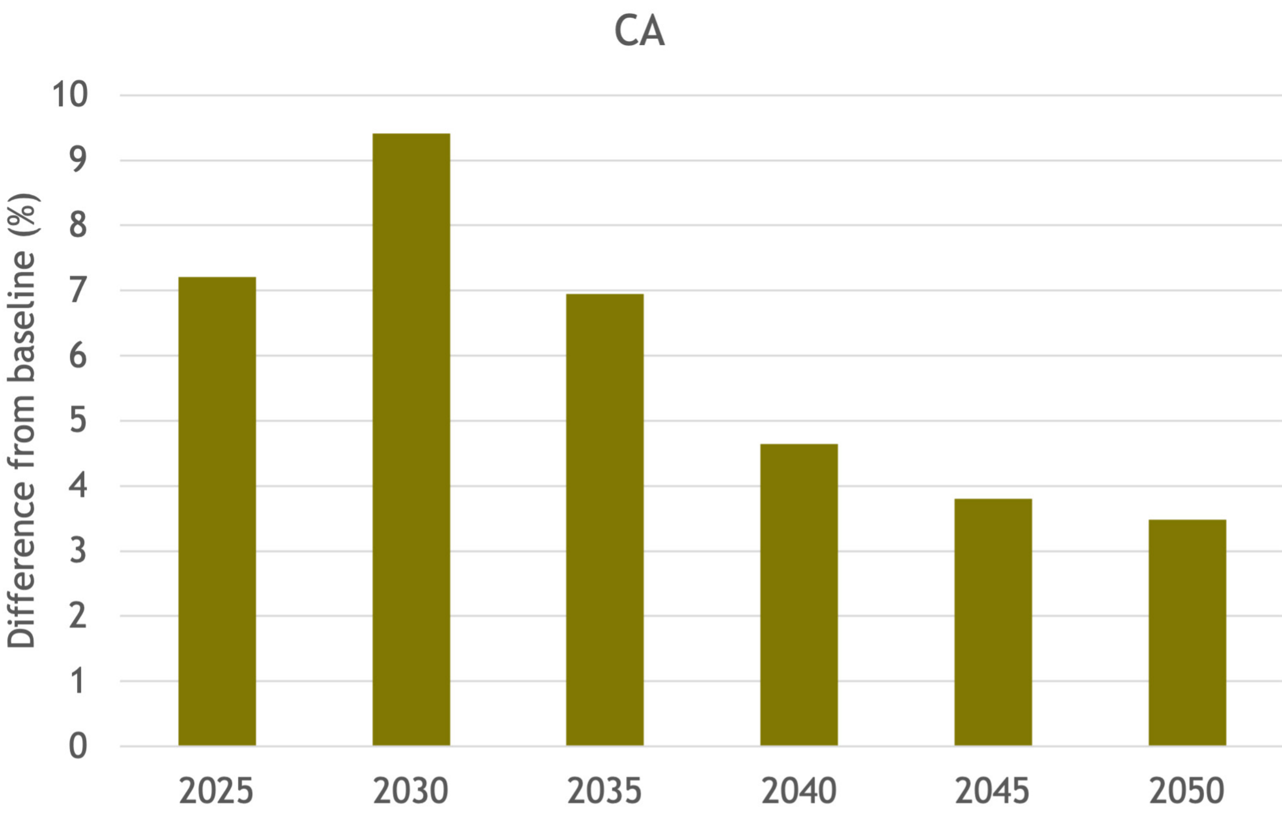

Figure 11: Investment over time, difference from baseline (%)

As an expansive country, stretching from the Pacific to the Atlantic, and from the Arctic to temperate zones along its southern border. This creates significant demand from households for heating and cooling. Figure 12 shows the impact of investment in the green transition on household expenditure on energy. Expenditure on natural gas falls 84.5% below the baseline by 2050, while expenditure on electricity increases to 66% above the baseline over the same period. This reflects the electrification of the economy, with homes being heated and cooled using electric devices, as well as the replacement of ICE vehicles with EVs. The rise of EVs leads to a dramatic fall in household expenditure on petrol (gasoline) and diesel, which falls by a third by 2030. By 2050 households spend nothing on fossil fuels for their cars. These savings represent a significant positive disposable income shock for households, with particular benefits felt by low-income households, whose expenditure tends to be dominated by housing, food and energy costs. Indeed, the shrinking reliance on fossil fuels will, all else equal, lead to lower food costs as production input and transport costs fall.

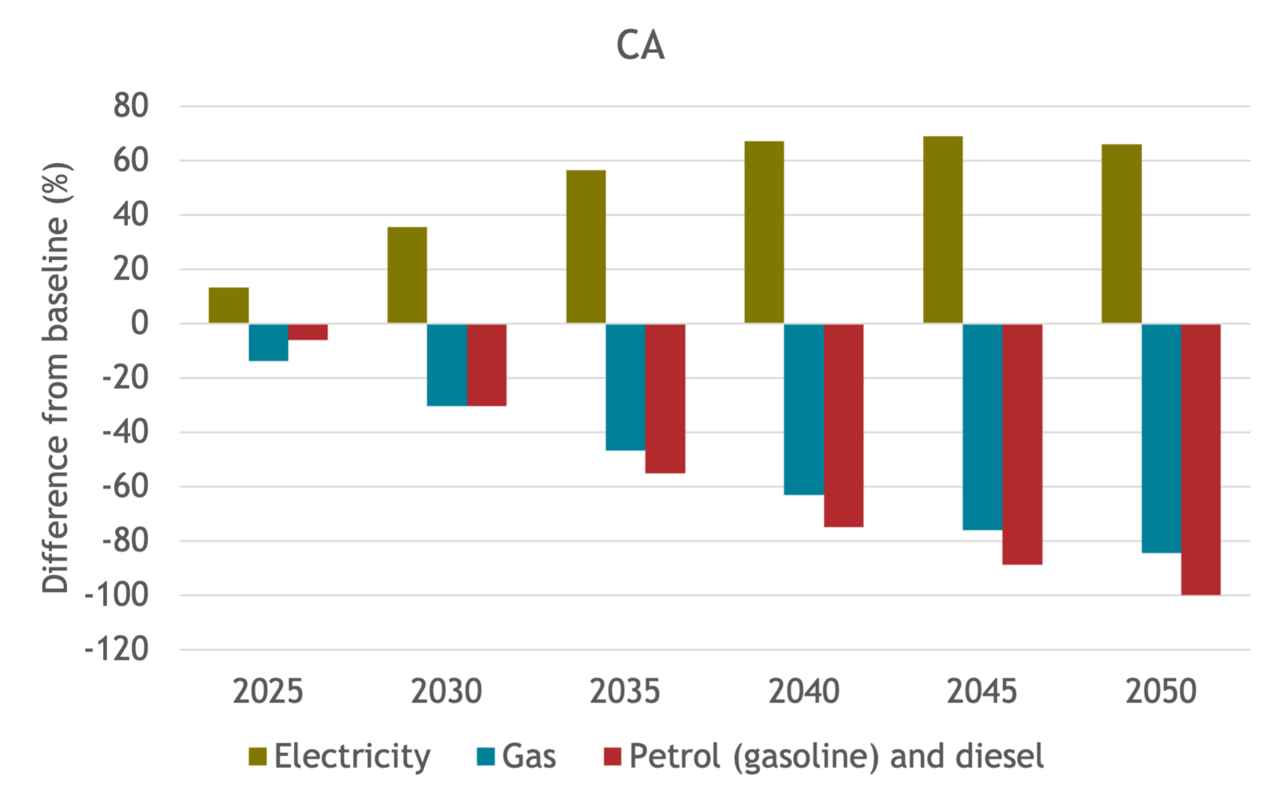

Figure 12: Household expenditure on energy over time, difference from baseline (%)

Despite significant benefits for Canadian households, as a fossil fuel exporter, it must be recognised that the green transition will present some challenges for Canada's economy. Our modelling shows that up to 2030, GDP is above the baseline, with marginal effects on employment, as shown in Figure 13. From 2035, as countries across the world transition away from fossil fuels, demand for oil and gas falls, with negative effects for Canada's economy. By 2050, GDP is 4.8% below baseline with employment 1.1% lower. Analysis of sectoral output finds that output from the fossil fuels sector is driving this result. It must be acknowledged, however, that global demand for oil and gas will fall regardless of Canada's own policies around decarbonisation. By considering the findings here, Canadian policymakers can work to reduce the negative impacts on those affected by the green transition while also seeking to develop new engines for growth within the Canadian economy. With negative effects only expected to materialise from the 2030s onwards, there is time to implement reform of the economy, maximising the benefits and minimising the challenges posed by getting to net zero.

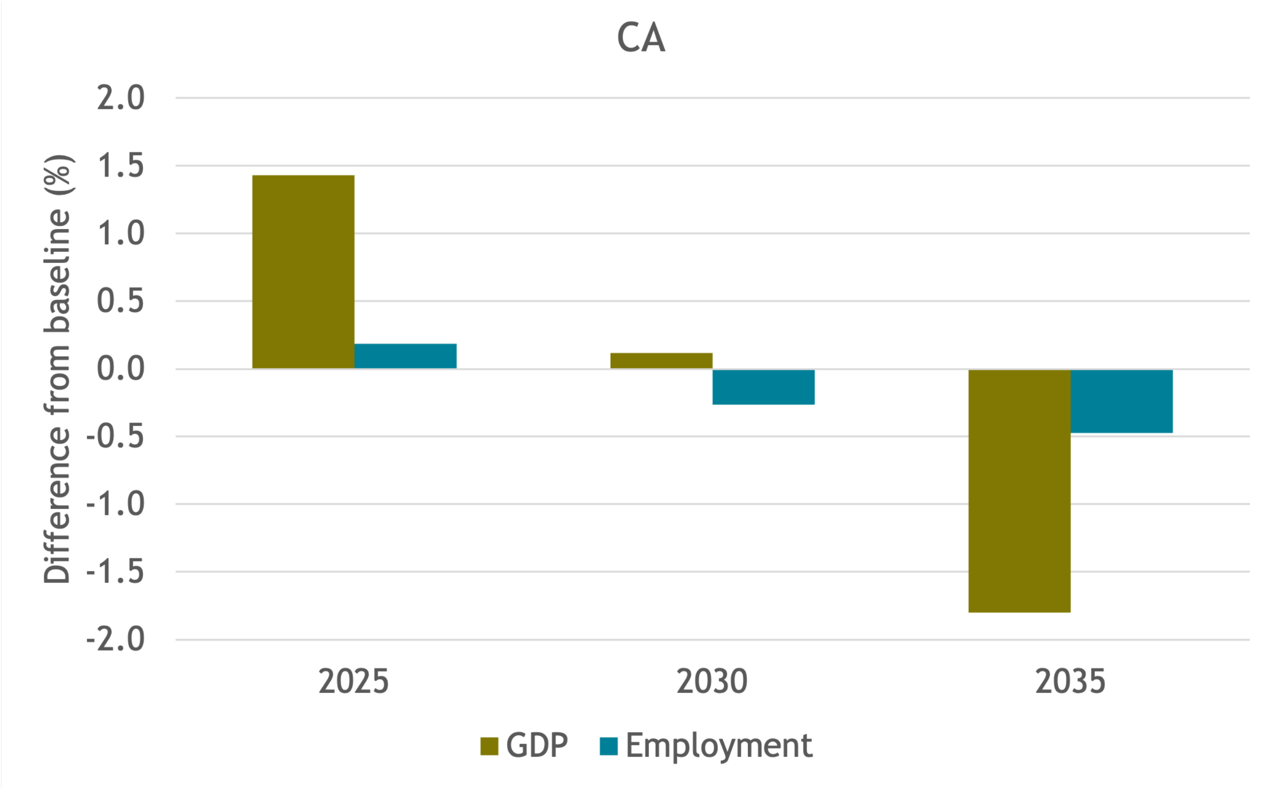

Figure 13: GDP and employment over time, difference from baseline (%)

India

India is the world's second most populous country and is expected to overtake China as early as 2026. Given the scale of the country and its ambition to increase living standards and quality of life, India's success in decarbonisation is a matter of great significance to the world. Enormous investment will be required for India to make the transition, and this will come from both public and private sources, from within India and without. Figure 14 shows the extent of the additional investment required between 2025 and 2050. As can be observed, investment is required to increase by a third in 2025. The additional investment required does not fall to rates comparable with the US or EU until 2040-2050. This will be a significant challenge for a country that already faces significant socioeconomic issues, including relatively high levels of poverty.

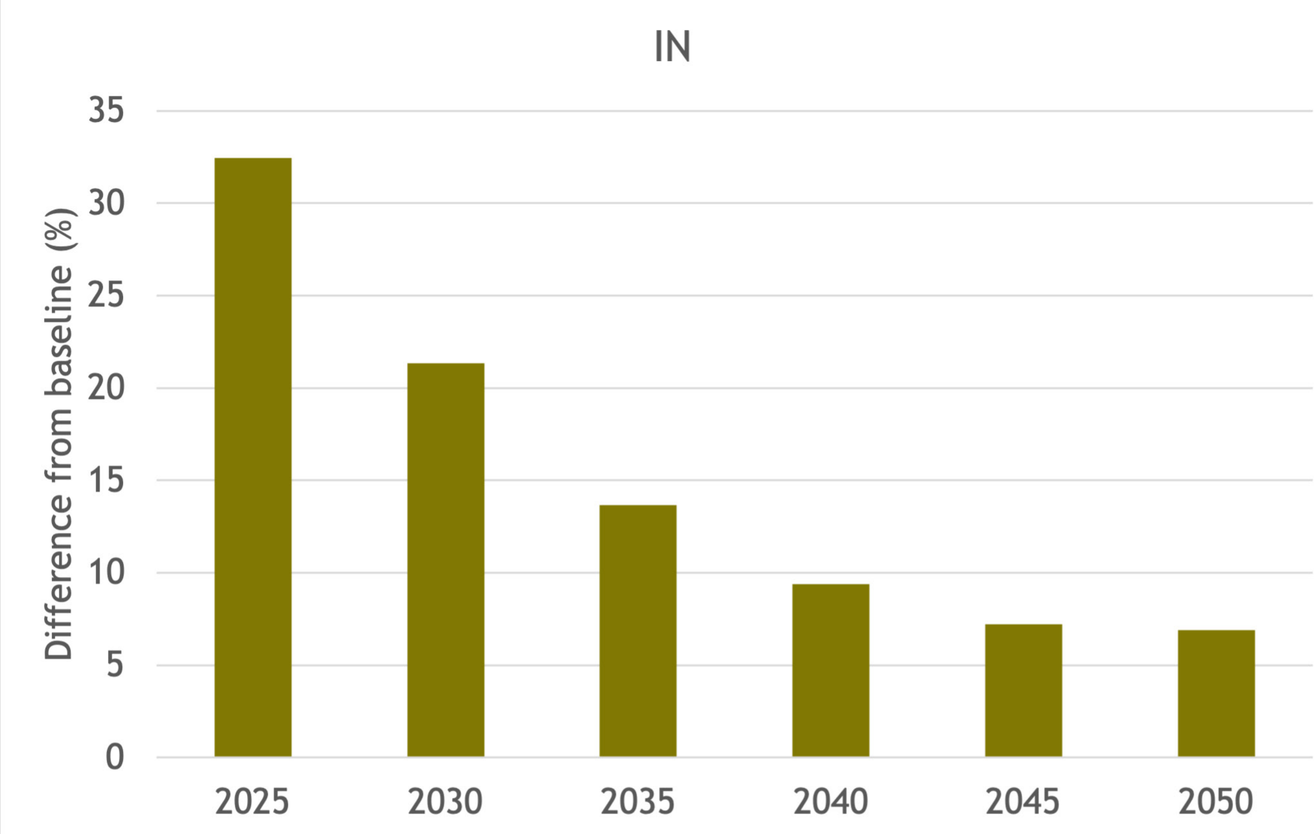

Figure 14: Investment over time, difference from baseline (%)

Nonetheless, if such additional investments are made, and the Indian economy is successfully decarbonised, households will experience very significant benefits in terms of energy expenditure. This has the potential to dramatically increase disposable income, with positive implications for poverty reduction. As Figure 15 shows, expenditure on natural gas is halved by 2030, and falls to 76.7% of baseline by 2050. Over the same period expenditure by households on petrol (gasoline) and diesel falls to zero, reflecting the transition away from ICEs and towards EVs. Expenditure on electricity increases slightly, to an average of 9.6% above the baseline, reflecting the electrification of the economy. These results do not simply point to financial benefits for Indians. India is a country beset by issues with air and water pollution, with all the very serious health implications of that. India is a major consumer of coal, and its cities are choked with smog from heating and transport. Investment in renewables and other green technologies has the capacity to greatly improve the lives of India's people.

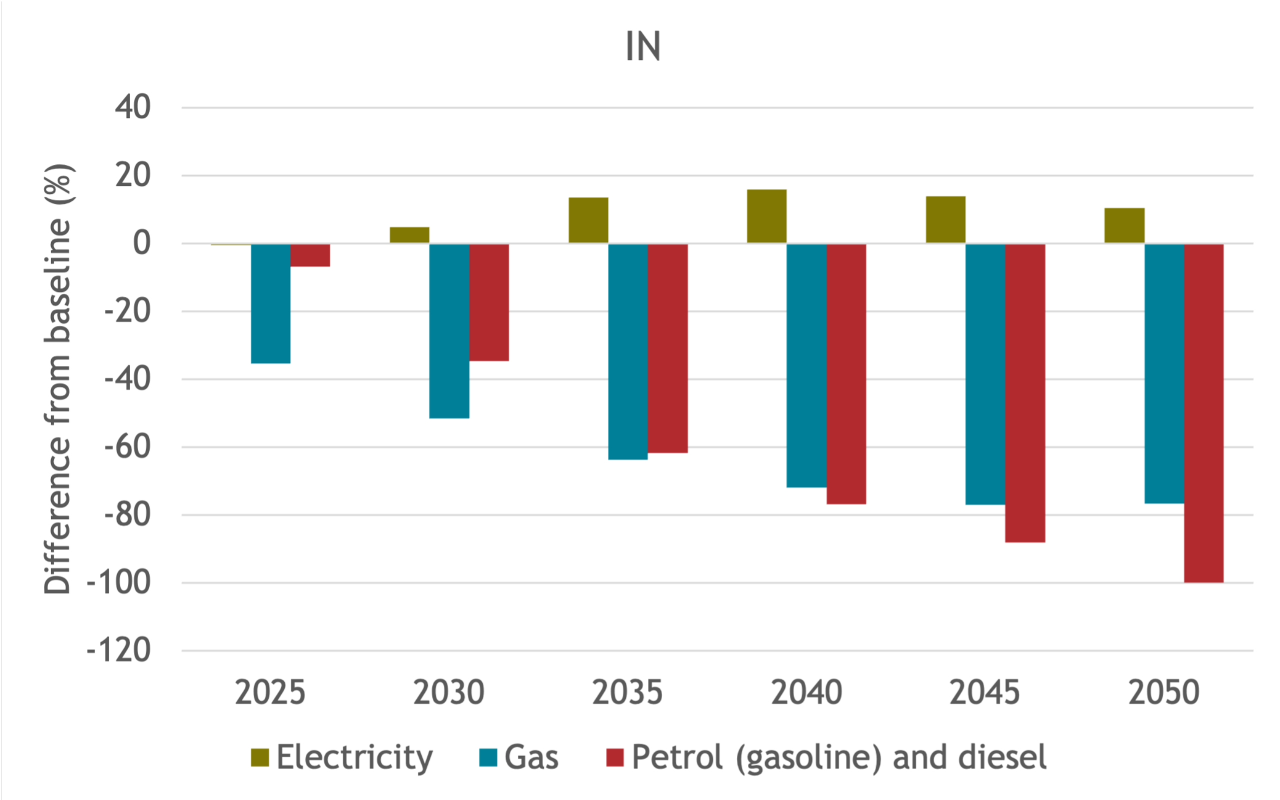

Figure 15: Household expenditure on energy over time, difference from baseline (%)

India's economy stands to gain very significantly the green transition, as shown in Figure 16. This should make the additional investment required easier to bear, while also increasing the capacity of the economy to address other socioeconomic issues. In short, decarbonising India's economy will not only reduce household energy costs and improve health outcomes, but it will also increase economic output and employment. In 2025, GDP is 9.9% above the baseline with a 2.9% increase in employment. These strong results gradually trend downwards, but even by 2050 the economy will see substantial benefits, with GDP 2.4% above the baseline and employment 0.1% higher.

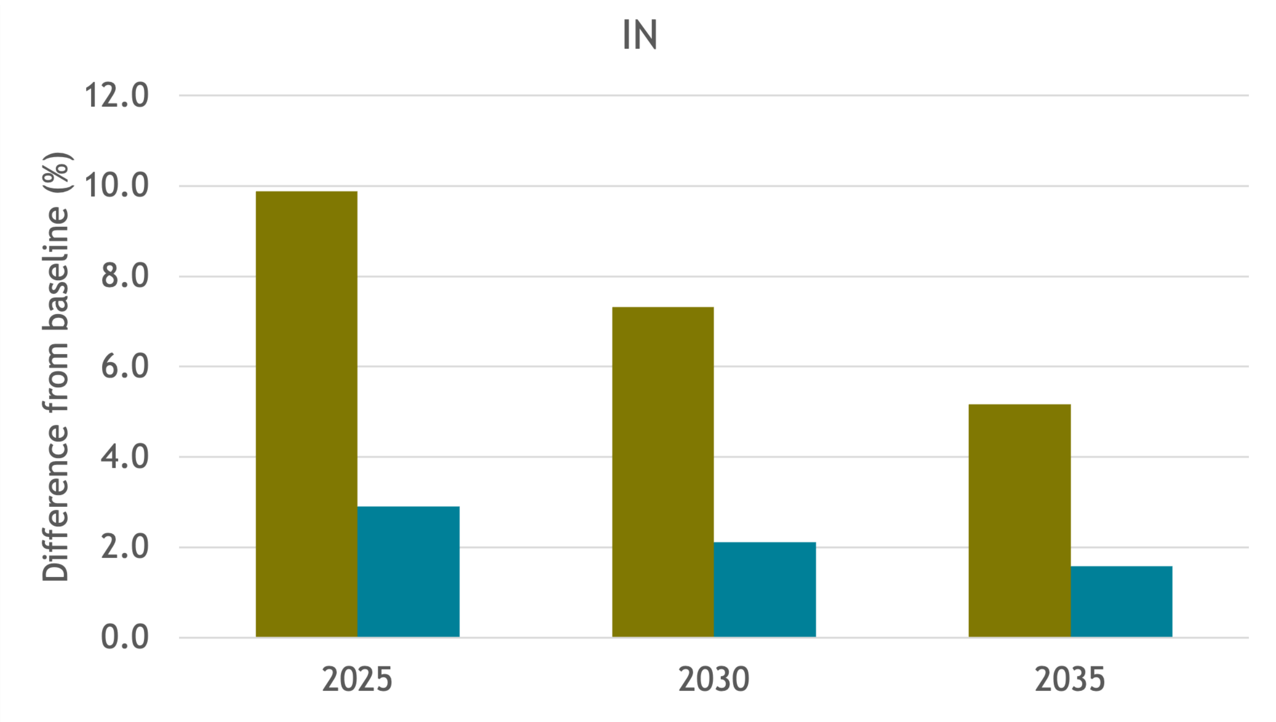

Figure 16: GDP and employment over time, difference from baseline (%)

Indonesia

As a populous island nation with many coastal settlements and persistent challenges around poverty, Indonesia must invest heavily to decarbonise its economy. Figure 17 shows that the greatest increase in investment is required around 2030, with the amount invested 35.8% above the baseline. Additional investment in other periods is substantially lower, representing an average increase of 13.1% on the baseline figure. This investment will come from both private and public sources but for a developing nation this is a significant outlay and international assistance and/or collaboration may be required.

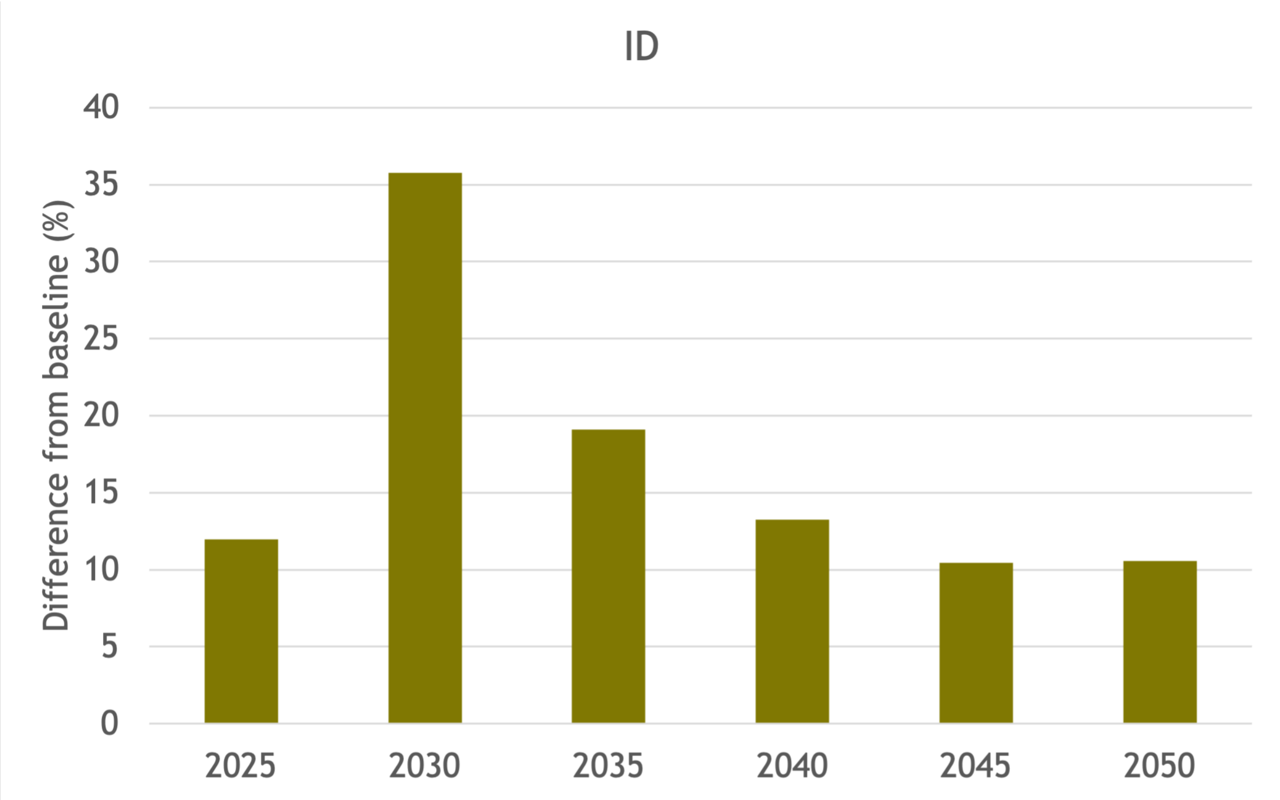

Figure 17: Investment over time, difference from baseline (%)

Despite the challenges that the country may face in terms of the level of additional investment required, the benefits experienced by households will be substantial as shown in Figure 18. Expenditure on natural gas by households is one quarter below the baseline by 2025 and it falls 76.9% below baseline by 2050. Household expenditure on petrol (gasoline) and diesel falls dramatically, and eventually to zero by 2050. Despite this, and the electrification of the economy, households will not experience major increases in their expenditure on electricity. Combined, these effects represent a significant positive disposable income shock for households, with particular benefits for those on low incomes who tend to spend a greater share of their money on energy.

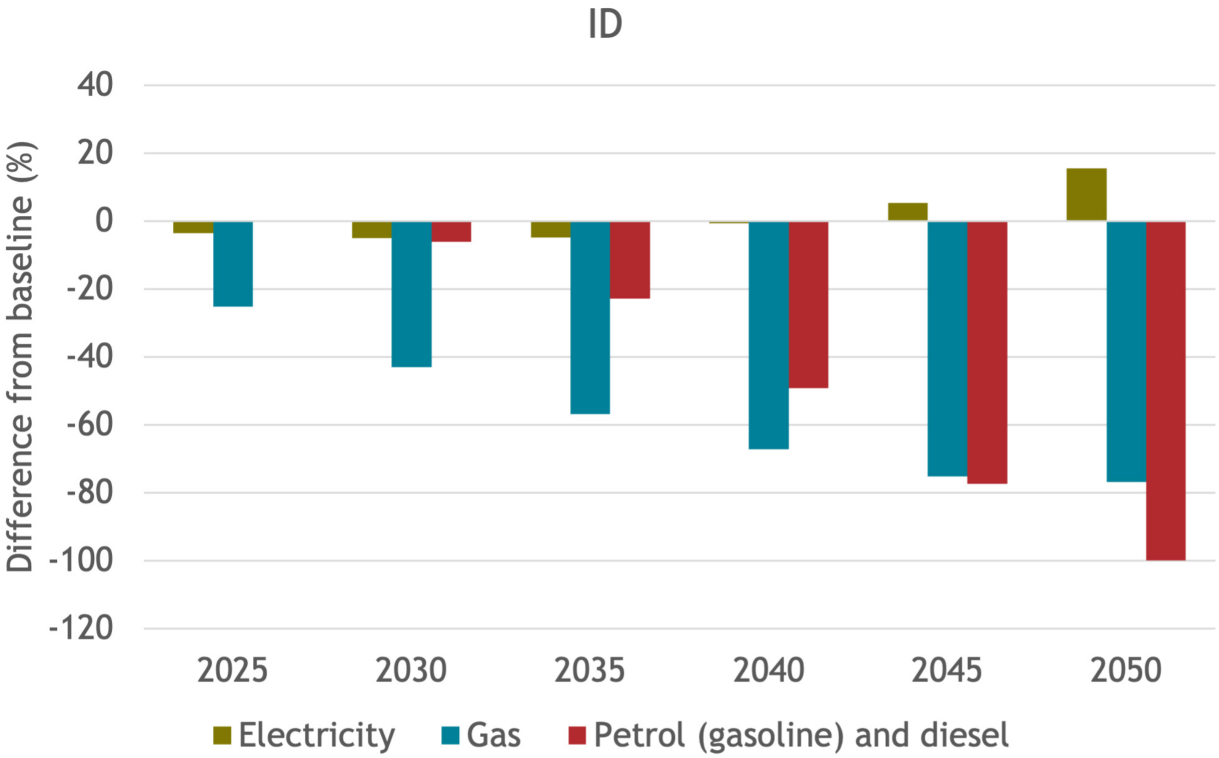

Figure 18: Household expenditure on energy over time, difference from baseline (%)

Indonesia's economy experiences immediate and significant gains from investment in the green transition. In 2030, GDP and employment are 6.2% and 3.3% above the baseline, respectively. The positive trend for employment continues up to 2050, being an average of 3.7% above the baseline from 2035 to 2050. Between 2035 and 2050, GDP is lower than the baseline by an average of 1.2%. As the world's fourth largest exporter of liquefied natural gas (LNG), this result is not surprising. Analysis of sectoral output shows that this result is dominated by a loss of output in the fossil fuel sector, which is 50.8% below baseline in 2050. With countries across the world setting to achieve net zero emissions by the middle of this century, demand for fossil fuels will fall, and with it the revenues of fossil fuel exporting countries. Given that these negative effects are not observed until 2035, policymakers have time to implement policies to protect those negatively affected by the green transition and invest in new growth areas across the economy.

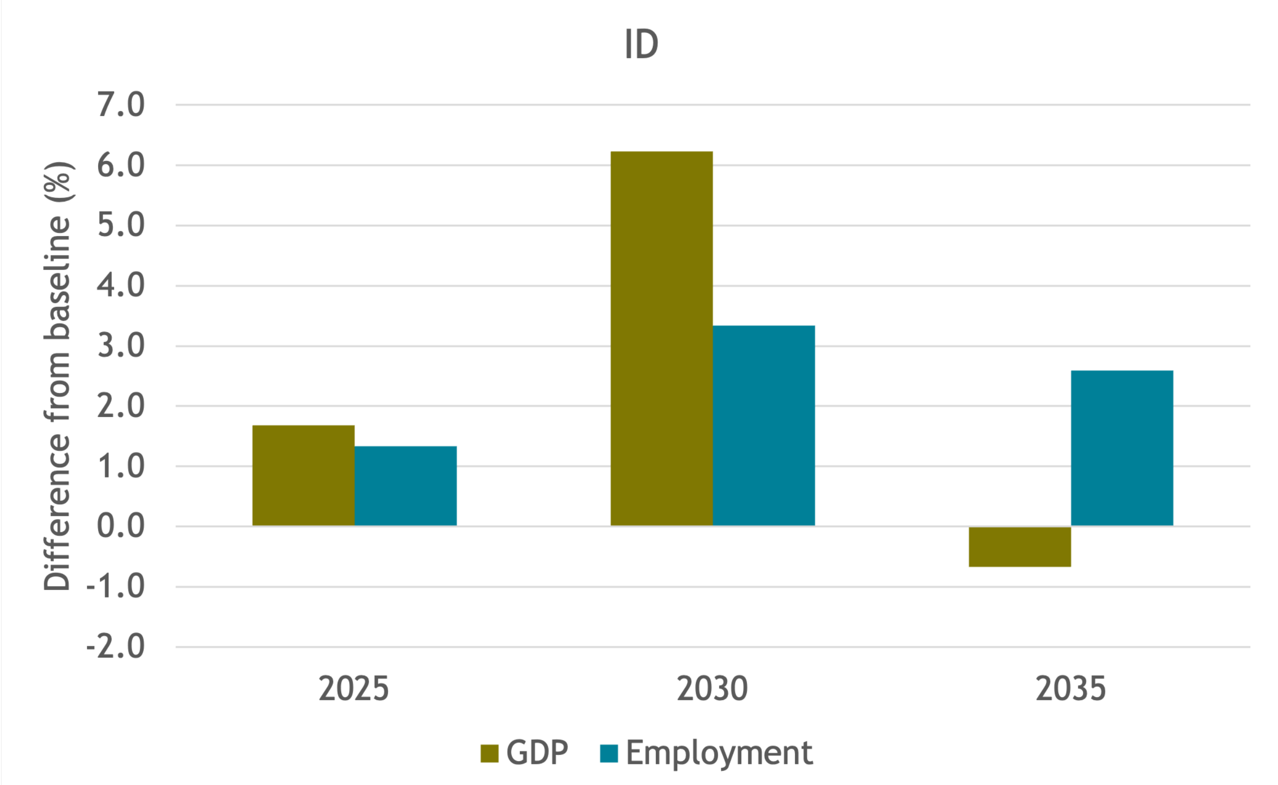

Figure 19: GDP and employment over time, difference from baseline (%)

Japan

As a highly developed and populous country with no natural energy resources, Japan is highly dependent on imported fossil fuels. Making the green transition will diversify Japan's energy provision and significantly reduce expenditure on imported fossil fuels but will require significant investment, as shown in Figure 20. Average additional investment required is 10.5% above the baseline between 2025 and 2050, with this being concentrated around 2030-2035, where investment is 16.5% above baseline on average.

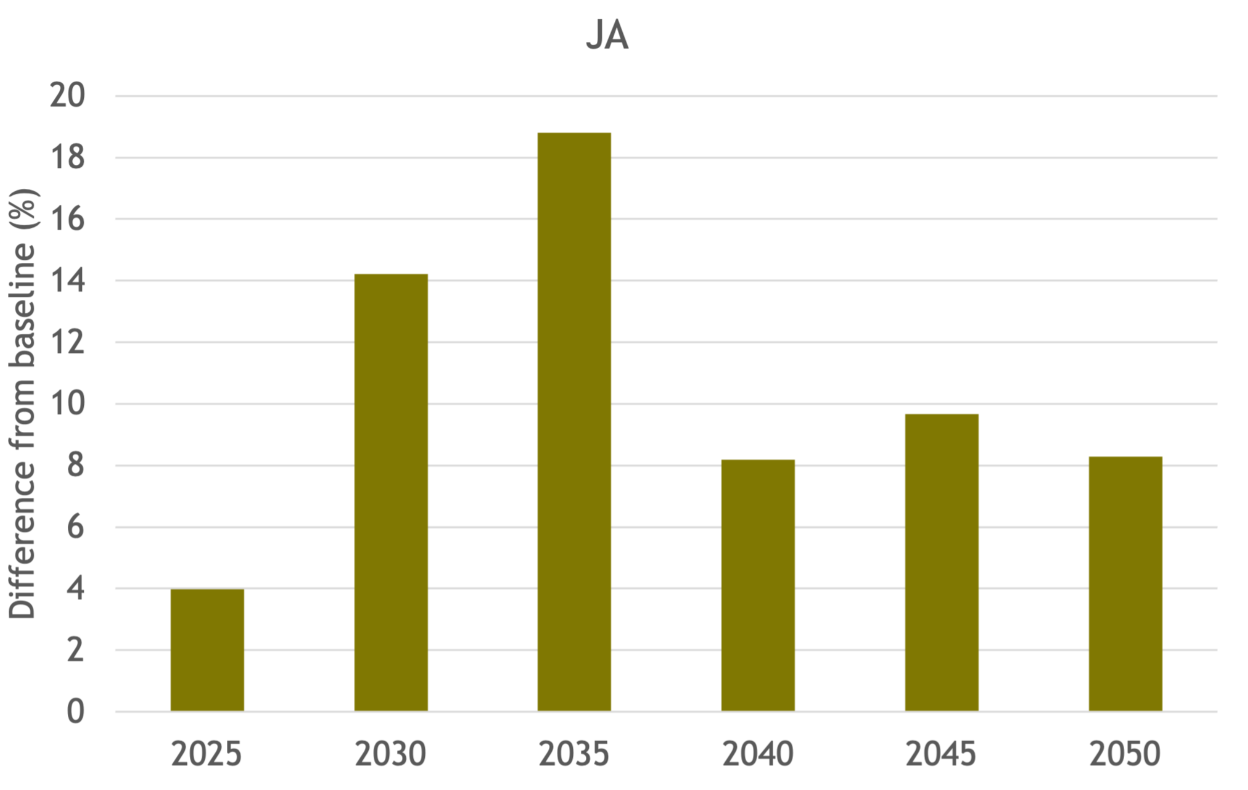

Figure 20: Investment over time, difference from baseline (%)

Japan's households stand to gain substantially from such high investment in decarbonisation, with energy expenditure falling dramatically, as shown in Figure 21. By 2035, expenditure by households on natural gas is 38% below baseline and by 2050 it is 77.9% below the baseline figure. As observed elsewhere, expenditure on petrol (gasoline) and diesel for transport falls to zero by 2050. Households experience only very minor increases in expenditure on electricity over the same period. With additional disposable income, low-income households will enjoy a better quality of life. Health outcomes across the country will increase also, as Japan ditches the high-carbon sources that currently dominate its energy system, such as coal. Other negative effects of burning fossil fuels including air and water pollution and acid rain will also be reduced significantly, improving the quality of life for people across Japan and in particular in urban areas.

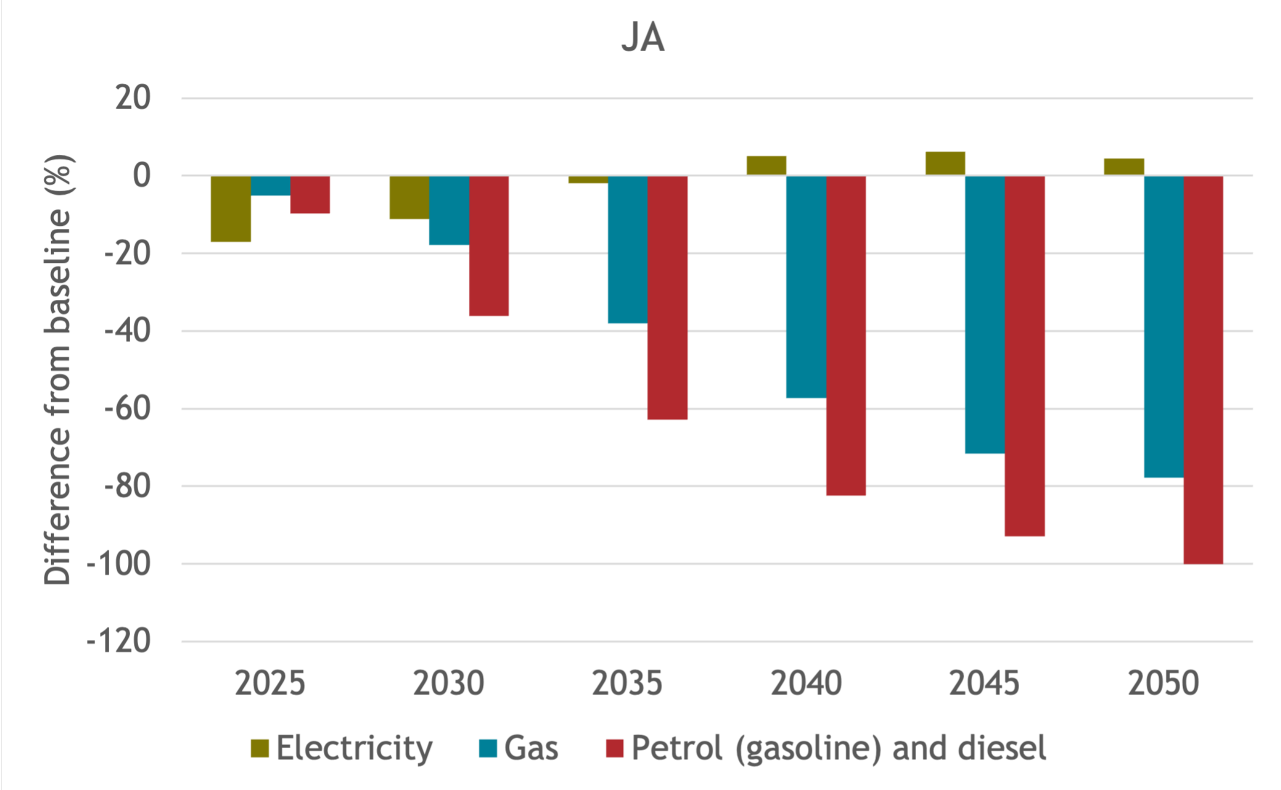

Figure 21: Household expenditure on energy over time, difference from baseline (%)

As a country poor in natural energy resources and as a centre of advanced manufacturing, Japan stands to gain economically from the green transition, as indicated in Figure 22. GDP will be as much as 5% above the baseline in 2035 and will on average be 3.1% above the baseline between 2035 and 2050. More jobs will be created also, with employment 1.2% above the baseline, on average, over the years considered. The green transition may well present an opportunity to a country whose economy has been famously stagnant for decades. By leveraging its significant manufacturing capacity and know-how to produce green technologies, such as heat-pumps, Japan can emerge from the green transition with a larger economy, better health outcomes, and lower energy costs.

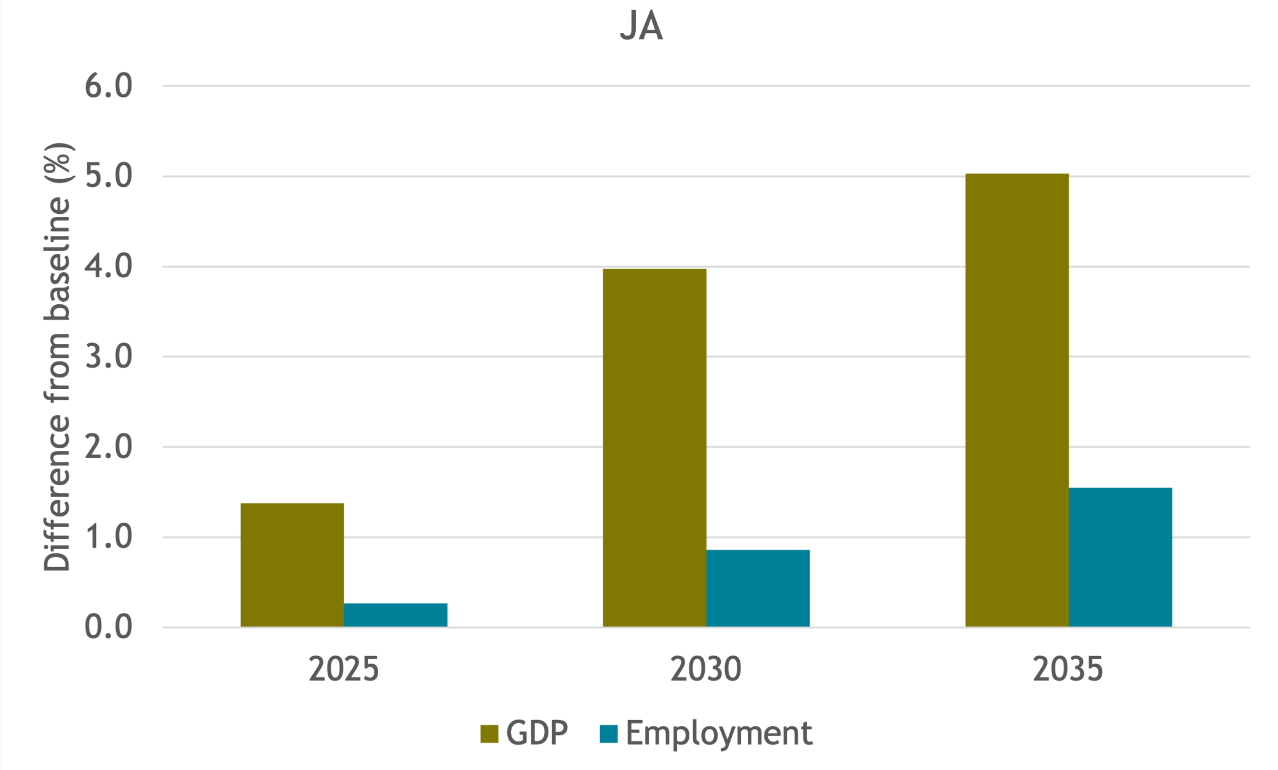

Figure 22: GDP and employment over time, difference from baseline (%)

South Africa

South Africa has an abundance of natural resources but is the smallest economy in our sample and its electricity is generated overwhelmingly from fossil fuels. Significant investment is required to decarbonise the country's economy. This additional investment peaks in 2030, at 49.7% above the baseline level of investment. As a developing country, facing many socioeconomic challenges, South Africa will require a diverse array of funding sources to make this level of investment. South Africa's financial system is relatively well developed however, which should facilitate the leveraging in of private investment.

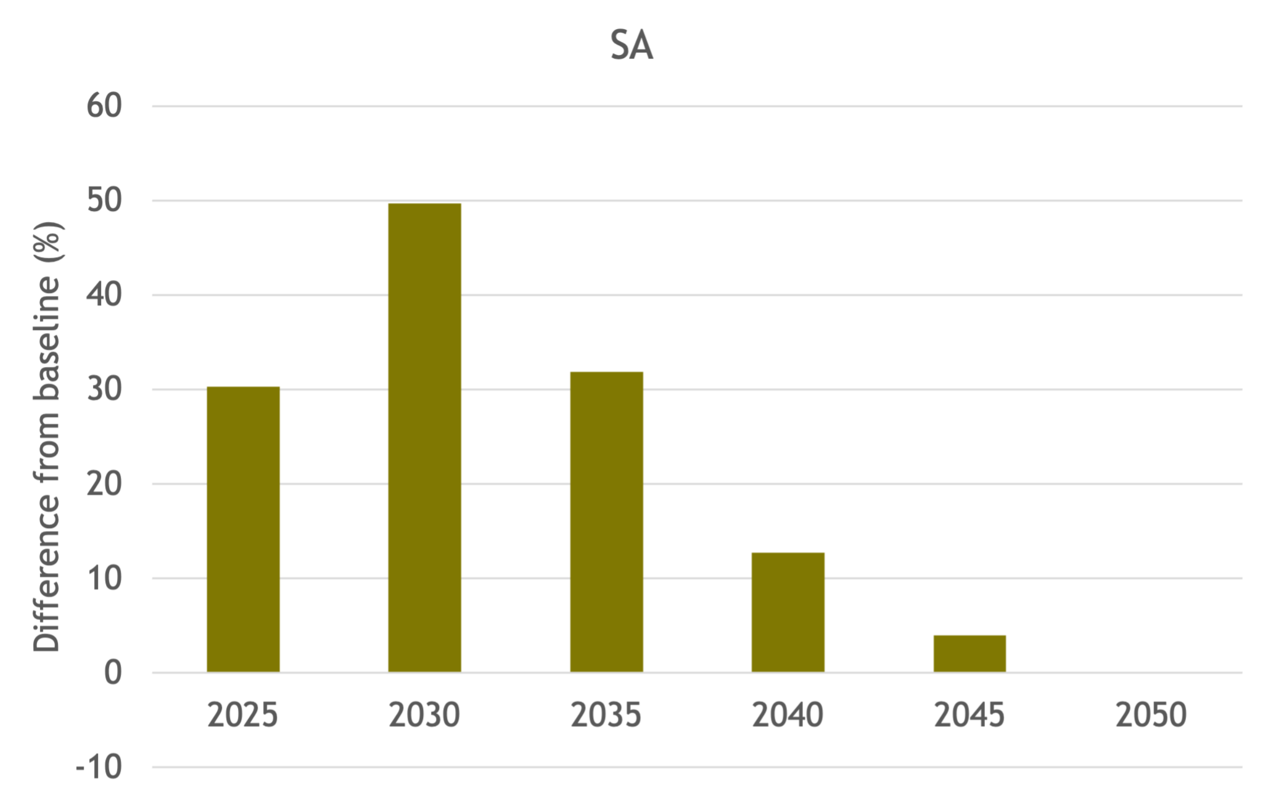

Figure 23: Investment over time, difference from baseline (%)

Achieving the level of investment described above would have a transformative effect on the South African economy. Households across the country experience very significant reductions in expenditure on energy, with spending on petrol (gasoline) and diesel falling to zero by 2050, as shown in Figure 24. South African households are not major consumers of natural gas, but the country's transition away from coal and towards electrification will see a modest increase in expenditure on electricity over the period. Overall, with less being spent on energy, households will be better off. In particular, low-income households - who tend to spend a greater share of their funds on energy – will benefit.

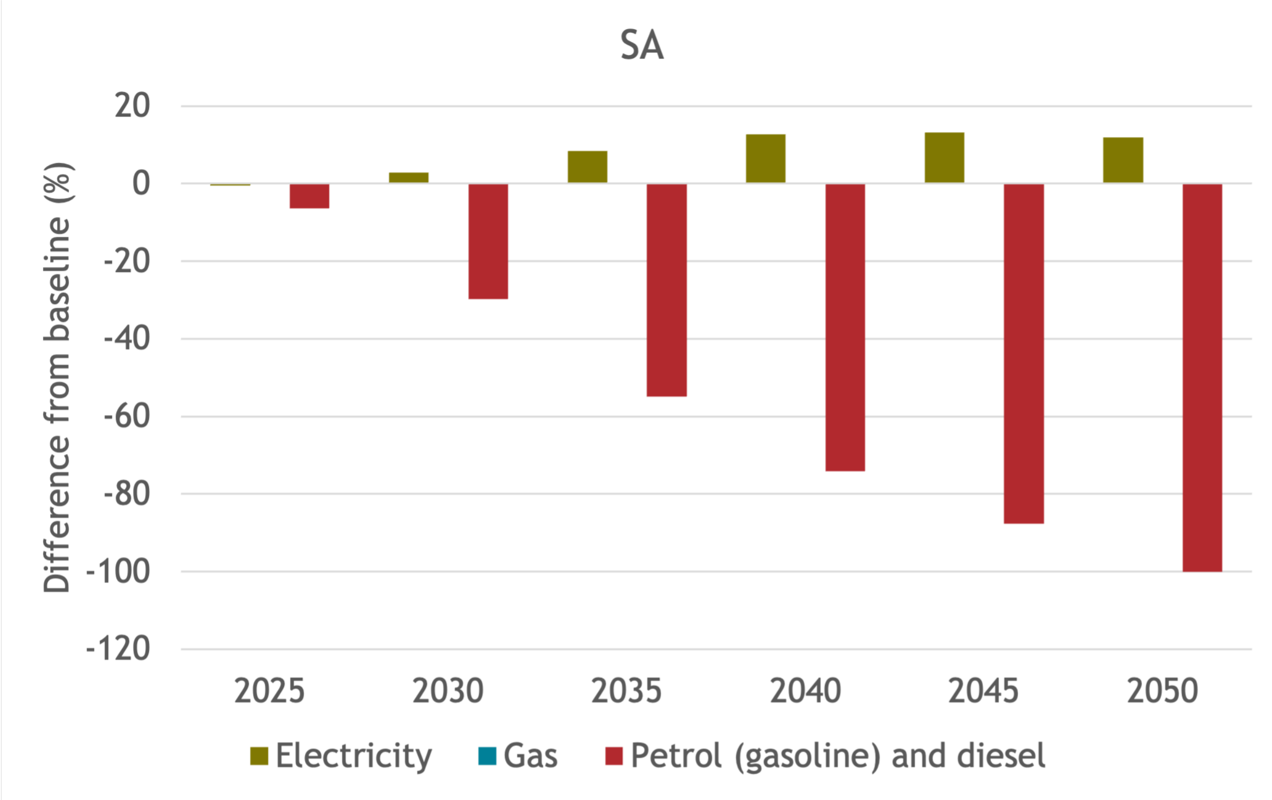

Figure 24: Household expenditure on energy over time, difference from baseline (%)

Achieving net zero will provide a significant boost to South Africa's economy, particularly in the first half of the transition, as investment drives economic activity. Figure 25 shows that in 2030 alone, GDP will be 6.4% above the baseline figure, with a 1.1% increase in employment. These effects diminish over time and turn slightly negative as 2050 approaches. However, with well calibrated policy interventions, these effects can be minimised. Moreover, policy which seeks to reinvest savings in the development of new highly productive sectors could lead to long term economic gains. By using the early years of the transition to plan and prepare for this eventuality, policy makers can maximise the benefits of decarbonisation.

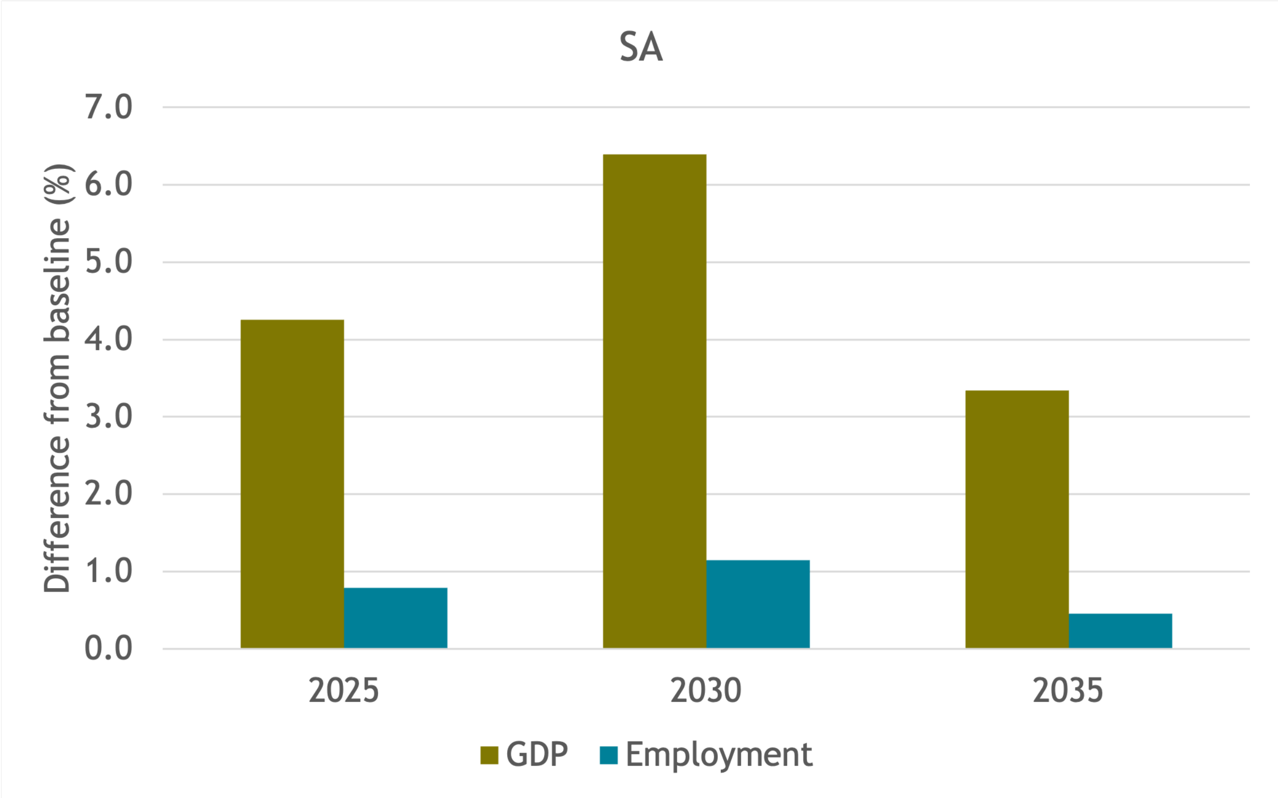

Figure 25: GDP and employment over time, difference from baseline (%)

4. CONCLUSIONS

The results of the study make clear that with adequate investment, achieving net zero is possible and will have deep and long-lasting effects for households in terms of their expenditure on energy. Effects on the wider economy of each country are less clear cut. The majority of countries (the UK, India, Japan, South Africa, and the EU) benefit from going green. As fossil fuel producers and exporters, the picture is more mixed for the US, Canada, and Indonesia, who typically see economic gains in the first half of the transition followed by losses. In all three cases these losses are concentrated in the fossil fuels sector and can be compensated by well designed policy.

From this, three key messages emerge: (i) despite various starting points, achieving net zero is possible for each country, (ii) the route to net zero will look different for every country, and (iii) investing now, and preparing for change as quickly as possible will make the transition smoothest for all concerned and give negatively affected people and sectors most time to respond.

Beyond economic gains, there are environmental, societal, and health benefits to consider also. Achieving net zero emissions across each of these countries by 2050 will not only greatly strengthen the fight against climate change, but it will also dramatically improve local environments, with an enormous drop in air, water, and land pollution. People's homes will be adequately heated and cooled through harsh winters and hot summers, improving their quality of life. A cleaner environment and more comfortable homes will bring with them significant health benefits across society.

By acting immediately to achieve net zero, collaborating with partners, developing the necessary policy over the long term, the green transition can positively transform the lives of billions of people and put the world on a more sustainable footing.

APPENDIX A– E3ME OVERVIEW AND POLICY ASSUMPTIONS

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Policy assumptions

The following table presents a summary of the policy assumptions that feed into the scenario used in the modelling. Where a cell is blank it means that the assumed policy for the country in question is the default global policy.

Table A1: Policy assumptions by country

Sector	Policy	Policy description	US	EU	UK	CA	IN	ID	JP	SA
Economy wide	Targets	All countries act according to a global 1.5C pathway	Net zero by 2050 50-52% 2030 NDC target 80% RE target by 2030 (100% by 2035)	At least 55% emission reductions by 2030, net zero by 2050; at least 50% of renewable energy and 36% of final energy efficiency[1]	Net zero 2050	Net zero by 2050	At least 500 GW of renewables power capacity by 2030, aiming for net zero by 2050	Net zero by 2050	Net zero by 2050 46-50% NDC 2030 target 2030 RE target 36-38%	Net zero by 2050
Economy wide	Carbon pricing	A global carbon price kicks in at $80/tCO2 from 2022, increasing to over $300/tCO2 by 2050.[3] Carbon price applies to all sectors with the exception of the road transport and residential sectors which have their own equivalent carbon tax (in the form of fuel excise duties, registration and boiler tax).	$15/tCO2 from 2023[4]	ETS price is currently $85/tCO2			$5/tCO2 from 2025	$2/tCO2 from 2022	$3/tCO2 from 2022[6]	$10/tCO2from 2022[7]
Economy wide		Investment in renewables technologies and energy efficiency programs is funded by revenues from carbon taxes and ETS								
Power sector	Coal phase-out	No new coal capacity is built from 2022. All unabated coal power plants are shut down from 2040.	Phase-out by 2035	Phase-out by 2030[8]	No new coal and phase-out by 2024[1] Fully decarbonise power system by 2035 and achieve 40GW of offshore wind by 2030[2]					Phase-out by 2042, with $8.5bn support from EU, UK and US [9, 10]

1. https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/
2. https://indbiz.gov.in/india-accelerates-towards-mission-500gw-by-2030/
3. https://www.nature.com/articles/s41560-021-00934-2
4. https://www.rff.org/publications/issue-briefs/emissions-projections-under-alternative-climate-policy-proposals/
5. https://ember-climate.org/data/data-tools/carbon-price-viewer/
6. https://www.sciencedirect.com/science/article/pii/S266604902100058X#:~:text=Japan%20is%20one%20of%20the,in%20carbon%20emissions%20by%202030
7. https://home.kpmg/us/en/home/insights/2022/02/tnf-south-africa-extension-carbon-tax-budget-2022.html
8. https://www.e3g.org/news/tracking-oecd-and-eu-coal-transition-progress/
9. https://www.reuters.com/business/environment/us-eu-others-will-invest-speed-safricas-transition-clean-energy-biden-2021-11-02/

Sector	Policy	Policy description	US	EU	UK	CA	IN	ID	JP	SA
Power sector	Public procurement for biomass CCS	From 2022 to 2025, CCS variants of power plants will be gradually built via government procurement.								
Power sector	Subsidies for renewables	From 2022, biobased and CCS technologies receive a 60% subsidy with the exception of biogas technologies. Biogas technologies and nuclear receive a 20% subsidy. Geothermal and CCS applications receive a 50% subsidy. Subsidies are phased out between 2035 and 2050.								
Power sector	Grids	Governments invest in upgrades to the power grid								
Industries	Subsidies	From 2022, all CCS applications receive a 10% subsidy on the investment costs and phased out between 2035 to 2050. Hydrogen based steelmaking receives a 50% subsidy on the investment costs and phased out between 2050 and 2063. Electricity based steel making is subsidised by 25% and phased out between 2045 and 2055.								
Buildings	Regulation of fossil fuel-based heating	From 2022, regulation on new sales of coal stoves, oil, and gas boilers is in place.			No new gas boilers sales by 2035[1]					
Buildings	Subsidies for heat pumps[11]	From 2022 onwards, heat pumps receive a 50% subsidy on the upfront investment costs, which is linearly phased out between 2030 and 2050.								
Passenger road transport	EV subsidies	From 2022, an additional 20% vehicle subsidy is applied on EV purchases. Subsidies are phased out over 2025-30 (assuming price parity is reached this decade .[12]								
Passenger road transport	Phase out of ICE sales	From 2022, regulation on new sales of ICEs is in place.	Target 50% EV new sales by 2030[13]	No ICEs may enter the market from 2035.	ICE sales ban from 2030[1]		Target 30% EV new sales by 2030[14]		ICE sales ban from 2035[15]	

11. Note that heating is not particularly relevant in India due to the hot climate. Policies will be modelled for comprehensiveness, but the focus is on cooling decarbonisation which will be targeted through energy efficiency improvements and decarbonisation of the power sector.
12. https://www.transportenvironment.org/discover/evs-will-be-cheaper-than-petrol-cars-in-all-segments-by-2027-bnef-analysis-finds/
13. https://www.reuters.com/business/autos-transportation/biden-set-target-50-evs-by-2030-industry-backs-goal-2021-08-05/
14. https://cef.ceew.in/solutions-factory/publications/financing-india-transition-to-electric-vehicles
15. https://www.reuters.com/article/us-japan-autos-gasoline-idUSKBN28D044

Sector	Policy	Policy description	US	EU	UK	CA	IN	ID	JP	SA
Other transport	Biofuel mandate	Blending rates increase linearly to 100% by 2050, meaning all remaining middle distillates (after accounting for electrification) are replaced by biofuels								
Land use	Tree planting	Governments invest in tree planting schemes to expand carbon sink removals. 1 trillion trees are to be planted globally by 2030[16], shared between countries by the relative sizes of their forestry sectors. The average cost is $8 per tree.								

16. https://www.1t.org/

THE E3ME 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 in Europe and beyond for policy assessment and for research purposes. A technical model manual of E3ME is available online at www.e3me.com.

E3ME is often used to assess the impacts of climate mitigation policy on the economy and the labour market. The basic model structure links the economy to the energy system to ensure consistency across each area.

As a global E3 (energy, environment, economy) model, E3ME can provide comprehensive analysis of policies:

- 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 higher economic activities
- overall macroeconomic impacts; on jobs and the economy including income distribution at macro and sectoral level

Theoretical underpinnings

Economic activity undertaken by persons, households, firms and other groups in society has effects on other groups after a time lag, and the effects persist into future generations, although many of the effects soon become so small as to be negligible. But there are many actors and the effects, both beneficial and damaging, accumulate in economic and physical stocks.

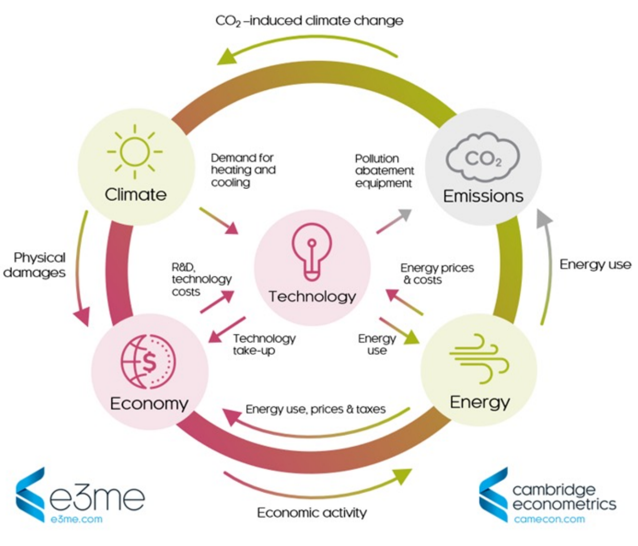

Figure 5: Overview of Cambridge Econometrics' E3ME model

The effects are transmitted through the environment (with externalities such as greenhouse gas emissions contributing to global warming), through the economy and the price and money system (via the markets for labour and commodities), and through the global transport and information networks.

The markets transmit effects in three main ways: through the level of activity creating demand for inputs of materials, fuels and labour; through wages and prices affecting incomes; and through incomes leading in turn to further demands for goods and services. These interdependencies suggest that an E3 model should be comprehensive and include many linkages between different parts of the economic and energy systems.

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, underlying this there are important theoretical differences between the modelling approaches.

In a typical CGE framework, optimal 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 a post-Keynesian framework, and it is possible to have spare capacity. The model is more demand-driven and it is not assumed that prices always adjust to market clearing levels.

The differences have important practical implications, as they mean that in E3ME regulation and other policy may lead to increases in output if they are able to draw upon spare economic capacity. This is described in more detail in the model manual.

The econometric specification of E3ME gives the model a strong empirical grounding. E3ME uses a system of error correction, allowing short-term dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis and rebound effects, which are included as standard in the model's results.

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. In total there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by country and by sector.

E3ME's historical database covers the period 1970-2018 and the model projects forward annually to 2050. The main data sources for European countries are Eurostat and the IEA, supplemented by the OECD's STAN database and other sources where appropriate. For regions outside Europe, additional sources for data include the UN, OECD, World Bank, IMF, ILO and national statistics. Gaps in the data are estimated using customised software algorithms.

The main dimensions of E3ME are:

- 70 countries – all G20 countries, the EU27 and candidate countries plus other countries' economies grouped
- 70 industry sectors, based on standard international classifications
- 43 categories of household expenditure
- 22 different users of 12 different fuel types
- 14 types of air-borne emission (where data are available) including the 6 GHG's monitored under the Kyoto Protocol

APPENDIX B – TABLE OF RESULTS

Table B1: Table of results, difference from baseline (%)

	Country	2025	2030	2035	2040	2045	2050
Emissions	US	-25.6	-49.9	-66.2	-79.4	-89.7	-100.0
	EU27	-18.4	-38.5	-55.3	-69.7	-82.1	-100.0
	UK	-16.0	-31.4	-51.5	-69.5	-84.8	-100.0
	CA	-16.3	-34.8	-50.9	-64.7	-77.1	-100.0
	IN	-41.0	-72.0	-84.3	-92.2	-97.0	-100.0
	ID	-38.1	-59.7	-79.3	-89.9	-95.1	-100.0
	JA	-18.6	-43.1	-71.7	-83.3	-92.3	-100.0
	SA	-22.0	-56.2	-72.2	-82.5	-90.3	-100.0
Investment	US	11.3	4.6	4.0	3.6	2.5	1.6
	EU27	6.9	6.4	3.7	4.0	3.3	2.7
	UK	5.5	4.2	6.0	5.2	6.1	5.2
	CA	7.2	9.4	6.9	4.6	3.8	3.5
	IN	32.4	21.3	13.7	9.4	7.2	6.9
	ID	12.0	35.8	19.1	13.2	10.4	10.6
	JA	4.0	14.2	18.8	8.2	9.7	8.3
	SA	30.3	49.7	31.9	12.8	4.0	-0.1
Electricity expenditure	US	-2.5	-1.4	4.4	12.5	17.2	19.6
	EU27	1.1	8.0	20.9	30.1	24.1	11.1
	UK	8.8	33.2	73.0	104.7	107.0	89.2
	CA	13.3	35.5	56.4	67.1	68.8	66.0
	IN	-0.4	4.8	13.6	15.8	13.8	10.4
	ID	-3.7	-5.1	-4.9	-0.7	5.2	15.5
	JA	-17.0	-11.1	-1.8	5.1	6.2	4.4
	SA	-0.5	2.8	8.4	12.7	13.3	11.9
Natural gas expenditure	US	-11.6	-25.7	-40.1	-55.2	-69.9	-81.5
	EU27	-7.5	-22.2	-41.4	-60.5	-75.6	-85.0
	UK	-3.2	-11.0	-23.9	-42.5	-63.5	-80.7
	CA	-13.9	-30.5	-46.8	-63.0	-76.0	-84.5
	IN	-35.4	-51.6	-63.7	-71.9	-77.1	-76.7
	ID	-25.2	-43.1	-56.9	-67.3	-75.2	-76.9
	JA	-5.2	-17.9	-38.0	-57.3	-71.5	-77.9
	SA	0.0	0.0	0.0	0.0	0.0	0.0

	Country	2025	2030	2035	2040	2045	2050
Petrol (gasoline) and diesel expenditure	US	-5.3	-31.1	-59.3	-79.0	-90.8	-100.0
	EU27	-9.6	-38.3	-66.7	-86.0	-94.8	-100.0
	UK	-9.0	-37.4	-67.5	-86.7	-95.0	-100.0
	CA	-6.1	-30.3	-55.3	-74.9	-88.7	-100.0
	IN	-6.9	-34.7	-61.8	-76.9	-88.0	-100.0
	ID	-0.2	-6.1	-22.8	-49.2	-77.4	-100.0
	JA	-9.7	-36.2	-62.8	-82.3	-93.0	-100.0
	SA	-6.4	-29.8	-54.9	-74.1	-87.7	-100.0
GDP	US	1.9	0.4	-0.2	-0.9	-1.2	-1.8
	EU27	1.8	1.4	1.0	1.4	1.1	0.9
	UK	1.1	0.7	1.0	1.3	1.0	0.9
	CA	1.4	0.1	-1.8	-2.7	-3.9	-4.8
	IN	9.9	7.3	5.2	3.4	2.7	2.4
	ID	1.7	6.2	-0.7	-2.0	-1.7	-0.7
	JA	1.4	4.0	5.0	2.7	3.2	2.5
	SA	4.3	6.4	3.3	0.7	-0.0	-0.2
Employment	US	0.6	0.3	0.2	-0.2	-0.3	-0.4
	EU27	0.6	0.6	0.4	0.5	0.3	0.2
	UK	0.5	0.5	0.8	1.1	0.9	0.8
	CA	0.2	-0.3	-0.5	-0.3	-0.8	-1.1
	IN	2.9	2.1	1.6	0.7	0.2	0.1
	ID	1.3	3.3	2.6	3.4	3.9	4.7
	JA	0.3	0.9	1.5	1.3	1.6	1.5
	SA	0.8	1.1	0.5	-0.0	-0.3	-0.5