The New Climate Economy

2018 Report for the Global Commission on the Economy and Climate

Unlocking the Inclusive Growth Story of the 21st Century: Accelerating Climate Action in Urgent Times

Technical Note

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clarity from complexity

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About this Note

Prepared by Cambridge Econometrics (CE) with feedback from the New Climate Economy (NCE) team, this draft note summarises methodological aspects, modelled scenarios and macroeconomic results to provide empirical inputs to the NCE 2018 Global Commission Report.

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Executive Summary

This technical note outlines the modelling results for Cambridge Econometrics' (CE's) contribution to the "Unlocking the Inclusive Growth Story of the 21st Century" Report (2018) published by the Global Commission on the Economy and Climate and its flagship project, the New Climate Economy (NCE). The aim of the modelling exercise was to illustrate examples of policies that can simultaneously promote economic growth and reduce the risks of climate change. The modelling has considered a set of six climate action scenarios, on areas including energy, cities, industry and innovation that cut across the different sections of the NCE report (see Table 1). These actions are a subset of the policy actions that could be undertaken to reduce greenhouse gas (GHG) emissions to reach global targets. A number of policies, notably on forests and land use, were not explicitly modelled for the purposes of this report.

Table 1 The modelled scenarios

Sector	Name	Focus	Horizon
Cities	S1a Urban retrofits	Improved efficiency of new buildings	2040
	S1b Urban densification	Reduced heating and cooling requirements for households and fuel consumption for transport	2040
	S2 Promoting EVs	Accelerated deployment of electric vehicles, and more renewables in the power sector	2040
Energy	S3 Carbon pricing and energy reforms	Power generation: removal of fossil fuel subsidies, introduction of a carbon price globally, feed-in-tariffs	2040
	S4 Reducing energy waste	As S1a plus S1b, plus reducing energy waste across all sectors of the economy	2040
Industry/ Innovation	S5/6 Innovation and industrial efficiency	Industrial innovations and a drive to a low carbon transition and more efficiency in industrial processes	2040
'Combined'	S1-S5 Clean energy systems	Includes all the above and further fuel switching	2050

Results are also presented for a Combined Scenario that includes all policies and interventions covered in the six individual cases with additional electrification measures. This scenario is designed to ensure that by (or before) 2100, peak median global warming is likely to stay at or below 2°C.

This summary outlines the key results from the modelling analysis and also the main elements of the approach, which are described in more detail in the body of this note.

Emission reductions

The scenarios that have been assessed in this report show that implementing a broad range of policy measures across different sectors of the economy could reduce emissions substantially. Our analysis covers energy and process CO_2 emissions. If land use and non-CO_2 emissions are assumed to follow a pathway that is consistent with Representative Concentration Pathway 2.6 (RCP2.6), then the Combined Scenario would stay below a 2°C peak median temperature change with 63% probability (equivalent to a 50% probability of peak warming of 1.92°C).

To provide the probabilistic projections, we performed 86-member ensembles of the GENIE climate-carbon cycle model, following the methodology in Holden et al (2018) and Mercure et al (2018).[1] The CO_2 emissions are taken from Cambridge Econometrics' E3ME macroeconomic model up to the year 2050 and then linearly extrapolated beyond 2050. Non-CO_2 trace gas radiative forcing and land-use-change maps are taken from RCP2.6.

Economic impacts

The modelling has shown that these emission reductions could be achieved, with associated global, economy-wide benefits in the short run. As shown below, there will be a shift away from employment in high carbon activities, such as oil, coal, gas extraction and manufacturing of fuels, into low carbon activities. There may also be a small increase in overall employment levels.

The Combined Scenario in particular shows immediate and sustained gains in real value added through the full period of estimation. On average, GDP is higher in the Combined Scenario than in the baseline over the period up to 2030. These gains in value added emerge as a result of positive feedback from adopting low carbon policies and transmit via a number of channels that include technological progress and improvement in human wellbeing. This leads to a cumulative increase in value added of nearly US$26 trillion (at 2011 prices, non-discounted) by 2030, relative to the baseline. These gains from the Combined Scenario relative to Baseline may be underestimated, considering that costs of inaction are not fully incorporated in this exercise, as explained below.

Overall employment is 0.6% higher in the Combined Scenario than in the baseline in 2030. That means that, overall, there about 27 million more workers in employment. However, the scenario would result in a more significant shift in the composition of employment. Undertaking ambitious climate action could generate over 65 million new low-carbon jobs by 2030.However, there is some displacement of existing jobs, for example in the fossil fuels sector.

Investment effects

There is a strong pattern across the scenarios that large amounts of investment will be required to achieve the emissions reduction. These findings are consistent with other analyses (and in some cases draw on these analyses, for example from the IEA). In many modelling exercises, this

[1] Holden, P.B. et al., 2018. Climate-carbon cycle uncertainties and the Paris Agreement, in Nature Climate Change, 8 pp609-613. Available at: https://www.nature.com/articles/s41558-018-0197-7; Mercure, J.-F. et al., 2018. Macroeconomic impact of stranded fossil-fuel assets, in Nature Climate Change, 8 pp588-593. Available at: https://doi.org/10.1038/s41558-018-0182-1.

investment to reduce CO_2 emissions is assumed to displace productive investment elsewhere in the economy, leading to economic costs. However, this assumption has been shown to be inconsistent with the way that the modern financial system works.[2]

In this report, we have applied a more realistic representation of finance, as depicted in the E3ME model. We see that important dynamics become apparent in the results. Investment provides a stimulus to economic production levels in the short term; in short, building and installing the new equipment that is required by the simulated policies also creates jobs and incomes for previously unemployed workers, who then spend their incomes in the wider economy.

Such positive effects persist but not indefinitely, because eventually the higher debt that is taken on to finance the investment must be repaid. The paying down of debts removes spending power from the economy and acts as a drag on economic growth and employment levels later on in the projection period. In the long term, the positive impacts of the additional investment are therefore likely to fall towards zero. However, there are several channels through which implementing low carbon policies, especially during an accelerated transition, can lead to longer-term economic benefits, for example through technological development. Furthermore, the economic and environmental benefits and costs of climate action are broader than what is reported in this exercise, and these are also simulated (see below) to provide a more complete picture of economic outcomes.

Impacts across regions

In these scenarios, we also see a consistent pattern in the regional impacts. Countries that are net importers of fuels tend to benefit overall from the adoption of low carbon policies. Leaving aside the investment dynamics, these countries see a shift in expenditure from imported fuels to other products that have a larger domestic component. This shift leads to a domestic stimulus effect which, unlike the investment effects, is permanent and even increases over time.

The negative side of this process is that some energy-exporting nations see reductions in GDP, as there is a much lower demand for the products in which they specialise. A loss of exports affects GDP directly but a loss of government revenues (e.g. from state-owned companies or royalty payments) will create additional downward pressure on employment in these countries, particularly as the government sectors are typically much more labour-intensive than the extraction sectors. The associated reduction in fuel spending – even in energy-exporting nations – results in increased domestic investment, especially in other sectors.

However, the Fourth US National Climate Assessment[3], a report by top US experts from 13 federal agencies, found that in a high-emissions future, economic damages from climate change would reach $500 billion per year in

[2] McLeay, M. et al., 2014. Money creation in the modern economy. Bank of England Quarterly Bulletin. Available at: https://www.bankofengland.co.uk/quarterly-bulletin/2014/q1/money-creation-in-the-modern-economy; Pollitt, H. & Mercure, J.-F., 2018. The role of money and the financial sector in energy-economy models used for assessing climate and energy policy, in Climate Policy, 18(2). Available at: https://www.tandfonline.com/doi/full/10.1080/14693062.2016.1277685.

[3] Martinich, J., et al., 2018. Fourth National Climate Assessment, Chapter 29: Reducing Risks Through Emissions Mitigation. Government of the United States of America. Available at:: https://nca2018.globalchange.gov/chapter/29/.

2090 due to extreme temperatures, rising seas, and other impacts. Reducing emissions, on the other hand, could cut those costs approximately in half to $280 billion per year.

So while the current exercise may be unable to represent what is commonly referred to as the “cost of inaction”, in this empirical exercise, representing this would imply a baseline case that is more optimistic in terms of economic outcomes relative to the social and economic consequences of inaction.

Beyond the split between energy exporters and importers, we see little difference in the impacts between developed and developing countries. The results do not suggest that developing countries would ‘pay more’ for decarbonisation, at least in terms of GDP and employment.

Non-economic impacts

The modelling in this report has also touched on several other impacts that may be positive for society overall. Improvements to energy efficiency could benefit low-income households that spend a larger share of their incomes on necessary heating fuels. Also, impacts on health have been integrated with the modelling framework, so that impacts on mortality and productivity affect the labour force directly, and government budgets are adjusted to account for changes in healthcare costs. However, due to data limitations, such impacts are computed only for European countries. Health impacts for other non-EU28 occur only via trade with the EU. As a consequence, and in order to be able to ascertain health impacts for a larger group of countries in the world, the analysis by E3ME is complemented by an empirical exercise for the calculation of changes in the number of premature deaths associated with changes in air quality, based on a methodology developed by the International Monetary Fund. This methodology takes as input the changes in air quality in baseline and alternative climate scenarios. It thus compares outcomes in premature deaths associated with the air quality change.

In 2030, changes in air quality under the Combined Scenario would result in an avoidance of over 700,000 annual premature deaths from pollution globally compared with the business-as-usual case. This is about a 25% reduction in premature deaths compared to the baseline in 2030, largely due to the impact of carbon pricing and energy reforms on reductions in fossil fuel combustion. Section 2.6 explains the methodology in more detail.

Moving forward

This report is consistent with other empirical models that demonstrate that a series of well-defined measures for climate action, with a combined focus on decarbonisation, electrification and reducing wasted energy, could move the world towards an emissions path that is consistent with limiting global temperature change to 2°C (or below) above pre-industrial levels by 2100. There remain challenges along the way, not least in implementing policies globally, and many other factors that the modelling cannot capture. For example, ensuring adequate access to finance is likely to be a key enabling measure.

It is also likely that, moving forward, much of the effort to reduce emissions will come from individuals, companies and local communities that pursue their own initiatives, which will contribute towards some of the measures assessed in this report. As the modelling shows, technology will play an important role, with positive feedbacks between rates of deployment and price reductions (due to scale and learning effects) also likely to play a crucial role in enabling rapid emission reductions.

The challenges thus remain for policy makers to make interventions that both provide a general framework for decarbonisation (e.g. carbon pricing or energy efficiency programmes) but also provide specific support for new technologies at the development and early deployment stage. These can be achieved, for instance, by improving access to green financing mechanisms. Macroeconomic and techno-economic modelling, when carried out well, can provide support to policy makers in these endeavours. To be useful, however, the modelling must be closely integrated with a broader analysis of the policy options that are available to policy makers. The modelling in this report provides one example of such a close interaction.

An important caveat regarding modelling climate impacts

Due to limitations in data and scientific knowledge, many large-scale models do not incorporate the negative economic impacts of a changing climate. Research in this area is ongoing but climate impacts are not included in our analysis.

It is therefore likely that the economic benefits presented in this report are underestimating the potential real-world outcomes. Two reasons that are often cited are:

1. Computed baselines or business-as-usual scenarios tend to be far too optimistic as they do not really show the losses in factors of production (physical capital, human capital, labour, and natural capital) that occur as a consequence of inaction regarding climate change, with a consequent impact on economic activity and society.

2. Climate action scenarios tend to be too pessimistic, as they underestimate the positive impacts on economic activity that would result from technological progress, including gains in efficiency, that are associated with a faster transition to a low carbon economy.

As a result, the US$26 trillion in cumulative gains from the Combined Scenario should be interpreted as a minimum, lower-end estimation of the potential benefits of climate action outlined.

1 Introduction

Overview

This technical note outlines the modelling results for Cambridge Econometrics' (CE's) contribution to the "Unlocking the Inclusive Growth Story of the 21st Century" Report (2018) published by the Global Commission on the Economy and Climate and its flagship project, the New Climate Economy (NCE). The modelling considers a set of six climate action scenarios, on areas including energy, cities, industry and innovation, that cut across the different sections of the NCE report. Results are also presented for a Combined Scenario that includes all policies and interventions covered in the six individual cases with additional electrification measures, which is designed to ensure that peak median global warming stays at or below 2°C by (or before) 2100.

The next chapter describes our analytical approach and provides a summary of CE's E3ME macro-econometric model,[4] including its main inputs and outputs. Chapter 3 presents how the policies were modelled within the E3ME modelling framework, describes the baseline and presents some of the modelling parameters. Chapter 4 provides an overview of the modelling process for each scenario and the results of the analysis. Chapter 5 concludes.

Aims and outputs

The aim of the modelling exercise was to illustrate examples of policies that can simultaneously promote economic growth and reduce the risks of climate change. Though a range of policies have been assessed, the focus of the study is limited to efforts to reduce emissions and the impacts on the economy. Moreover, policies that do not necessarily promote economic growth – that is, boosting GDP – are not considered in this analysis; only those that aim for harmony between objectives are modelled. Aside from levels of GDP and emissions, key outputs from the analysis include labour market impacts, distributional impacts (where data are available) and other environmental impacts such as changes in air quality. The modelling analysis is accompanied by an analysis of health impacts (namely, number of avoided deaths) following a methodology developed by IMF, and using alternative air quality scenarios that are based on the E3ME results.

Methodology

When interpreting the results, it is important to understand the modelling approach that was used. In summary the key strengths of the E3ME model are:

- The close integration of the economy, energy systems and some elements from the environment, with two-way linkages and feedback between each component[5].
- The detailed sectoral disaggregation in the model's classifications of sectors, allowing for the analysis of similarly detailed scenarios.
- Its global coverage, while still allowing for analysis at the national level for large economies and regions.
- An econometric approach with a reliance on historical data, which provides a strong empirical basis for the model and means it is not

[4] For a more detailed description, see the model website www.e3me.com.

[5] Although it should be stressed that climate damages are *not* included in this analysis.

reliant on some of the restrictive assumptions common to Computable General Equilibrium (CGE) models.
- The econometric specification of the model, making it suitable for short- and medium-term assessment, as well as longer-term trends.

2 Modelling Approach

2.1 Introduction to the E3ME model

E3ME is a computer-based model of the world's economic and energy systems and the environment. It is a global and dynamic simulation model that is estimated using econometric methods. The macro-econometric framework is complemented by bottom-up technology diffusion models of the power and transport sectors. E3ME was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment, forecasting and research purposes. The 2018 version of E3ME includes 59 global regions[6]. It is the most comprehensive model version of E3ME to date and it includes all the previous features of the previous E3MG model.

E3ME is not a Computable General Equilibrium (CGE) model but produces many of the same outputs and is based on a similar accounting framework. However, the underlying philosophy about human behaviour and how the economy works is quite different in the two modelling approaches (see below).

This chapter provides a summary of the E3ME model. For further details, the reader is referred to the full model manual available online from www.e3me.com. A full set of equations for the model has also been published in the journal *Energy Strategy Reviews.*[7]

2.2 Comparison with CGE models

E3ME is often compared to other integrated approaches. Neoclassical Economists often are interested in comparisons with Computable General Equilibrium (CGE) models. This section provides a high-level comparison of E3ME with such models, but it is acknowledged that a number of other integrated approaches exist that are also worth considering in order to assess strengths and advantages of each method.

In many ways the E3ME and CGE modelling approaches are similar; they are based on the same accounting frameworks, are used to answer similar questions and operate with similar inputs and outputs. However, underlying these similarities, there are important theoretical differences between the modelling approaches relating to human behaviour and the organisation of economic activity.

CGE models are founded on neoclassical economic theory. In a standard CGE framework, agents are assumed to have 'perfect' knowledge of the options available to them and can optimise their decision making so as to maximise their utility (households) or profits (firms). Markets can operate freely with fully adjustable prices so that demand and supply can be matched. Under

[6] See Appendix A for a list of classifications included in E3ME, including regions, sectors of economic activity, expenditure categories, emission types, demographics and labour cohorts, energy technologies, fuel users, vehicle technologies and others.

[7] Mercure, J.-F., 2018. Environmental impact assessment for climate change policy with the simulated-based integrated assessment model E3ME-FTT-GENIE, in Energy Strategy Reviews, 20 pp 195-208. Available at https://www.sciencedirect.com/science/article/pii/S2211467X18300129#app.

such assumptions, the level of production in the economy is determined by supply-side factors (i.e. the amounts of each factor of production) because the modelling assumptions ensure that the available resources are used in the most efficient manner possible.

Post-Keynesian economic framework

In contrast, the E3ME model is based on a post-Keynesian economic framework. Agents are assumed to make decisions based on conditions of fundamental uncertainty and therefore lack the knowledge with which to optimise their behaviour. It is assumed instead that behaviour follows trends derived from the historical data (i.e. from the econometric equations). The result of this is that the level of aggregate demand in the economy determines production levels and, while the level of available resources may place an upper bound on production, there is no guarantee that all the available capacity is used. For example, involuntary unemployment is a standard output from E3ME, whereas standard CGE models typically assume full employment.

These 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. Changes in demand are often linked to debt levels in the economy and so the interaction between the real economy and the financial system is critical to understanding the economic impacts from the model.[8] For example, if there is an ambitious programme to increase wind capacity, E3ME modelling will show an initial debt-driven stimulus to the economy through higher construction levels, followed by a period of debt repayment (i.e. through higher electricity prices) that may act as a drag on growth.[9]

2.3 E3ME's structure, data and econometric approach

Structure

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.

Main dimensions

The main dimensions of E3ME are:

- 59 countries – all major world economies (i.e. G20), the EU28 and candidate countries, plus other countries' economies grouped
- 43 industry sectors, based on standard international classifications
- 28 categories of household expenditure
- 22 different users of 12 different fuel types
- 14 types of air-borne emissions (where data are available) including the six greenhouse gases monitored under the Kyoto Protocol[10]

[8] Pollitt, H. & Mercure, J.-F., 2017. The role of money and the financial sector in energy-economy models used for assessing climate and energy policy, in Climate Policy, 18. Available at: https://www.tandfonline.com/doi/full/10.1080/14693062.2016.1277685.
[9] Public revenue balancing is currently assumed to be performed annually (no lag). In the private sector, specifically power generation, investment expenditure in capacity is recouped over the lifetime of the project.
[10] They are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), and, sulphur hexafluoride (SF_6).

Data E3ME's historical database covers the period 1970-2016 and the model projects forward annually to 2040 for the individual scenarios and to 2050 for the Combined Scenario. 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 statistical agencies. Gaps in the data are estimated using customised software algorithms.[11]

National accounts For data on national accounts, Eurostat data is used for European countries, combined with the OECD STAN data set for sectoral disaggregation. For non-European countries, the OECD STAN database is used as the primary data source, the Asian Development Bank has been used for information on Asian countries, and for the remaining regions data have been collected from national sources.

Input-output tables The input-output tables in E3ME are derived where possible from Eurostat and OECD data. National sources have been used for remaining countries. All the input-output tables are expanded to the 43 E3ME sectors and moved to a base year of 2005 using RAS techniques.[12] The input-output tables include domestic production and imports. For projections, coefficients are based on logistic trends.

Trade The primary data source for trade is COMTRADE for manufacturing sectors. Data for services were taken from the OECD for all member countries over the period 1995-2010 and expanded to include trade with non-OECD countries. The remaining values were estimated based on data that are available nationally and using share estimates. For projections, we hold shares fixed initially but allow them to vary in the economic equations.

Emissions Time-series data for CO_2 emissions, disaggregated by energy user are obtained from the EDGAR database. These are allocated to fuels using standard coefficients and then scaled to be consistent with the total. Non-CO_2 emissions in E3ME include SO_2, NO_x, CO, methane (CH_4), particulates (PM_{10} and $PM_{2.5}$), volatile organic compounds (VOC), ammonia (NH_3) and the other four greenhouse gases N_2O, HFC, PFC, and SF_6. These data are obtained from the EDGAR database. For projections, we use fixed coefficients.

Econometric specification 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,[13] which are included as standard in the model's

[11] CE has developed a software package to fill in gaps in any of the E3ME time series. This uses growth rates and shares between sectors and variables to estimate missing data points, both in cases of interpolation and extrapolation. See Section 3.3 of the E3ME technical manual at: www.e3me.com.
[12] The RAS method is a well-known method for data reconciliation. Its aim is to achieve consistency between the entries of some non-negative matrix and pre-specified row and column totals.
[13] Where an initial increase in efficiency reduces demand, but this is negated in the long run as greater efficiency lowers the relative cost and increases consumption. See: Barker et al,2009. The macroeconomic rebound effect and the world economy, in Energy Efficiency, 2 pp 411-427. Available at: http://www.euro-ciss.eu/fileadmin/user_upload/Redaktion/Seco@home/nachhaltiger_Energiekonsum/Literatur/rebound_effekt/macroeconomicRebound.pdf.

results. Further information on the econometric method, and the specification of each equation set, is provided in the model manual.

Model validation

Each individual econometric equation is estimated to fit the historical data as well as possible, given certain assumptions about plausibility (e.g. that price elasticities are negative). Standard measures of error are produced as part of the estimation process and the equations are checked for goodness of fit. In the design phase, several of the model equations were tested with alternative specifications to improve their accuracy.

There is no equivalent formal statistical test for validating the performance of the model as a single framework. Instead, the model was tested by running it endogenously over the historical data period (without correcting the equation errors) to see how well it matched the historical data. The results, reported in a book chapter that was published in 2014,[14] show a high degree of accuracy in matching the model results to the actual data. Although the model has been further developed since 2014, the underlying equation structure has not changed.

2.4 Model inputs and outputs

Inputs

Many of E3ME's inputs are fixed and do not vary between the different scenarios, including:

- the historical data
- the econometric behavioural parameters estimated from the data
- exogenous factors (e.g. population growth, non-relevant policy)
- the baseline projections (see Section 3.2 for information on how the baseline is defined)

A further set of inputs is required to define each of the scenarios. These inputs come in the form of numerical assumptions, which represent the policies that are assessed in each case. The NCE team and CE worked together to define the values that were used. They are discussed further in Chapter 3 and presented in Appendix B.

Outputs

As a general model of the economy, based on the full structure of the national accounts, E3ME can produce a broad range of economic indicators. In addition, there is a range of energy and environment indicators available. The following list provides a summary of the most common model outputs:

- GDP and the aggregate components of GDP (household expenditure, investment, government expenditure and international trade)
- sectoral output and Gross Value Added (GVA), prices, trade and competitiveness effects
- international trade (Imports and Exports) by sector, origin and destination
- consumer prices and expenditures
- sectoral employment, unemployment, sectoral wage rates and labour supply
- energy demand, by sector and by fuel, energy prices

[14] Anger, A., Barker, T. and Syddall, M.,2014. 'Modelling Decarbonisation Scenarios', pp 85-123 in Barker, T. and Crawford-Brown, D. (eds) 'Decarbonising the World's Economy'. World Scientific, London.

- CO_2 emissions by sector and by fuel
- other air-borne emissions
- material demands[15]

In addition to the sectoral dimension mentioned in the list, all indicators are produced at the national and regional level and annually over the period up to 2040 or 2050 depending on the scenario.[16]

Table 2.1 E3ME Model outputs

Category	Detailed outputs
Economic outputs	At macro level: • GDP • real incomes • consumption • investment • international trade (exports, imports) • inflation rates At sectoral level: • output • prices • investment • trade
Social outputs	At macro level: • unemployment rates At sectoral level: • employment, wage rates By household group (quintiles[17]): • real incomes
Environmental outputs	At macro level: • energy consumption by carrier • CO_2 (GHG where relevant) emissions, material consumption (DMC), local air pollutants At sectoral level: • CO_2 emissions, • energy consumption by carrier

For more detail, please see Appendix A, which presents the E3ME model classifications.

2.5 E3ME as an E3 model

The E3 interactions

Figure 2.1 shows how the three components (modules) of the model—energy, environment and economy—fit together. Each component is shown in its own

[15] The definition of materials here is inputs used as part of the production process and not bought by households directly. Materials are the output of primary sectors: agriculture and fishing produce food and feed; the forestry sector produces forestry; and non-energy mining produces all mineral categories.
[16] E3ME model outcomes are generated up to 2050 and reported up to 2040 for individual scenarios and through 2050 for the Combined Scenario. See Section 3 for details of individual and the Combined Scenario.
[17] The household groups depend on available survey data in each country. For developing countries even income quintiles may be unavailable. For many developed countries, specific socio-economic groups such as retired, economically inactive, manual/non-manual labour or urban/rural can be identified.

box. Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component. For each region's economy the exogenous factors are economic policies (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of the energy industries). For the environment component, exogenous factors include specific policies. The linkages between the components of the model are shown explicitly by the arrows that indicate which values are transmitted between components.

The economy module provides measures of economic activity and general price levels to the energy module; the energy module provides measures of emissions of the main air pollutants[18] to the environment module, which in turn can give measures of damage to health. The energy module provides detailed price levels for energy carriers distinguished in the economy module and the overall price of energy as well as energy use in the economy.

The role of technology

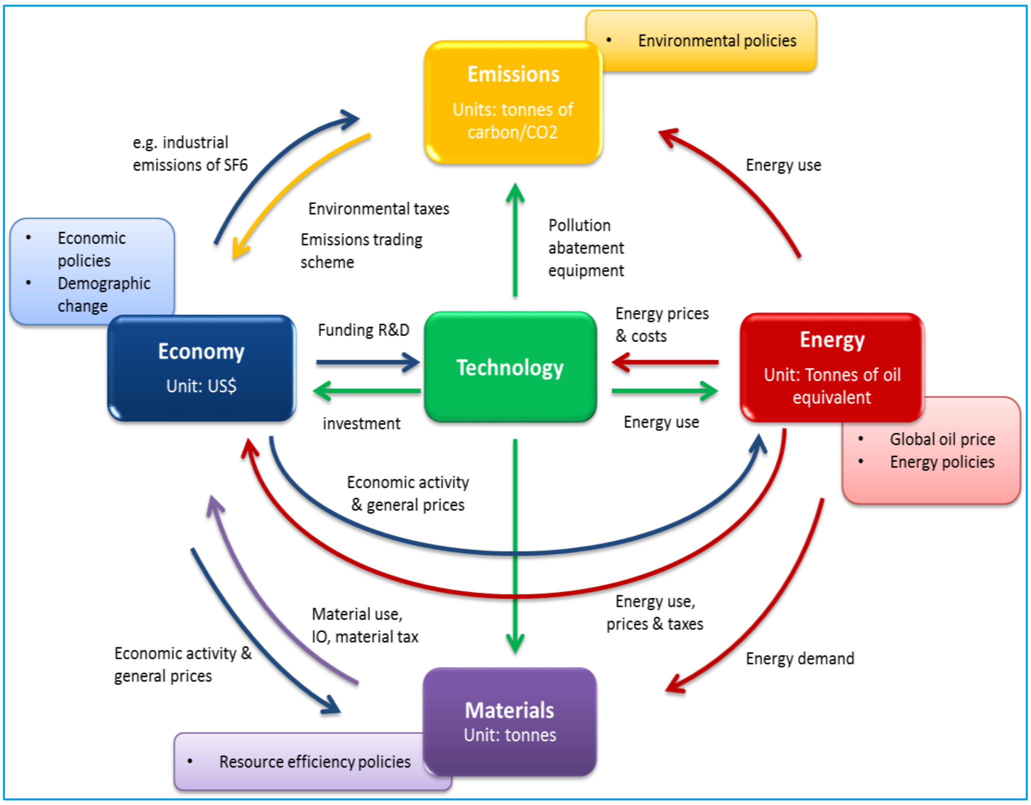
Technological progress plays an important role in the E3ME model, affecting all three E's: economy, energy and environment. The model's endogenous technical progress indicators (TPIs), a function of R&D and gross investment, appear in nine of E3ME's econometric equation sets including trade, the labour market and prices. Investment and R&D in new technologies also appears in the E3ME's energy and material demand equations to capture energy/resource savings technologies as well as pollution abatement equipment.[19]

In addition, E3ME also captures low carbon technologies in the power and road transport sectors through the Future Technology Transformations (FTT) modules. The "FTT: Power module" provides a representation of global power systems based on market competition, induced technological change (ITC) and natural resource use and depletion. The "FTT: Transport module" follows a similar structure for modelling decisions on purchases of passenger vehicles. ITC occurs in both modules as a result of technological learning produced by cumulative investment and leads to highly non-linear, irreversible and path-dependent technological transitions. The modules use dynamic coupled sets of logistic differential equations. As opposed to traditional bottom-up energy models based on systems optimisation, such differential equations offer an appropriate treatment of the times and structure of change involved in sectoral technology transformations or disruptive technology change, as well as a much-reduced computational load.

Resource use and depletion are represented by local cost-supply curves, which give rise to different regional energy landscapes.[20]

[18] They are: Carbon dioxide, Sulphur dioxide, Nitrogen oxides, Carbon monoxide, Methane, Particulates, VOCs, Radiation – air, Lead - air , CFCs , N2O (GHG) , HFCs (GHG) , PFCs (GHG) , and, SF6 (GHG)
[19] Mercure, J-F., Lam, A, Billington, S. & Pollitt, H., 2018. Integrated assessment modelling as a positive science: private passenger road transport policies to meet a climate target well below 2∘C. Climatic Change. 1-21. 10.1007/s10584-018-2262-7.
[20] See: Mercure, J.-F., 2012. FFT:Power : A global model of the power sector with induced technological change and natural resource depletion, in Energy Policy, 48 pp 799-811. Paper is not open access. Can be found at: https://www.sciencedirect.com/science/article/pii/S0301421512005356?via%3Dihub.

Figure 2.1 E3 linkages in the E3ME model



2.6 Treatment of trade, labour market, health impacts and land use change, and non-CO_2 emissions

International trade

An important part of the modelling concerns international trade. E3ME solves for detailed bilateral trade between regions (similar to a two-tier Armington model).[21] Trade is modelled in three stages:

- econometric estimation of regions' sectoral import demands
- econometric estimation of regions' bilateral imports from each partner
- forming exports from other regions' import demands

Trade volumes are determined by a combination of economic activity indicators, relative prices and technology.

The labour market

Treatment of the labour market is an area that distinguishes E3ME from other macroeconomic models. E3ME includes econometric equation sets for employment, average working hours, wage rates and participation rates. The first three of these sets are disaggregated by economic sector while participation rates are disaggregated by gender and five-year age bands.

The labour force is determined by multiplying labour market participation rates by population. Unemployment (including both voluntary and involuntary unemployment) is determined by taking the difference between the labour

[21] Armington, P.S., 1969. A Theory of Demand for Products Distinguished by Place of Production. Staff Papers (International Monetary Fund),16(1) pp 159-178. Available at: http://www.jstor.org/stable/3866403?seq=1#page_scan_tab_contents.

force and employment. This is typically a key variable of interest for policy makers. Labour market participation rates are modelled individually for male and females, in 5-year age bands. Employment results are calculated for both males and females.

Health impacts

The E3ME model has been expanded to account for the health impacts of local air pollution. Health impacts feedback to other model variables so that the analysis considers impacts on the size and quality of the labour force.

The modelling is based on data from the EcoSenseLE tool that provides estimates of life expectancy and life quality changes due to changes in emissions and their associated monetary value. However, the tool contains information that is limited to European countries.

Given the geographic limitation of this approach, an off-model calculation of avoided premature deaths at the global level due to air pollution was also carried out, for key countries and regions. Using outputs from the E3ME model, this calculation of health impacts was based on a dataset and tool that was created by the International Monetary Fund, Fiscal Affairs Department from their project *Getting Energy Prices Right*. Based on this analysis, 710,000 premature deaths due to air pollution are avoided globally as a result of the actions in the Combined Scenario.[22] See Box 2.1 for methodological details.

Box 2.1 Methodology for Calculating Avoided Premature Deaths

The methodology for calculating avoided premature deaths for each policy scenario utilises outputs from Cambridge Econometrics' E3ME model and data from the IMF study, 'Getting the Prices Right' by Ian Parry et al. (2014). The approach allows for computing deaths per tonne of primary pollution per emission source (power plants, ground sources) for three primary pollutants (SO_2, NO_x, $PM_{2.5}$). These estimates require an estimation of intake fractions, and a measure of relative risk of cardiovascular diseases, as follows:

1. Intake fractions. These are estimates of grams of $PM_{2.5}$ inhaled per metric ton of primary pollutant. $PM_{2.5}$ is a primary pollutant from fossil fuel combustion, but is also created by secondary formation from precursor emissions of SO_2 and NO_x. They are dependent on three main factors: (i) the height at which emissions are released; (ii) the size of the population exposed to the pollution, and (iii) meteorological and physical conditions, e.g. wind speed and direction, topography, and ambient ammonia concentrations (which catalyse atmospheric reactions of SO_2 and NO_x). To calculate intake fractions from power plant emissions, Parry et al. (2014) use: (i) the Carbon Monitoring for Action (CARMA)[23] database to determine the geographical location of about 2,400 coal, and 2,000 natural gas plants in over 100 different countries, (ii) LandScan data[24] to obtain 2010 gridded population counts for each country, and (iii) regression estimates from Zhou et al.[25] on the fraction of an average plant's emissions

[22] This is about a 75% reduction from the calculated IMF baseline. See: https://www.who.int/sustainable-development/cities/health-risks/air-pollution/en/; https://sustainabledevelopment.un.org/content/documents/1008357_Piqueras_The%20rapidly%20growing%20death%20toll%20attributed%20to%20air%20pollution-A%20global%20responsibility.pdf.

[23] Center for Global Development, Carbon Monitoring for Action (CARMA). http://carma.org/

[24] Oak Ridge National Laboratory, LandScan. http://web.ornl.gov/sci/landscan/.

[25] Zhou, Y., Levy, J.I., Evans, J.S. and Hammitt, J.K., 2006. "The Influence of Geographic Location on Population Exposure to Emissions from Power Plants throughout China". Environment International, Vol. 32, pp. 365–73.

that are inhaled by an average person residing within pre-defined, alternative bands. Country-level intake fractions for ground sources of SO_2, NO_x, and $PM_{2.5}$ are estimated from both the work of Apte et al.[26] (2012) and Humbert et al. (2011).[27]

2. Relative risk of cardiovascular diseases. The main air pollution-related diseases are lung cancer, chronic obstructive pulmonary disease, ischemic heart disease (from reduced blood supply) and stroke. Parry et al. (2014) obtained annual mortality rates for these four illnesses for each country from the World Health Organization Global Burden of Disease data for 2010.[28] Relating changes in local air pollution to increased mortality is based on concentration-response functions, derived from US-based studies. Based on empirical studies, the US Environmental Protection Agency estimated that a 10 μg/m^3 increase in $PM_{2.5}$ concentrations raises all pollution-related mortality risks by 10.6%.[29] The mortality risks were extrapolated to other regions of the world with different concentrations of $PM_{2.5}$ using the above relationship for all countries.

Avoided Premature Deaths

The E3ME model outputs include primary pollutants (SO_2, NO_x, $PM_{2.5}$) per region and sector (power, industry, transport, buildings, and agriculture) for each policy scenario. The estimate of the avoided premature deaths for each policy scenario is calculated by multiplying the change in pollutant emitted for each country between the baseline and policy scenario in 2030 by the country-specific values for deaths per pollutant and source from the IMF dataset. This is summed across all countries and the three pollutants to get an overall estimate of avoided premature mortality for each policy scenario.

For the purposes of computing avoided deaths based on E3ME, some methodological amendments were made. First, the E3ME model divides the world into 59 regions. In order to estimate pollutants emitted during any time period and policy scenario for all 188 countries in the IMF dataset, we disaggregated groups of countries (Rest of Annex I, Rest of Latin America, Rest of ASEAN, Rest of OPEC, Africa OPEC, Rest of Africa, Rest of World) by weighting primary pollutants by individual country shares of CO_2 emissions among the regional group, using 2015 data from IEA.[30] Second, since the E3ME model provides emissions by sector, while the IMF dataset gives mortality estimates by source of pollutant, for primary pollutants emitted from the power and industry sectors, we used the IMF mortality estimates from power plant emissions, selecting the higher value for each country among coal and natural gas plants. Similarly, for primary pollutants emitted from transport and buildings, we used the IMF mortality estimates from ground sources. We disregarded emissions from the agriculture sector.

The health impacts of ozone are not included in this analysis.

Modelling outputs

The results from the E3ME empirical work are presented as follows:

- Mortality - the modelling reports the number of life years gained (lost) from decreased (increased) emissions over a population in a region

[26] Apte, J.S., Bornbrun, E., Marshall, J.D. and Nazaroff, W.W., 2012. “Global Intraurban Intake Fractions for Primary Air Pollutants from Vehicles and Other Distributed Sources”. Environmental Science & Technology, Vol. 46, pp. 3415–23.
[27] Humbert, S.; Marshall, J., Shaked, S., Spadaro, J., Nichioka, R., Preiss, P., McKone, T., Horvath, A. & Jolliet, O., 2011. “Intake Fraction for Particulate Matter: Recommendations for Life Cycle Impact Assessment”. Environmental Science & Technology, Vol., pp. 4808–16.
[28] WHO Global Burden of Disease project: http://www.who.int/healthinfo/global_burden_disease/about/en/.
[29] United States Environmental Protection Agency (US EPA). The Benefits and Costs of the Clean Air Act from 1990 to 2020. Report to Congress; Washington, DC.
[30] IEA, 2017. IEA CO_2 emissions from fuel combustion (2017 edition). IEA. Paris, France.

(results for Europe only). Given this limitation in E3ME, an off-model calculation of avoided deaths linked to improvements in air pollution is computed, based on work by Parry et al. at the International Monetary Fund (See Box 2.1 above), for most countries in the world, and for selected types of pollutants and sources of emissions.

- Avoided premature deaths due to avoided air pollution (global and regional results).
- Labour productivity – the modelling reports the number of healthy life years gained (lost) from decreased (increased) emissions over a population in a region (results for Europe only).
- Healthcare costs – the modelling reports reduced (additional) governmental expenditures on health from decreased (increased) emissions (results for Europe only).

Land use change and non-CO_2 emissions

The current version of the E3ME model does not cover emissions from land use or land use change. Although it does include estimates of the non-CO_2 greenhouse gas emissions, the treatment is relatively basic. For example, agriculture is considered as a single sector in the model.

In the Combined Scenario, it is necessary to make an assumption about the level of land use and non-CO_2 emissions so as to ensure consistency with a 2°C pathway. We use the assumption that these emissions follow a pathway that is consistent with RCP2.6,[31] which has the lowest emissions amongst the four RCP scenarios and is broadly consistent with a 2°C pathway. Although not modelled, effectively we assume that a similar level of ambition is applied to these emissions as to energy CO_2 emissions.

It is noted that such a pathway would entail some impacts on land use. Cropland increases in RCP2.6, largely as a result of bio-energy production, which is broadly consistent with our results. The use of grassland is more-or-less constant in the RCP2.6, as the increase in production of animal products is met through a shift from extensive to more intensive animal husbandry.

[31] RCP's (Representative Concentration Pathways) are emissions scenarios used in the IPCC's 5th Assessment Report. These describe alternative trajectories for greenhouse gas emissions and the resulting atmospheric concentration from 2000 to 2100. In the RCP 2.6 scenario, global CO_2 emissions peak by 2020 and decline to around zero by 2080. Concentrations in the atmosphere peak at around 440 ppm in mid century and then start slowly declining. Global population peaks mid century at just over 9 billion and global economic growth is high. Oil use declines but use of other fossil fuel increases and is offset by capture and storage of carbon dioxide. Biofuel use is high. Renewable energy (e.g. solar & wind) increases but remains low. Cropping area increases faster than current trends, while grassland area remain constant. Animal husbandry becomes more intensive. Forest vegetation continues to decline at current trends. For further details, see van Vuuren et al. (2011).

3 Modelling the Scenarios

This chapter provides an overview of the scenarios (Section 3.1), the baseline case used as a reference (Section 3.2), and it outlines several modelling issues that cut across the scenarios: revenue-recycling mechanisms, subsidies in power generation and employment impacts (Section 3.3).

3.1 Overview of the scenarios

Table 3.1 provides an overview of the scenarios and describes the policies included in each scenario.

Separate model runs have been conducted for each of the scenarios, which allows for reporting the impacts of each policy and decarbonisation area. Three scenarios were run for cities: one for 'urban retrofits' (S1a), one for 'urban densification' (S1b) and one focusing on urban transport electrification (S2). Two scenarios focused on the energy system: one on introducing a global carbon price and additional energy reforms (S3) and one focusing on efficiency measures, 'reduction of energy waste' (S4). An 'innovation and industrial efficiency' (S5) was also assessed.

In addition, a Combined Scenario was produced that includes all the policies and interventions referred to in the individual scenarios. The time horizon for assessing the individual policy areas is 2040, but the Combined Scenario was run to 2050 to provide a comparison with long-term emissions reduction targets.

The Combined Scenario includes policies for a shift away from high carbon activities and high carbon dependency, and improvement in energy efficiency in cities, both at the household and industry level. It also incorporates implicitly policies on food, land use and waste.

Table 3.1 Modelled policies in the scenarios

	Cities		Energy		Industry	
Modelled policies	**S1 Urban Retrofits and densification**	**S2 Promoting EVs**	**S3 Carbon pricing and energy reforms**	**S4 Reducing energy waste**	**S5 Innovation and industrial efficiency**	**Combined Scenario**
Improved efficiency of new buildings	x					
Reduced heating requirements for households and fuel consumption for transport	x					
Investment in energy efficiency to meet set efficiency targets, tailored for different economic sectors	x			x	x	x
Regulation of vehicles with internal combustion engines to promote uptake of EVs		x				x
Road, vehicle and/or fuel taxation to promote uptake of EVs		x				x
Public purchasing schemes/incentives for the private sector to invest in EV charging infrastructure		x				x
Carbon taxation, assuming different rates and start years across global regions, increasing over time			x			x
Removal of fossil fuel subsidies			x			x
Feed in tariffs for the electricity grid to promote renewable energy			x			x
Subsidies on capital investments in power generation			x			x
Regulation for different technologies, e.g.			x			x

	Cities		Energy		Industry	
Modelled policies	**S1 Urban Retrofits and densification**	**S2 Promoting EVs**	**S3 Carbon pricing and energy reforms**	**S4 Reducing energy waste**	**S5 Innovation and industrial efficiency**	**Combined Scenario**
phasing out of coal and/or boosting renewable energy sources						
Boosting research and innovation to improve industrial processes					x	x
Boosting uptake of new technologies as they reach maturity					x	x
Switch away from coal in district heating systems in coal heavy states			x			x
Fuel switching: from coal to electricity in industry and from gas to electricity in domestic cooking			x		x	x
Other policies as in the baseline[32]	x	x	x	x	x	x

[32] For information on the baseline, see Section 3.2 of this document.

3.2 The model baseline as a reference case

Policy scenario results are usually presented as differences from a baseline case, as opposed to absolute forecasts. In providing inputs to the policy scenario, knowledge of the reference/baseline is important.

Main inputs to the baseline

For energy projections, the E3ME baseline is calibrated to the 2017 IEA Current Policy Scenario (CPS)[33] from *World Energy Outlook 2017*. The CPS includes projections of energy consumption, disaggregated by country, sector and carrier. Unlike the New Policies Scenario (NPS) from the same publication, the CPS does not include additional policies and therefore there is no risk of double counting when additional policies are added in the scenarios. Baseline energy prices are also assumed to be consistent with the IEA 2017 CPS.

Economic projections

Population data in E3ME are calibrated to UN forecasts. For economic projections, E3ME has been calibrated to match the 2017 published IEA *World Energy Outlook* on future growth rates; the IEA uses World Bank & IMF data for projections. Sectoral growth rates are extrapolated from historical data but constrained to be consistent with the published aggregate projections. Projections are formed for all the main accounting indicators, using a series of proxy values.

Climate impacts

A substantial fraction of the climate impacts that we will see in the period up to 2050 will result from the delayed effects of past emissions. They are therefore not dependent on current or future climate policy and would be expected to occur in both the baseline case and the policy scenarios.

Due to the high level of uncertainty around climate impacts, we have not included feedbacks to the economy in the analysis in this report. However, it is noted that a changing and more volatile climate would have economic impacts and that these impacts could be limited in scenarios in which emissions are reduced. For instance, the US Fourth National Climate Assessment Report indicates that climate change is already affecting all regions of the United States. The US is on track to lose hundreds of billions of dollars annually by the end of the century, and in the absence of steep emissions cuts, climate change will irreparably harm ecosystems and other resource-dependent parts of the economy.

In the current exercise, E3ME includes climate change damages in the baseline in so far as these are included in the economic forecasts, which the model has been calibrated to. There is no change in the policy scenarios.

Evolution of technology costs

Technology costs are modelled endogenously in the FTT modules, based on cumulative installed capacity and assumed learning rates. The learning rates are derived from historical time-series data of costs per technology and are not changed in the projections. Costs fall faster for technologies that are at an earlier stage of deployment and the costs for an individual technology will fall by more in a scenario in which that technology has a high level of deployment.

[33] See: https://www.iea.org/publications/scenariosandprojections/.

3.3 Discussion on modelling parameters

Balancing public budgets

When assessing scenarios that affect public balances, modellers generally assume that there is a mechanism to maintain revenue neutrality.[34] The modelling results then show the impact of a shift in resources rather than an overall stimulus/contraction of the economy from the public sector. In the E3ME model, such 'revenue recycling' from a higher public balance sheet (e.g. due to carbon taxes) is usually based on one of the following options:[35]

- reductions in income tax rates
- reductions in sales tax / VAT rates
- reductions in employers' social security contributions
- increases in government spending
- the introduction of lump sum payments to households[36]

As described below, the first three of these taxes are adjusted in the scenarios to balance net government revenues. These taxes are all substantial enough in tax base that a relatively small change is required to achieve revenue balancing in most scenarios, thus minimising any distortions. As such, we have not investigated relative multipliers of different categories of government expenditure.

Treatment of oil and gas extraction royalties is differentiated from other policies. Half of the difference in royalties from the baseline directly reduces government expenditure, and half enters the revenue recycling mechanism. This reflects a more realistic approach of governments facing lower resource royalties: a combination of reducing government expenditure alongside increasing taxation.

Savings from removal of fossil fuel subsidies are directly distributed to households as lump sum payments. All other policies enter a single revenue recycling mechanism. Where the net balance is positive, 70% is used to decrease sales tax, and 30% is used to increase benefit/social security payments. Where the balance is negative, 100% is used to raise sales tax. Asymmetry of the mechanism is used to avoid reducing benefit payments where policies have a net negative fiscal balance; a symmetrical mechanism would lead to highly regressive policies in some cases.

Funding private sector investment

Capital costs in the power generation sector are paid for over the lifetime of built capacity: investment is therefore paid for through higher electricity prices over the medium term.

Other *additional* private investment (mostly energy efficiency) that is entered as part of the scenario, both by industry and households, is assumed to be paid for in the year in which the investment is made. For industry, investment is modelled as an additional cost of production, leading to an increase in the

[34] Revenue neutrality means that the measures in the scenario are paid for and carbon tax revenues are recycled. This is different from the idea of fiscal neutrality, where government balance is the same in baseline and scenario.
[35] If the public balance sheet worsened, then we would impose the opposite effects.
[36] With a treatment of adding to wealth or income, which significantly changes marginal propensity to consume from the lump sum payment.

price of output (subject to cost pass through rates in the econometric equations). Private investment by households is assumed to offset other consumption expenditure.

Power generation subsidies

There are two distinct subsidy mechanisms used in the FTT:Power module. They are capital investment subsidies and feed-in-tariffs. Capital investment subsidies are applied to Carbon Capture and Storage (CCS), biomass, and geothermal technologies, as a fixed proportion of investment costs. These subsidies can be assumed to be public-private partnerships in which the public covers part of the capital cost. Feed-in-tariffs are used for onshore and offshore wind, solar photovoltaic systems (PV), and concentrated solar power (CSP). Feed-in-tariffs only provide a subsidy payment when the Levelised Cost of Electricity (LCOE)[37] is higher than the electricity price; in this case, a percentage of the difference between LCOE and the electricity strike price per MWh is paid to the generator. In many regions, the feed-in-tariff provides no subsidy to solar PV and onshore wind because the levelised cost of generation is already less than the electricity strike price.

Gender-based employment results

The treatment of employment by gender is estimated through a basic off-model calculation, in the absence of econometric estimation. The methodology is to calculate gender ratios within each sector using the latest year of data available, and to assume that this ratio remains constant throughout the forecast period. The methodology is applied to the EU28 Member States and the remaining G20 countries.[38]

[37] Also known as Levelised Energy Cost (LEC), is the net present value of the unit-cost of electricity over the lifetime of a generating asset.

[38] Non-EU G20 data sourced from ILO databases.

4 Modelling Results

4.1 S1-S5: Clean energy systems (Combined Scenario)

Overview

The Combined Scenario includes all the inputs from S1-S5[39] plus additional energy efficiency in households in the ‘Rest of World’ E3ME region.

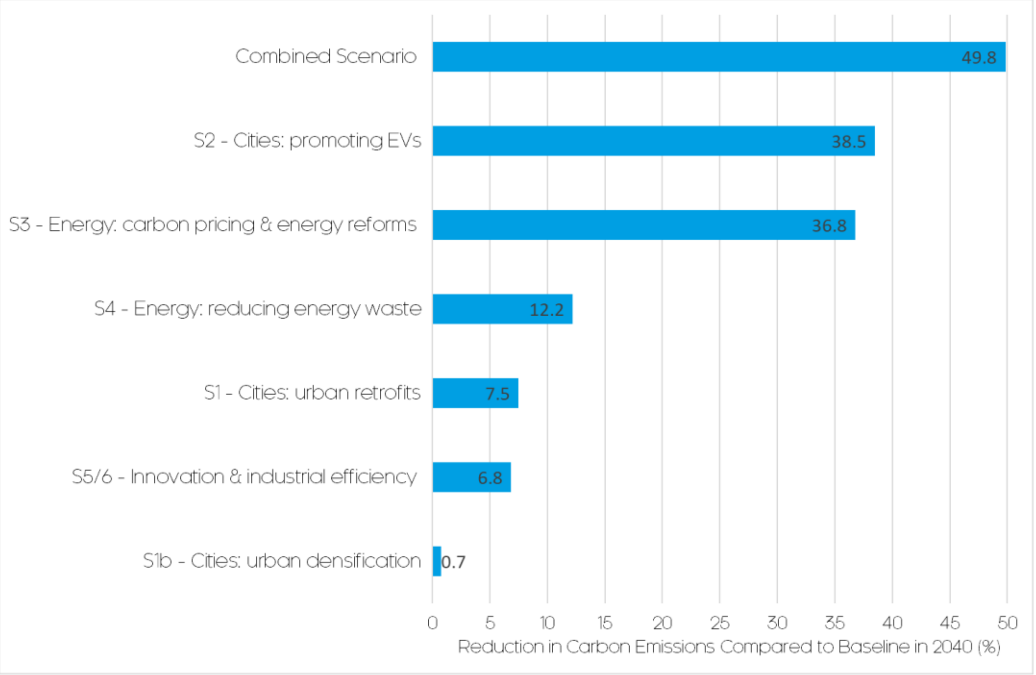
This Combined Scenario represents a comprehensive push to decarbonisation within the energy system. Whilst each of the individual scenarios are run annually up to 2040, the Combined Scenario gives projections up to 2050 so that longer-term climate impacts may be estimated.

Modelling results

Figure 4.1 compares the level of effort by scenario in terms of implied change in CO_2 emissions relative to baseline by 2040.[40] Scenario 2 (Promoting EVs) is simulated under the assumption that carbon pricing and energy reforms take place; together, these measures lead to a reduction in CO_2 of over 38% relative to baseline by 2040.

Emissions

Figure 4.1 Change in carbon emissions, by Scenario, Relative to Baseline in 2040



In terms of the aggregate level of effort from the Combined Scenario, the implied reduction of CO_2 emissions relative to baseline reaches 49.8% by 2040 (about 20.9 $GtCO_2$) and nearly 64% by 2050 (about 30.5 $GtCO_2$).

Figure 4.2 shows the absolute level of emissions under the Combined Scenario for the period 2018-2050 (21.1 $GtCO_2$ in 2040 and 17.6 $GtCO_2$ in 2050). The figure also shows, as a reference, the path of carbon emissions under the so-called 2°C Scenario (2DS) from the International Energy Agency

[39] The exception being densification, only retrofitting from Scenario 1 is included so as to avoid double counting of household energy savings.
[40] Given the model structure and non-linearities, the results for the Combined Scenario cannot be interpreted as the individual sum of results from individual scenarios.

(IEA) Energy Technology Perspectives 2017 report.[41] If we assume that land use and non-CO_2 emissions follow a path that is consistent with RCP2.6, our analysis shows a pathway for the Combined Scenario to stay below a 2°C pathway of warming with 63% probability. This is equivalent to a 50% probability of peak warming of 1.92°C. In contrast, the IEA's 2°C Scenario (2DS) lays out an energy system pathway and a CO_2 emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C by 2100.

Figure 4.2 Combined Scenario CO_2 Emissions (Gt CO_2) 2018-2050

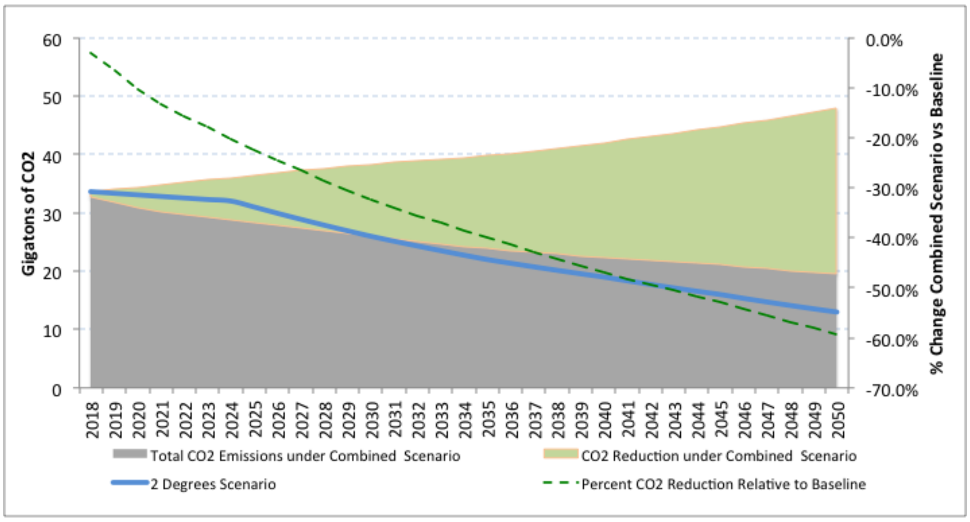
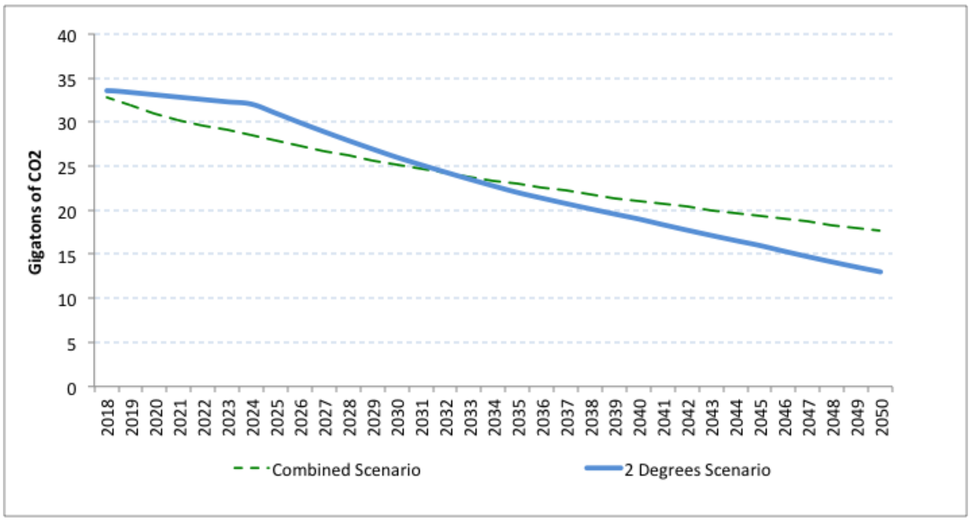


Figure 4.3 shows the emission reductions relative to baseline (in percentage terms).

Figure 4.3 Combined Scenario CO_2 emissions reductions relative to baseline and path for 2 Degrees Scenario (IEA). 2018-2050



Source: Combined Scenario and IEA Energy Technology Perspectives 2017

[41] See: http://www.iea.org/etp/explore/.

The economic results are of higher magnitude for the Combined Scenario than each of the scenarios individually, as is expected given that each of the scenarios yields positive economic results individually. However, the differences between the Combined Scenario and S2 and S3 are relatively small as S2 and S3 already include the most ambitious measures.

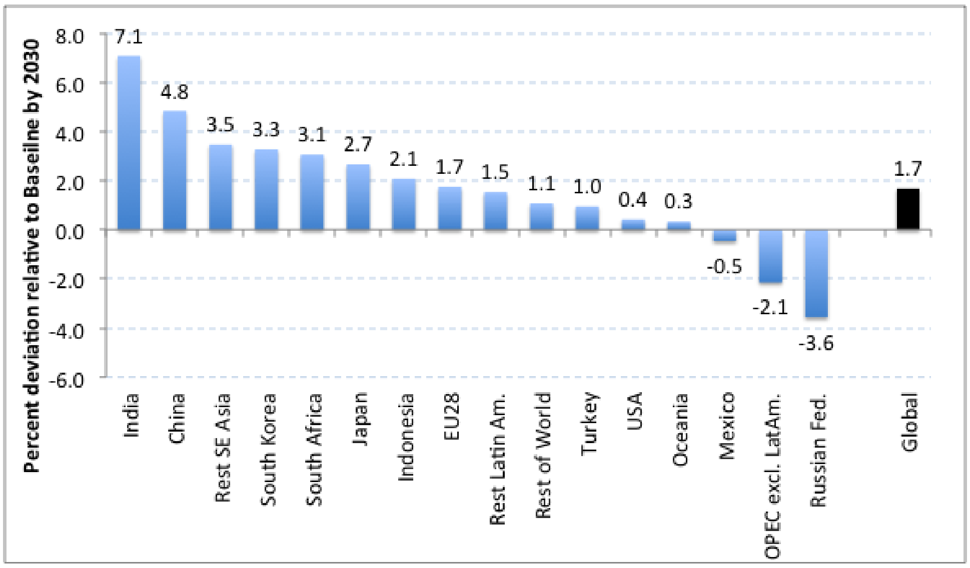
GDP

The effect on GDP varies across world regions. The largest positive impacts are observed in Asia. In percentage terms, India shows the largest increase from baseline, driven by promotion of electric vehicles, and a reform of the electricity system to support transition to clean energy sources. India sees a large increase in investment (in energy efficiency, power sector equipment and EV infrastructure) and an improvement in its trade balance due to a reduction in imports of fossil fuels.

Figure 4.4 shows changes in real GDP by 2030 in the Combined Scenario relative to baseline, by region. There is a notable split between countries that are energy importers and those that are energy exporters. All the countries that experience negative impacts are ones in which fossil fuel extraction accounts for a sizable share of GDP. In the Combined Scenario, however, lower oil prices means it is not economic to develop the tar sands to such an extent, so a large share of the resources remain unexploited.

One must keep in mind that having a GDP level that is lower than the baseline does not necessarily mean that the country or region would experience an economic recession. It is important to emphasise that all countries, including fossil fuel abundant countries, achieve growth in per capita income over the scenario compared to 2015. Many also achieve more rapid growth than in the baseline. The resulting increase in global GDP by 2030 (1.7% above baseline) is equivalent to the total value added generated by Australia or Spain in 2017.

Figure 4.4 Combined Scenario Change in GDP by 2030 Relative to Baseline,

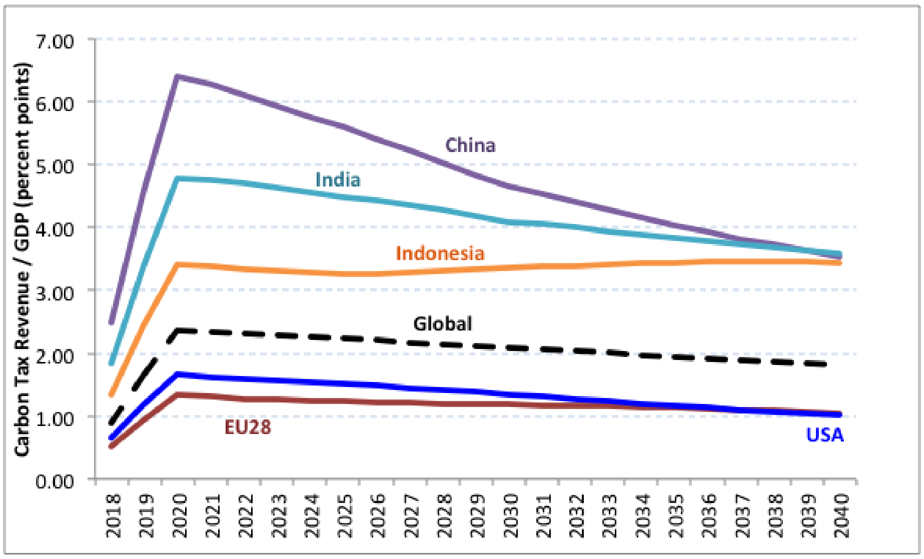


By Regions

Carbon tax revenues

The path of tax revenues reflects the offsetting influences of rising carbon prices and falling emissions (see Figure 4.5). Revenues obtained from higher carbon tax rates increase rapidly in the years up to 2020, reflecting the effort to meet the Stern-Stiglitz corridor values.[42] The tax rates used in the Combined Scenario are described in Appendix B. Beyond 2020, in the EU28 and Japan revenues stay relatively constant in nominal terms over the period to 2040; the increases in carbon tax rates balance the reductions in emissions. However, in the US, Canada and Australia, revenues fall in nominal terms as emissions fall faster than the rate of carbon tax increase. In most developing countries, revenues increase in nominal terms up to 2040, but at a slower rate than inflation and hence fall in real terms.

Figure 4.5 Combined Scenario Carbon Tax revenues 2018-2040



Phasing out fossil fuel subsidies

The removal of fossil fuel subsidies provides a stimulus in regions that are fuel importers. Savings are distributed directly to households, resulting in higher consumer expenditure throughout the domestic economy and a general shift away from fossil fuel consumption (i.e. imports). The reallocation of expenditure is substantial in many regions, particularly those that are domestic producers of fuel; for example, fossil fuel subsidies amount to over 4% of GDP in many OPEC regions. Figure 4.6 shows the path for savings from fossil fuel subsidy removal as a proportion of GDP in selected regions for the period 2018-2040. Figure 4.7 presents the same variable for all regions in 2025 when, based on the scenario definition, the policy has its maximum annual savings.

Globally, the combination of increasing carbon prices along the Stern-Stiglitz corridor and phasing out fossil fuel subsides as described above results in US$2.8 trillion in 2030 in both carbon price revenues and fossil fuel subsidy

[42] The High-Level Commission on Carbon Prices was launched in November 2016 at COP22 in Morocco, led by prominent economists Lord Nicholas Stern and Joseph Stiglitz, and comprising economists, climate change and energy specialists from all over the world. The Commission's objective was to identify indicative corridors of carbon prices which could be used to guide the design of carbon pricing instruments and other climate policies, regulations, and measures to incentivise bold climate action and stimulate learning and innovation to deliver on the ambition of the Paris Agreement and support the achievement of the Sustainable Development Goals. Results from the High Level Commission work produced, among others, indicative paths for carbon pricing across countries in the world that are consistent with ambitious climate goals. See: https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f2409f8dce5316811916/1505227332748/CarbonPricing_FullReport.pdf.

savings to reinvest in public priorities. The associated improvements in air quality resulting from these policies would bring additional economic benefits. In European countries alone, these reforms result in savings from the subsequent reductions in government health expenditures of approximately US$7.2 billion between 2018-2030. Due to data constraints, this reduction in health expenditures associated with increasing carbon pricing and phasing out fossil fuels is only available for European countries (see Section 2.6), but significant savings would be expected in regions where the burdens from air pollution-related disease are greater. For example, it is possible to extrapolate these results to estimate savings in the Americas. If countries in the Americas move towards more robust and aligned carbon prices of US$50—100 per tonne CO_2 by 2030, and phase out fossil fuel subsidies, they could realise over US$528 billion per year in revenues or savings by 2030.

Figure 4.6 Combined Scenario Fossil Fuel Subsidy Removal Savings 2018-2040

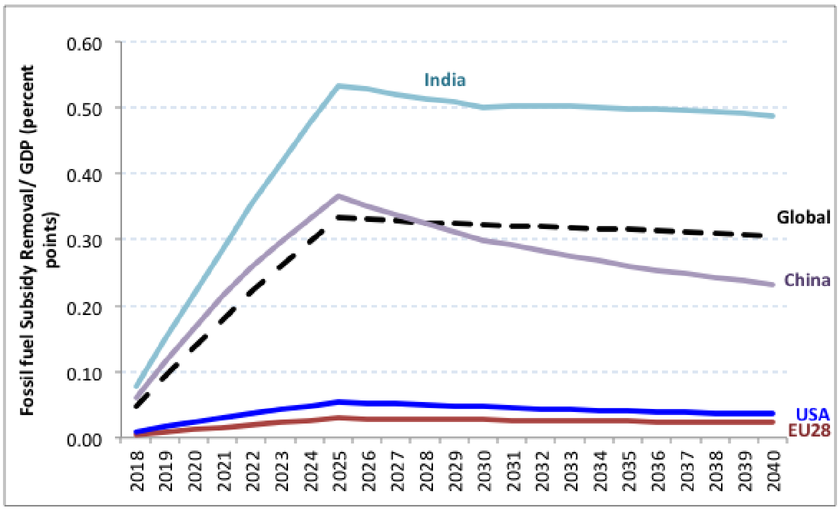
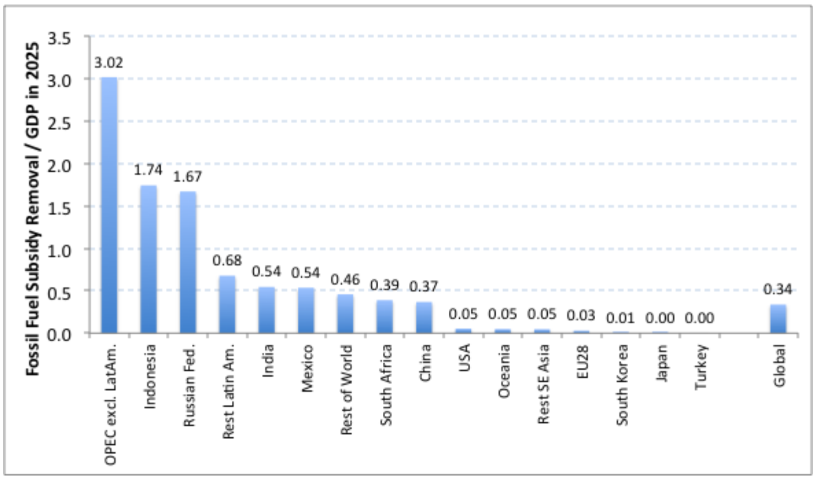


Figure 4.7 Combined Scenario Fossil Fuel Subsidy Removal Savings by 2025 by Regions



Employment

Under the Combined Scenario, global employment increases by up to 0.7% compared to the baseline in 2030, and by 0.4% in 2050. South Korea, Indonesia and South Africa see the largest relative increase (Figure 4.8 Combined Scenario Changes in Employment Relative to Baseline by Regions in 2050). Changes in employment across regions are fundamentally explained by changes in economic activity, which, in the case of the Combined Scenario, are mainly driven by the relative strength of policies on carbon pricing (and to a lesser extent on removal of fossil fuel subsidies). The implication is that the largest reductions in employment tend to be associated to countries with larger oil, gas and coal sectors relative to the overall size of the economy (Figure 4.9). The relative changes in employment are smaller than the changes in GDP, indicating an elasticity of less than one for employment in most regions. The relationship between GDP and employment reflects impacts at sectoral level as well as labour market characteristics (e.g. degree of flexibility) that are captured in the model's econometric equations. At the global level, the net increase in employment is 27 million jobs in 2030, which is enough to offset job losses in high-carbon sectors. The employment effects result in 65 million new low-carbon jobs in 2030.

Figure 4.8 Combined Scenario Changes in Employment Relative to Baseline by Regions in 2050

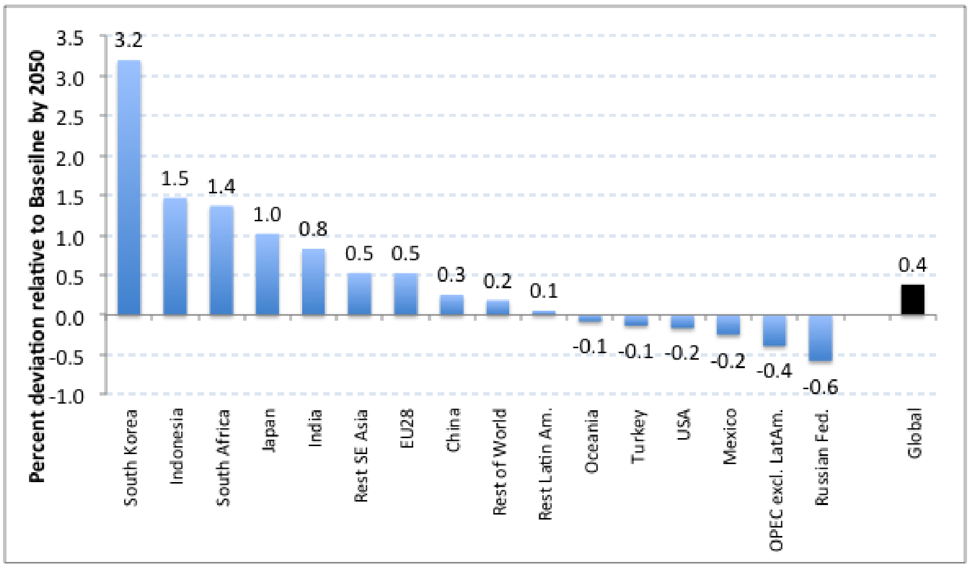
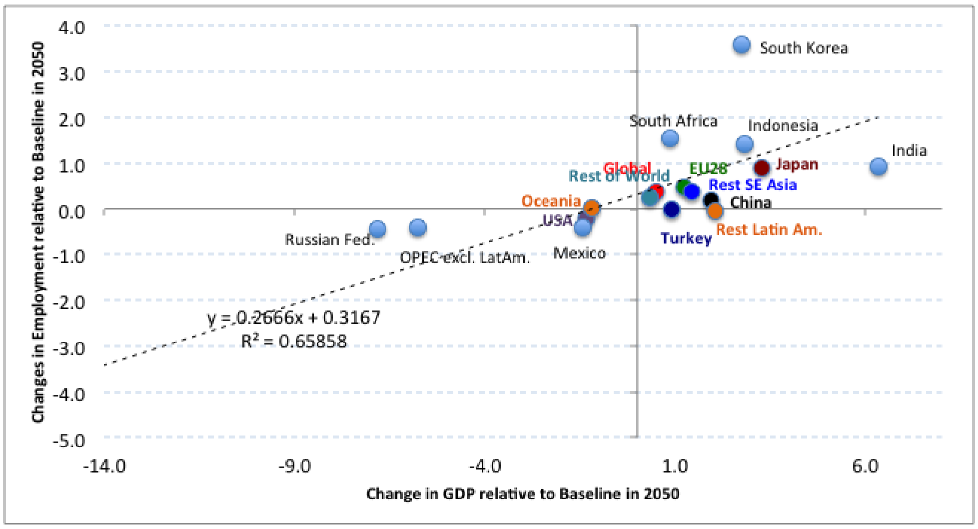


Figure 4.9 Combined Scenario Changes in GDP relative to baseline vs changes in employment relative to baseline in 2050,



Distributional Impacts

Distributional impacts are only available for a subset of regions because of limited data availability. The key determinants of distributional impacts are the revenue recycling mechanism and impacts on energy prices. In Western and Northern Europe, the lowest income quintile consistently benefits the most because of increased expenditure on social benefits that are funded by carbon tax revenues. In Korea, the lowest income quintile benefits the least because of patterns in expenditure and changes in relative prices. In the US, there is no dominant effect, with each quintile being similarly affected.

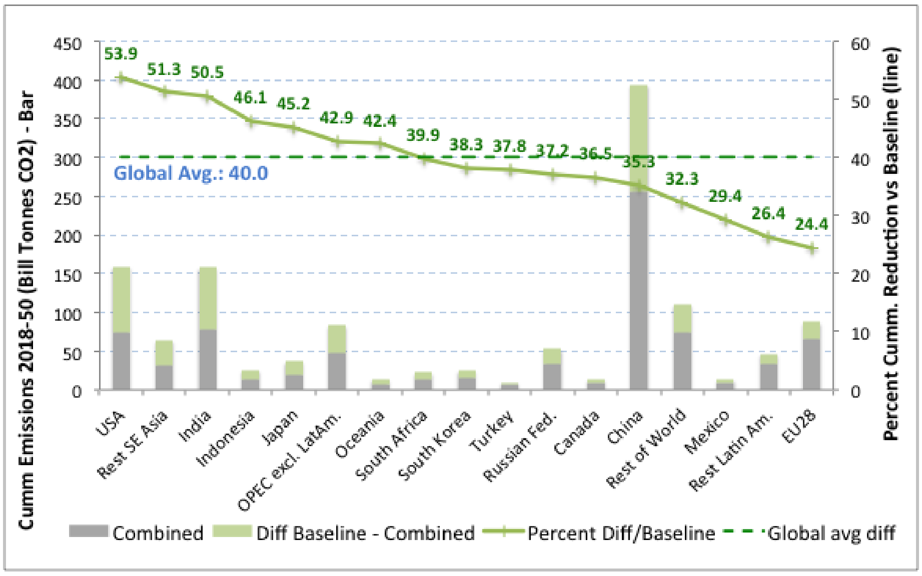
Messages from the distributional impacts in the EU28, US, Korea and Japan cannot be extrapolated to developing regions. The key differences in developing regions for distributional impacts are that fossil fuel subsidy removal is of a magnitude higher in many developing regions, and energy expenditure as a share of income is likely to be much higher.

Emissions

In the Combined Scenario, global CO_2 emissions (excluding land use) are reduced by 34.5% by 2030, and 49.8% by 2040 compared to the baseline. There are also reductions in other greenhouse gas emissions in the Combined Scenario. Figure 4.10 shows the absolute and relative implied reductions in CO_2 emissions, by region, for the period 2018-2050. The figure shows cumulative emissions for the period 2018-2050 under the Combined Scenario, along with cumulative emission reductions, both total and relative as a share of cumulative emissions in the baseline. The figure indicates countries' relative reduction levels compared to global cumulative reductions over the same period.

Emissions of PM_{10}, $PM_{2.5}$, NO_X and SO_2 all decrease compared to baseline in the projection period. By 2040, global PM_{10} emissions are 16.8% below baseline levels and the reduction compared to baseline in $PM_{2.5}$ emissions is 22.1%; these values become 20.4% and 26.3%, respectively, by 2050. The reduction of SO_2 emissions is 53.2% by 2050, and of NO_X by 41.5%.

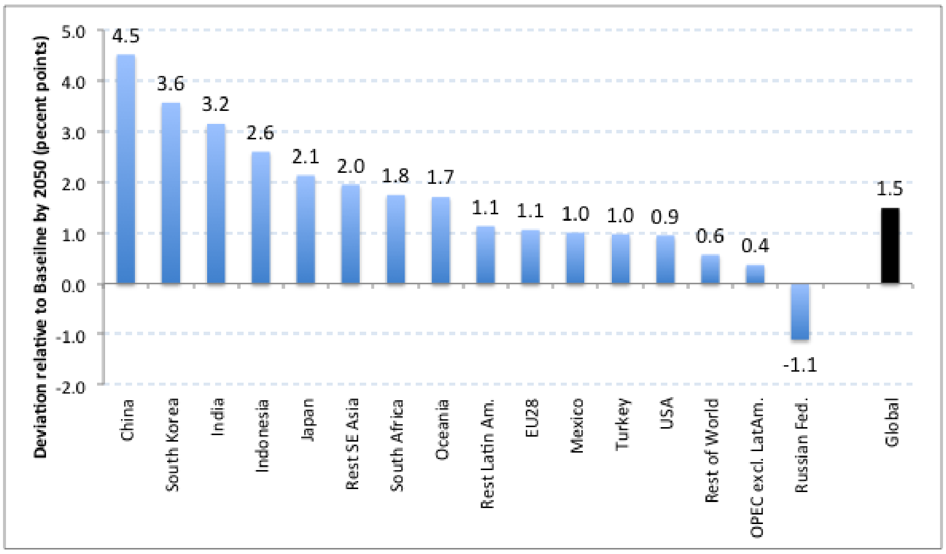
Figure 4.10 Combined Scenario. Cumulative CO_2 Emissions and Emission Reduction vs Baseline, 2018-2050 by Regions



Further regional analysis

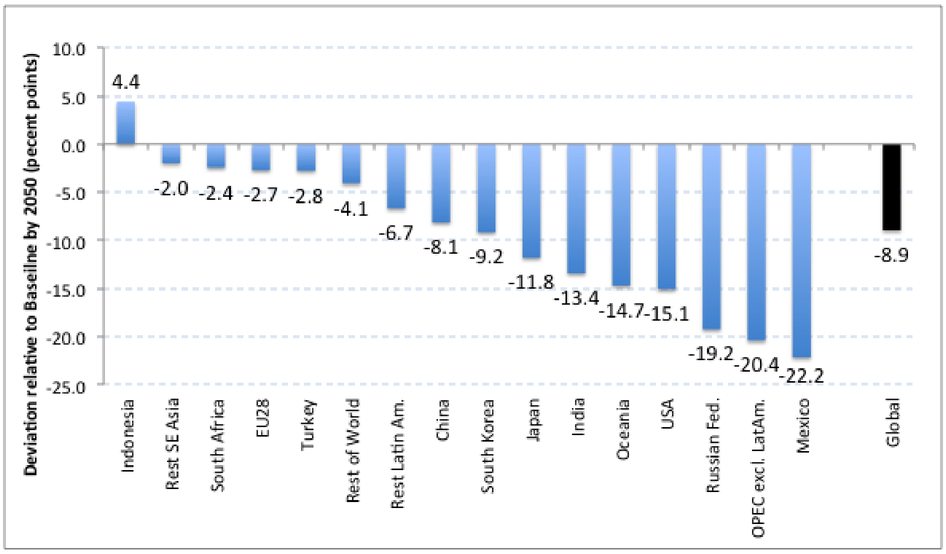
Under the Combined Scenario, there is a shift in employment away from high carbon sectors. Figure 4.11 and 4.12 indicate the changes in employment in the Combined Scenario by region, for both high carbon and low carbon activities, relative to the baseline, by 2050. High and low carbon activities are defined based on information about emissions levels per unit of economic activity (in line with the E3ME sectors) published by Eurostat.[43] Based on the model's classification, high carbon activities include: Coal; Oil and Gas; Other mining; Manufactured Fuels, Electricity, Gas and Water Supply. The rest are considered low carbon.

Figure 4.11 Changes in Employment in Low Carbon Activities in 2050 Relative to Baseline, Combined Scenario



[43] European Commission,2018. Database - Eurostat. See: http://ec.europa.eu/eurostat/web/environment/emissions-of-greenhouse-gases-and-air-pollutants/air-emission-accounts/database.

Figure 4.12 Changes in Employment in High Carbon Activities in 2050 Relative to Baseline. Combined Scenario



It is also important to understand the nature of the reduction in CO_2 emissions across different countries. Figure 4.13 shows how such reductions occur as a result of changes in the carbon intensity of energy, energy intensity and to the pace of economic activity. The figure is constructed based in the following identity:

$$C_t = (C_t/E_t) * (E_t / Y_t) * Y_t$$

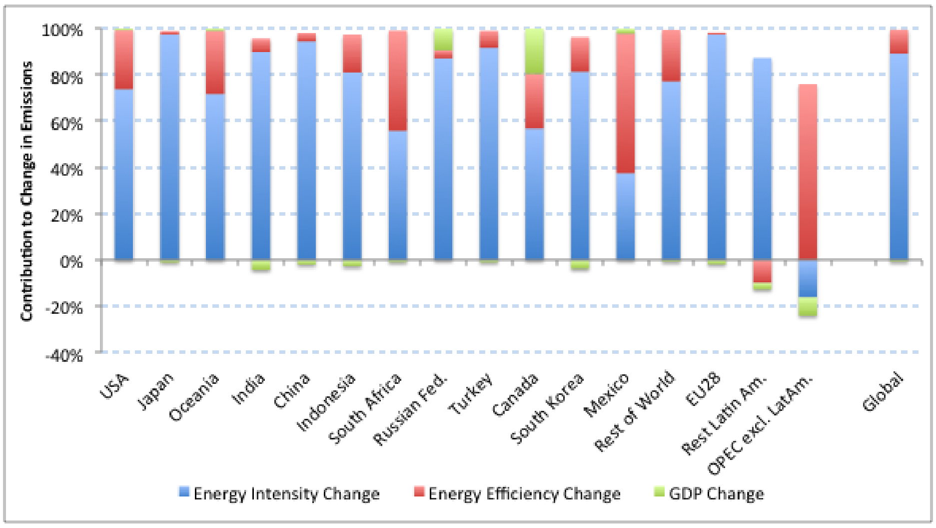
Where C is carbon emissions (in tonnes of CO_2); E is energy use (obtained as the sum of energy consumption across all different energy sources in a particular period) (in GW/year); and Y is Real GDP (in Million US$); so C/E is the rate of carbon emissions per unit of consumed energy (an indicator of carbon intensity); E/Y is an indicator of the amount of energy required on average to produce one unit of output (an indicator of efficiency). The subscript t is for the time period (years). The above expression can be transformed into period growth rates or to express changes across scenarios by taking log-differences:

$$dL(C)= dL(C/E) + dL(E/Y) + dL(Y)$$

Changes in carbon emissions result from changes in the carbon intensity of energy, changes in energy efficiency rates or from changes in GDP. This is plotted in Figure 4.13. The figure shows that the majority of emission reductions occur because of a reduction in the carbon intensity of energy use. A phase-out of coal (mainly responding to carbon pricing) is a major part of this shift, but higher uptake of renewable energy technologies and electrification of final energy demand also make substantial contributions. Globally, a shift away from fossil fuels and towards renewable sources of energy under the Combined Scenario yields a 37.8% increase in the amount of energy produced per unit of carbon emissions by 2030 (representing a 1.8% annual increase in the carbon productivity of energy). Notably, energy-efficiency measures in the Combined Scenario lead to a full 23.4% increase in the amount of value added per unit of energy generated by 2030, that is, a

1.2% improvement in energy efficiency per year, which is roughly on a par with trends since 2010.

Figure 4.13 Contribution to Reduction in Carbon Emssions by 2050 Relative to Baseline, by Regions

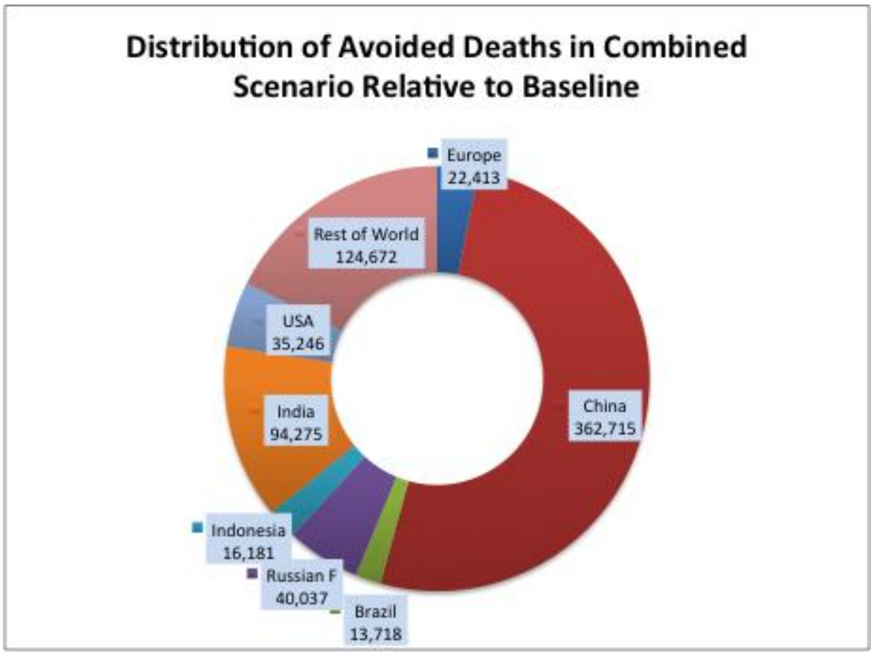


Health impacts

The combination of policies leads to reduced government spending on healthcare due to reduced air pollution. In 2040, almost 19,000 working years are gained across EU countries, and over 21,000 working years in 2050. Productivity effects increase over time as the benefits from the policies accumulate. Government expenditure on healthcare reduces over time along a similar path, reaching over US$1 billion (2017 prices) each year by 2050.

Empirical work carried out by the NCE team based on the methodology used by Parry et al. (see Box 2.1), and using the E3ME air pollution results, indicates that up to 710,000 deaths would be avoided under the Combined Scenario. Figure 4.14 shows the distribution of avoided deaths by countries / regions with larger death avoidance impacts. More than half of death avoidance would occur in China, a reflection not only of the large population but of substantive improvements in air quality in the Combined Scenario relative to baseline (again due to a phasing out of coal).

Figure 4.14 Avoided deaths in 2030 due to changes in air quality



Note: These reflect deaths only in the year 2030.

The vehicle fleet

There is a substantial reduction in the deployment of gasoline and diesel vehicles in the Combined Scenario, while electric and hybrid vehicles increase their market shares. Globally, this scenario indicates that new EV sales would rise to over 1 per 100 people by 2030, and to a level in which almost one in ten people have EVs by 2050. A shift to electric motorcycles is also important in India and other Asian countries. In China, EV ownership could increase to about 3 vehicles per 100 people by 2030 (also leading to an increase in total employment in the motor vehicle sector of more than 124,000 people and value-added gains in the same sector of more than 6% relative to the baseline). Section 4.4 provides more detail, discussing Scenario 2 focusing on electrification of the transport sector.

4.2 S1a: Urban retrofits

Overview

This scenario considers the impacts of global action in retrofitting buildings in urban areas, including substantial investment by the public sector, private businesses and households in energy efficiency measures. These measures include heating system retrofits and the improved efficiency of new buildings.

The most recent example for similar analysis using CE's E3ME model was a study for the European Commission, which contributed to the most recent Impact assessment of energy efficiency targets.[44]

Data

Data are taken from the NCE 2015 report "Accelerating Low-Carbon Development in the World's Cities".[45] The original source of the data is research undertaken by the Stockholm Environment Institute.[46] For the purpose of this scenario, the basic assumption is a linear energy saving profile up to 2030 and then from 2030 to 2050 in the Combined Scenario. Incremental investment up to 2050 is assumed to be spread equally across the forecast period (up to 2040 in this individual scenario). Some processing of the input data was required:

- The data on energy savings are global with no regional disaggregation. We have allocated the energy savings across E3ME regions according to consumption rates.
- The data have no disaggregation across fuel types for energy savings. We have allocated the savings proportionally according to baseline fuel use by the relevant sectors.
- The investment data are global with no regional disaggregation. We have used the 2014 IEA World Energy Investment Outlook *energy savings to investment* ratios to distribute regional shares of investment across E3ME regions.

To assess the relative magnitude of energy savings and investment costs we compared our figures against recent IEA scenarios: the New Policies Scenario (NPS) and the Sustainable Development Scenario (SDS). Table 4.1 provides a comparison of the annual investments in buildings.

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[44] Cambridge Econometrics, 2017. Energy efficiency programme could lead to economic, social and environemntal benefits. Available at: https://www.camecon.com/news/beyond-carbon-emissions-measuring-impact-energy-efficiency-policies/.

[45] Gouldson, A., Colenbrander, S., Sudmant, A., Godfrey, N., Millward-Hopkins, J., Fang, W. and Zhao, X., 2015. *Accelerating Low-Carbon Development in the World's Cities*. New Climate Economy, Washington, DC. Available at: https://newclimateeconomy.report/workingpapers/workingpaper/accelerating-low-carbon-development-in-the-worlds-cities-2/.

[46] Erickson, P. and Tempest, K., 2014. Advancing climate ambition: How city-scale actions can contribute to global climate goals. SEI. Available at: http://admin.indiaenvironmentportal.org.in/files/file/Advancing%20climate%20ambition.pdf.

Table 4.1 Investment costs in different sources

	NCE	IEA NPS	IEA SDS
Investments (USD)	660bn*	111bn**	192bn**
Energy efficiency	-612 Mtoe***	-798 Mtoe****	

*Notes: *2015 USD, **2012 USD*

****NCE (2015) Cities report, residential & commercial buildings energy savings 2030*

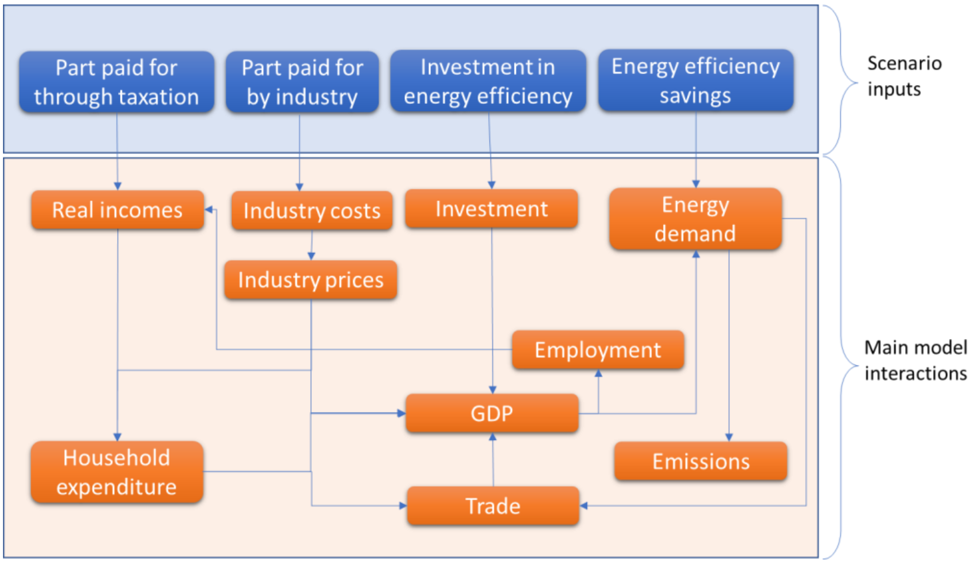
*****Difference between IEA NPS and SDS energy demand in 2030*

Modelling process

The main inputs to the scenario are the estimates of energy savings, the costs involved and the assumption about how the costs are financed.

The key interactions in E3ME are the energy savings, changes in expenditure on energy, investment demand and impacts of the funding mechanism. Public investment is funded by increases in tax rates, and private investment by higher product prices. The steady investment in real terms is decreasing as a proportion of baseline GDP throughout the period to 2040, as economies are forecast to expand. Figure 4.15 shows these interactions for both S1a and S1b.

Figure 4.15 S1 key interactions



Modelling results

In S1a, there is an increase in investment, which feeds directly into GDP and leads to job creation. For energy-importing nations there are also benefits from reducing imports and improving trade balances. In most countries, these positive effects outweigh the negative effects of diverting funds from other economic activities.

The impacts of retrofitting urban dwellings are evaluated across economic, social and environmental areas.

GDP and employment

The effect on GDP varies across world regions, but global GDP initially increases in comparison to the baseline. By 2030, however, global GDP falls slightly below baseline levels. The initial positive difference from the baseline is due to a combination of the increased investments in retrofitting commercial and residential buildings, and energy efficiency in heating and light in residential buildings, which, together, create a stimulus effect. In the longer term, negative impacts from reduced fuel production slightly outweigh the positive impacts. It should be noted that there would not be a negative effect on welfare though; households still benefit from warmer homes, even if their expenditure on energy (which counts towards GDP) is reduced.

Effects on employment show a similar pattern, but without as large an initial increase. By 2030, employment decreases by 0.1% compared to the baseline, with a similar reduction in 2040. Again, the impacts result from lower levels of fuel production, although this time the driving factor is a loss of royalty payments that fund labour-intensive activities in energy exporting countries.

Emissions

The policies in S1a reduce global CO_2 emissions over the projection period, compared to the baseline scenario. The difference to baseline is -5.9% by 2030, and -7.5% by 2040, corresponding to a reduction of 612 million tonnes and 857 million tonnes carbon, respectively. The global total is driven by large decreases of CO_2 emissions in North America, China and India in absolute levels.

Emissions of PM_{10}, $PM_{2.5}$, NO_x and SO_2 all decrease compared to the baseline in the projection period. PM_{10} emissions decrease rapidly in absolute terms until 2030, after which reductions are slower. By 2040, PM_{10} emissions are 4.6% below baseline emissions, corresponding to a reduction of 4.7 million tonnes. The change compared to baseline in $PM_{2.5}$ emissions is 8.7% by 2040, corresponding to 3.4 million tonnes. The change in SO_2 emissions is 8.3% by 2040, corresponding to 8.0 million tonnes. The change in NO_x emissions is 5.4% by 2040, corresponding to 5.9 million tonnes.

Health impacts

The health impacts are only modelled for European countries and are very limited as the policies in S1a do not include measures to address local pollution levels. However, in S1a there is still a reduction in government spending on healthcare by over $US190 million (2017 prices) in 2040. By 2040, over 4,000 working years are gained across the EU countries.

4.3 S1b: Urban densification

Overview

This scenario considers the impacts of global action in densification on urban areas. Densification primarily leads to energy savings for households and transport. The scenario models a policy in which the largest 25% of the world's cities are made 25% denser by 2040.

Data

The calculations of energy savings depend on two relationships:

- electricity consumption and density for households
- fuel consumption and density for transport

The relationships are based on regression analysis from Kennedy et al. (2015),[47] using data for 27 cities. Regional density is based on data from the Atlas of Urban Expansion.[48] There are nine different average densities, where each E3ME region was mapped to one density region. City population data come from the UNSD Demographic Statistics database.[49]

Modelling process

Using these data, energy savings associated with a 25% densification are estimated for each E3ME region. This is the only input for the scenario, and the key interactions in E3ME are the energy savings and change in expenditure on energy. It is assumed that the same activity takes place in the scenario as in the baseline, only that buildings are being built closer together in this scenario.

Modelling results

The impacts of densification are evaluated across economic, social and environmental areas.

GDP and employment

The effect on GDP varies across world regions, but global results show almost no overall impact. Exports and imports are reduced, mainly of energy products, but these trade effects cancel at the global level. There are small negative impacts on investment due to reduced power generation investment as a result of of lower electricity demand.

It should be noted that it is likely that densification also is associated with agglomeration effects, which would have a more positive affect on GDP. However, such effects are not considered in the scenario and is the main reason for the moderate impacts.

Effects on employment show a similar pattern as GDP, with minimal global impact. By 2030, employment increases by 0.01% compared to the baseline, which is the same as the effect in 2040.

Emissions

The policies in S1b reduce global CO_2 emissions over the projection period, compared to the baseline scenario. The difference to baseline is -0.5% by 2030, and -0.7% by 2040, corresponding to a reduction of 53.3 million tonnes and 83.9 million tonnes of carbon, respectively.

Emissions of PM_{10}, $PM_{2.5}$, NO_x and SO_2 all decrease compared to the baseline over the projection period. By 2040, PM_{10} emissions are 0.3% below baseline

[47] Kennedy, C.A. et al., 2015. Energy and material flows of megacities, in Proceedings of the National Academy of Sciences, 112 (19) 5985-5990; DOI: 10.1073/pnas.1504315112 http://www.pnas.org/content/112/19/5985.

[48] See: http://atlasofurbanexpansion.org/cities

[49] The exception for this is Italy, Slovakia, Turkey and Argentina where the population data was taken from the World Bank largest city data.

levels, corresponding to a reduction of 320 thousand tonnes. The change compared to baseline in $PM_{2.5}$ emissions is -0.7% by 2040, corresponding to 273 thousand tonnes of reduction. The change in SO_2 emissions is -0.4% by 2040, corresponding to 417 thousand tonnes reduction. The change in NO_x emissions is -1.8% by 2040, corresponding to 2.0 million tonnes reduction.

Health impacts

The policies in S1b lead to a reduction in annual government spending on health by almost US$100 million (2017 prices) by 2040. By 2040, 2,000 working years are gained across the EU countries.

4.4 S2: Promoting EVs

Overview

This scenario models the accelerated deployment of advanced powertrain vehicles. The scenario uses E3ME's bottom-up technology sub-model for passenger vehicles (FTT:Transport[50]) to model consumption decisions for the passenger car fleet to show an accelerated transition to EVs, through policies promoting adoption. Consumption decisions are a function of comprehensive costs (vehicle price, fuel costs, road tax, etc.) and consumer preferences for familiar/established technologies.

This scenario also includes policies to promote renewables in power generation (see also Scenario 3). Without at least some decarbonisation of the power generation sector, the electrification of road transport could increase total greenhouse gas emissions in some regions. Even in those regions with relatively clean power generation, the benefits of EVs are increased by further reduction in the carbon intensity of power generation.

Data

The choice of policy inputs is taken from those used in Mercure et al. (2018)[51] and Holden et al. (2018)[52] as they show a potential path to decarbonisation for the sector (Table 4.2 and Table 4.3). Results from these scenarios are useful in providing an indication of technology diffusion under the proposed policies; the caveat being that 2°C scenarios are comprehensive in nature and therefore wider modelling dynamics (e.g. economic growth and demand for transport) will have fed into the FTT:Transport model solution.

Table 4.2: Share of Electric Vehicles in Stock (including 2-wheelers)

Region	Baseline 2030	2°C 2030	Baseline 2050	2°C 2050
USA	2.3%	4.5%	46.8%	80.0%
Germany	1.3%	11.0%	30.0%	66.7%
Japan	3.2%	5.0%	32.5%	79.3%
China	0.6%	6.8%	35.9%	59.8%
Global	0.7%	5.9%	13.2%	38.3%

Source: Mercure et al. (2018)

Table 4.3: New sales of Electric Vehicles (including 2-wheelers)

Region	Baseline 2030	2°C 2030	Baseline 2050	2°C 2050
USA	4.8%	7.9%	63.3%	85.5%
Germany	2.8%	21%	50.0%	79.8%
Japan	5.3%	9.0%	46.1%	84.6%
China	1.5%	6.9%	61.6%	77.3%
Global	1.5%	15.2%	24.2%	60.0%

Source: Mercure et al. (2018)

[50] Mercure, J.-F. & Lam, A., 2015. 'The effectiveness of policy on consumer choices for private road passenger transport emissions reductions in six major economies', Environ. Res. Lett., 10; Mercure, J.-F., Lam, A., Billington, S. & Pollitt, H., 2018. Integrated assessment modelling as a positive science: private passenger road transport policies to meet a climate target well below 2°C. Climatic Change. 1-21. 10.1007/s10584-018-2262-7.

[51] Mercure, J.-F., Viñuales, J.E., Edwards, N.R., Holden, P.B., Chewpreecha, U., Salas, P., Sognnaes, I., Lam, A. & Knobloch, F. ,2018. 'Macroeconomic impact of stranded fossil fuel assets', Nature Climate Change, Volume 8, pp 588–593.

[52] Holden et al., 2018. Climate-carbon cycle uncertainties and the Paris Agreement, in Nature Climate Change, 8 pp 609-613. Available at: https://www.nature.com/articles/s41558-018-0197-7.

Modelling process

FTT:Transport is a non-optimisation technology diffusion model. Consumption decisions are a function of both costs of vehicle technologies and how established technologies are in the market (the intuition is that consumers are more likely to buy vehicles they are familiar with, currently internal combustion engines). Diffusion patterns in FTT:Transport are characterised by S-shaped curves, which have been examined for many years in technology diffusion literature (see Mercure et al., 2014).[53]

FTT:Transport models diffusion of advanced powertrains as a function of the exogenous policy inputs. As such, it is not possible to provide a relationship between policy and deployment; the latter is an endogenous result of the scenario inputs.

Monetary and regulatory instruments are used to promote the purchase of electric and advanced internal combustion engine vehicles. These monetary instruments include fuel taxes and registration taxes. A key characteristic of the FTT technology diffusion models is endogenous costs, determined by deployment and decreasing costs through learning rates. Numerous policies are introduced into the sub-model, both price-based and regulatory, including:

- regulatory bans – by type of vehicle[54]
- fuel tax – a tax rate in line with carbon prices used is applied per litre of fuel, for a given t/CO_2 price.
- registration vehicle tax – a tax to be paid at the time of the purchase based on the environmental classification (gCO_2/km) of the vehicle was introduced:
    - from 2020, 50 US$/g$CO_2$/km
    - from 2031, 100 US$/g$CO_2$/km
    - from 2041, 150 US$/g$CO_2$/km
- public purchase schemes or regulations (e.g. electrifying public fleets or taxis) were modelled through an exogenous share increase. For example, the share of the electric vehicles increased in 2020 by 1% compared to the previous year.

This scenario also includes all the policies in Scenario 3 on Carbon Pricing and Energy Reforms (see next section) to account for decarbonisation of the power sector. Figure 4.16 shows the key modelling interlinkages for the transport parts.

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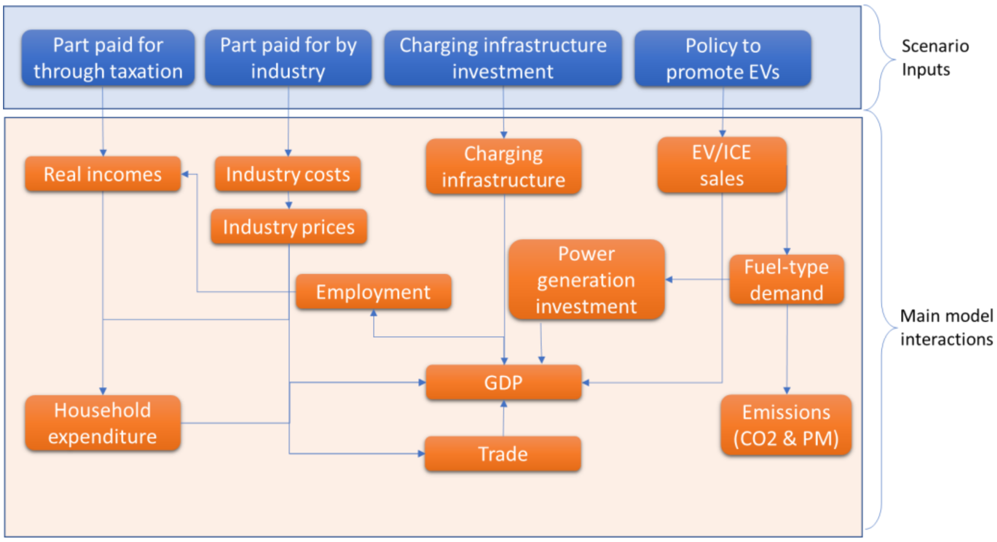
[53] Mercure, J.-F., Pollitt, H., Chewpreecha, U., Salas, P., Foley, A.M., Holden, P.B. & Edwards, N.R., 2014. The dynamics of technology diffusion and the impacts of climate policy instruments in the decarbonisation of the global electricity sector, in Energy Policy, 73 pp710-721. Available at: https://www.sciencedirect.com/science/article/pii/S0301421514004017?via%3Dihub.

[54] Regulatory bans and fuel tax introduced are shown quantitively, by year and by region in Appendix B.

Figure 4.16 S2 key interactions



Modelling results

When compared to the baseline, the economic results in S2 are driven largely by the measures that are outlined in S3 (see below). There is an increase in power sector investment, which is at least in part funded by additional debt. At the same time, the carbon tax reallocates resources in the economy. The reform of the electricity system, combined with additional investments in vehicle charging infrastructure, leads to positive effects on GDP and employment, but over time higher debt levels (recouped through higher electricity prices) become a drag on growth. Fuel importing countries benefit from lower imports that allow a redistribution of spending to domestically-produced goods, boosting production levels and employment further.

The impacts of promoting electric vehicles are evaluated across economic, social and environmental areas below. Comparisons are made against the baseline and also results from 'S3 Carbon pricing and energy reforms,' to isolate the impacts of the transport measures.

GDP and Employment

The effect on GDP is very different across the evaluated regions, and there is a larger spread in impact between the regions than in Scenario 1. GDP and employment effects are driven by the large global reduction in demand for middle distillates in road transport. Oil exporting countries face a contraction in GDP, by 2040; 2.1% in Russia, and 3.1% in Middle Eastern OPEC regions (excluding Saudi Arabia), compared to the baseline. More diversified oil exporters also face contraction, but oil importing regions are characterised by marginally positive GDP effects: oil imports are replaced partly by domestically generated electricity, and consumer expenditure is relocated. The jobs in the motor vehicle sector would also shift towards EV production, with half a million more people engaged in EV production within this sector by 2030, relative to baseline.

Emissions

The policies in S2 reduce substantially CO_2 emissions over the projection period, both compared to S3 and to the baseline. The difference to baseline is -25.3% by 2030 and -38.5% by 2040. This corresponds to a reduction of 2.6 billion tonnes and 4.4 billion tonnes of CO_2 respectively. CO_2 emissions from road transport are 17.4% lower by 2040 (direct emissions, not considering implied emissions from power generation), compared to S3.

Emissions of PM_{10}, $PM_{2.5}$, NO_x and SO_2 all decrease compared to the baseline in the projection period. By 2040, PM_{10} emissions are 13.1% below baseline emissions, corresponding to a reduction of 13.4 million tonnes. The change compared to baseline in $PM_{2.5}$ emissions is 12.4% by 2040, corresponding to 4.8 million tonnes. The change in SO_2 emissions is -36.7% by 2040, corresponding to 35.2 million tonnes reduction. The change in NO_x emissions is -26.5% by 2040, corresponding to 29.1 million tonnes reduction. Particulate matter pollution in road transport is not eliminated through diffusion of advanced powertrains: it has been estimated that exhaust and non-exhaust sources 'contribute almost equally to total traffic-related PM_{10} emissions' (EC JRC 2014).[55]

Health impacts

Somewhat counterintuitively, health impacts are slightly less positive in S2 than in S3: the positive effects on GDP, and associated increases in economic activity amongst emission sources, outweigh the reduction in air pollution from the road transport sector in terms of positive impacts.

The vehicle fleet

All petrol and diesel driven vehicles see a significant reduction in deployment in S2, while electric and hybrid vehicles increase their market shares. A shift to electric motorcycles is particularly important in India, China and other Asian countries. Traditional internal combustion engine vehicles make up little over 2.5% of new vehicle sales by 2040 globally. Almost half of these sales are in China and India.

[55] Grigoratos, T. & Martini, G., 2014. Non-exhaust traffic related emissions. Brake and tyre wear PM. European Commission. Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC89231/jrc89231-online%20final%20version%202.pdf.

4.5 S3: Carbon pricing and energy reforms

Overview

This scenario models the impact of reforming the electricity system through a combination of different policy instruments. The policies are applied in FTT:Power, the bottom-up technology model of the power generation sector that is fully integrated into E3ME.

Data

- carbon prices consistent with the Stern-Stiglitz carbon price corridor are used (see Appendix B for the prices by region).
- for capital investment subsidies, the approach in Mercure et al. (2018) is used.

Modelling process

Globally, regulation is introduced to phase out coal-fired power plants. Regulation is non-binding, but significantly limits building of new capacity. The basket of modelled policies is:

- removal of known fossil fuel subsidies on consumption (% subsidy/ technology, see Appendix B)
- feed-in-tariffs - fixed subsidy per MWh, globally: between 2018 – 2029: 75% of the difference between the LCOE and electricity price for Offshore and Onshore wind, Solar PV, CSP technologies
- capital investment subsidies (% subsidy/ technology, see Appendix B)
- carbon taxation on all sectors (see Appendix B)
- gradual change in fuel use (an annual 3% switch away from coal) in supplying district heating systems in coal heavy states (Russia, Rest of Latin America, Rest of ASEAN, and Ukraine)
- fuel switching globally in domestic cooking and heating from natural gas and oil to electricity (3% annual change)

Previous testing of different policy packages has shown that initial policy support is important to allow new technologies to become established before they achieve cost competitiveness. Financial incentivisation is thus provided through a combination of feed-in-tariffs and capital subsidies. A carbon tax is implemented across all regions to assist with the deployment of technologies that are close to being cost competitive. The carbon tax is more limited in scope in developing countries, but the overall magnitude is consistent with the Stern-Stiglitz carbon price corridor.[56] Fossil fuel consumption subsidies are phased out globally by 2025.

An important aspect of modelling reform of the electricity system is the capacity of the grid to integrate intermittent renewables. For high penetration of renewables, it is necessary both for the renewables to become cost-competitive and for the grid to be able to integrate a high renewable share. A more flexible grid, which could include more storage, demand-side management and interconnectors, has been modelled in FTT: Power.

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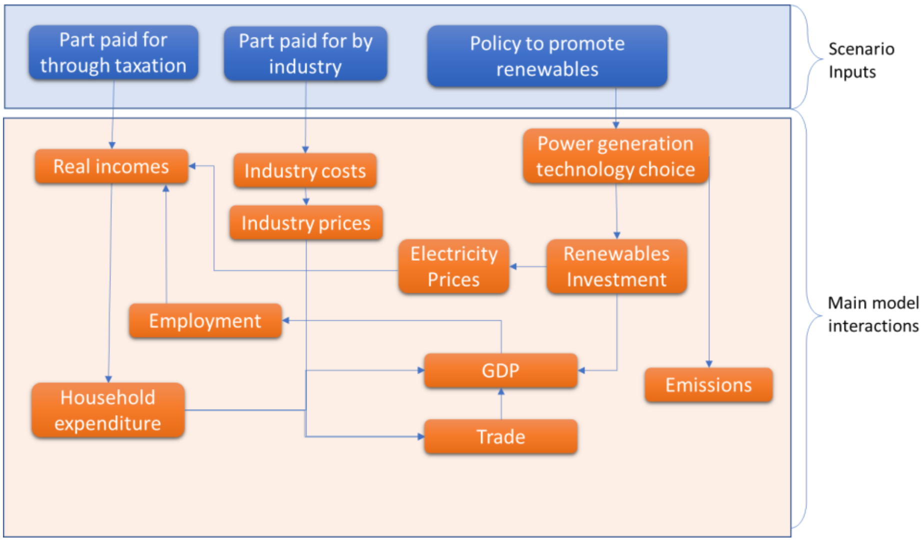
[56] Carbon Pricing Leadership Coalition, 2017. Report of the High-Level Commission on Carbon Prices. World Bank, Washington, DC. Available at: https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f2409f8dce5316811916/1505227332748/CarbonPricing_FullReport.pdf
.

The penetration rate of renewables is thus an endogenous result of the exogenous policy inputs. By 2040, the share of renewables in total capacity reaches 61% in China, 66% in Japan, 65% in the US, 75% in India and 86% in Germany.

The scenario includes capital investment subsidies that specifically support CCS, and the carbon taxes would also benefit CCS. However, the scenario does not show a strong take-up of CCS, primarily because, by the time CCS becomes technologically viable, the prices of wind and solar have fallen so much that they dominate the market. There would, however, be a larger role for CCS in the power sector if grid flexibility remained problematic. Globally, CCS reaches approximately 10% of total generation by 2040. CCS is featured in both baseload and flexible generation.[57]

The economic results are driven mainly by investment in the power system, the carbon taxes and the recycling of their revenues, and the redirection of fossil fuel subsidies to reduce other taxes. The other subsidies (e.g. to the power sector) are smaller in scale. Figure 4.17 shows these interactions.

Figure 4.17 Key interactions for Scenario 3



The detailed scenario inputs are specified below and detailed in Appendix B:

- The carbon tax covers all sectors, increases over time and is introduced at different times across regions, depending on country characteristics such as level of development. Carbon prices consistent with the Stern-Stiglitz carbon price corridor are used (see Appendix B for the prices by region). An initial allocation of regions to lower/higher ends of the corridor has been made: EU28, Japan, Canada, US at the maximum; the rest of the G20 in the middle; remaining regions at the corridor minimum. The current allocation is consistent with the argument in the Stern-Stiglitz report [58] that

[57] The basic assumption is that CCS with coal & gas is 90% effective; i.e. emissions per MWh from coal with CCS is 10% of the emissions without CCS.
[58] Carbon Pricing Leadership Coalition, 2017. Report of the High-Level Commission on Carbon Prices. World Bank, Washington, DC. Available at:

lower-income countries may need to introduce lower carbon prices initially, given concerns over development and poverty reduction.

- We reflect the arguments in the Stern-Stiglitz report that lower income countries can introduce lower carbon prices initially, increasing at a later date. This approach may be particularly effective given the economic environment in some developing countries. As a result, carbon prices converge over time (in percent terms) in the scenario.
- For capital investment subsidies, the approach in Mercure et al. (2018) is used. Subsidies are applied to provide incentives to increase uptake across a range of technologies, in this case for EV uptake. The subsidies differ across regions, gradually decrease over time and are phased out by 2050, i.e. they are used as a transitional policy. In addition to this, feed-in-tariffs for solar and wind in are introduced, although these are also reduced in scale gradually to zero as the technologies become cost-competitive and in locations where the technologies are already cost-competitive the subsidies are not used at all.

Modelling results

In S3, there is a large increase in power sector investment, which is at least in part funded by debt. Higher levels of construction activity create a stimulus effect that boosts GDP and employment initially, but over time the higher debt levels (recouped through higher electricity prices) become a drag on growth.

At the same time, the carbon tax reallocates resources in the economy. For fuel importing countries there is a shift from imported to domestic products that may boost domestic consumption (i.e. a double dividend effect). Fuel exporters will lose out, however.

Impacts on key indicators

The overall impacts of reforming the electricity system and greening the grid are evaluated across the main economic, social and environmental areas below:

GDP and employment

The largest positive impacts in S3 occur in China and India. The EU and North America see lower positive changes in GDP by 2040 due to the lasting effects of higher debt levels (developed countries take action earlier and so the stimulus effects dissipate before 2040), but present steady growth in absolute terms. For effects on employment, the same characteristics can be observed as with GDP.

Emissions

Reforming the electricity system in S3 substantially reduces CO_2 emissions over the projection period. While the reduction in emissions is not as large in S3 as in S2 (due to not including electrification of the transport sector), there are still significant reductions in emissions both in absolute tonnes of CO_2 emitted over time and compared to the baseline scenario projection. The difference to baseline is -23.6% in 2030, and -36.8% in 2040. Electrification also contributes to a reduction of non-CO_2 greenhouse gas emissions.

Emissions of PM_{10}, $PM_{2.5}$, NO_x and SO_2 all decrease compared to baseline in the projection period. By 2040, PM_{10} emissions are -13.3% below baseline

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https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f2409f8dce5316811916/1505227332748/CarbonPricing_FullReport.pdf emissions, corresponding to a reduction of 13.5 million tonnes. The change compared to baseline in $PM_{2.5}$ emissions is -12.2% by 2040, corresponding to 4.7 million tonnes. The change in SO_2 emissions is -37.1% by 2040, corresponding to 35.6 million tonnes. The change in NO_x emissions is -24.5% by 2040, corresponding to 26.9 million tonnes.

Health impacts

S3 leads to reduced government spending on health due to a healthier population. By 2040, almost 10 thousand working years are gained across the EU countries, and savings in government expenditure on health is US$475 million (in 2017 prices).

4.6 S4: Reducing energy waste

Overview

S4 has similarities to Scenario 1 (Urban densification and retrofits). The scope of S4 is wider, however, in terms of both geography and the energy users affected. As in S1, the main interactions with the economy come through changes in expenditure on energy, investment demand and the impacts of the chosen funding mechanism. Similar analysis was done using CE's E3ME model for the European Commission, DG Energy: *Impact assessment of energy efficiency targets*[59] and *Assessing the Employment and Social Impact of Energy Efficiency*.[60]

The scenario includes substantial investment in reducing energy waste across all sectors of the economy: households (retrofitting and appliances), commercial buildings, industry, and transport. Private sector investment[61] by businesses adds to production costs, which over time filter through to increased prices. Public sector investment is funded by an increase in sales taxes.

Data

The E3ME model does not have the necessary level of technological detail to estimate potential energy savings itself and so an external data source was used. The reduced waste in energy consumption (i.e. energy savings) is therefore defined by taking the difference between consumption in two IEA WEO scenarios:

- Current Policy Scenario (CPS)
- Sustainable Development Scenario (SDS)

Modelling process

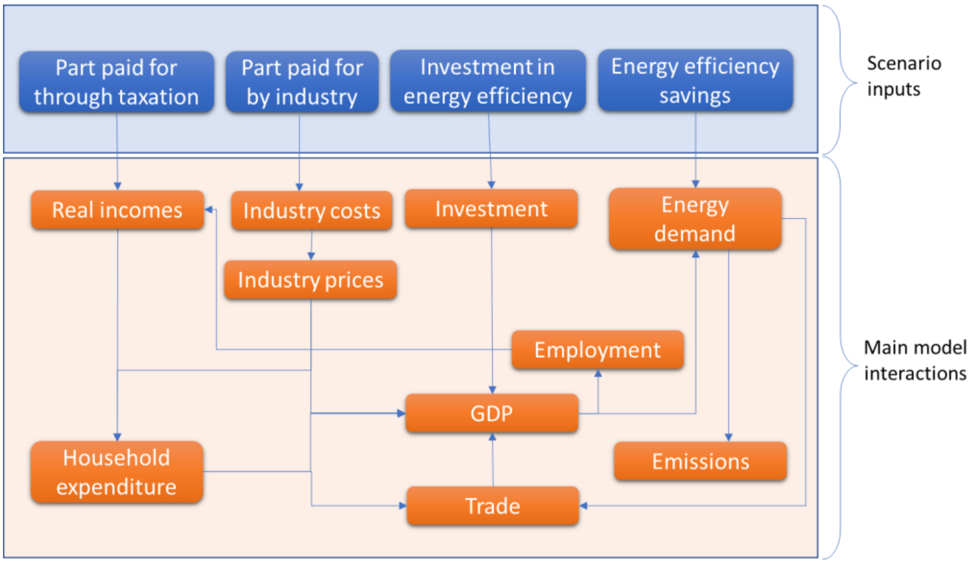
The differences in fuel use between the scenarios are a function of measures that include increasing energy efficiency, encouraging the deployment of new technologies and incentivising behavioural changes. A mapping exercise was carried out to allocate the energy savings to the sectors in E3ME.

The inputs used for energy efficiency in buildings are the same as that in S1. This scenario used the energy module equations within E3ME to proxy for the effects of reducing energy waste. The key inputs to E3ME are energy savings from these developments.

The key interactions in E3ME are similar to those in S1: energy savings, change in expenditure on energy, investment demand, and impacts of the funding mechanism. Public investment is funded by increasing taxes, and private investment by industry. Investment is the largest effect in magnitude, although, as a share of GDP, it declines over time as the global economy grows. Figure 4.18 shows these interactions.

[59] Cambridge Econometrics, 2017. Energy efficiency programme could lead to economic, social and environmental benefits. Available at: https://www.camecon.com/news/beyond-carbon-emissions-measuring-impact-energy-efficiency-policies/.
[60] Cambridge Econometrics, 2015. Assessing the Employment and Social Impact of Energy Efficiency. https://ec.europa.eu/energy/sites/ener/files/documents/CE_EE_Jobs_main%2018Nov2015.pdf.
[61] Currently, investments are apportioned between public and private sector based on baseline investments across the tertiary sector.

Figure 4.18 Key interactions for Scenario 4



Investment

In modelling investment in energy efficiency, the investing sector is largely guided by the investment demand input-output tables. In previous work, investment in energy efficiency in buildings has been modelled as investment by the government sector 'public administration & defence,' given that this sector's IO composition is representative with a large share of investment in buildings. The choice of sector is not overly important, however, because investment demand is dominated by intermediate demand to the construction sector in most cases.

The split of the investment across detailed sectors is assumed to follow existing investment patterns.

Revenue Recycling

The policy narrative of this scenario is public investment to achieve energy efficiency savings in line with those detailed in the NCE report '*Accelerating Low-Carbon Development in the World's Cities*'[62] (2015) and the IEA SDS. Each policy scenario modelled is revenue neutral. This practice ensures a 'complete' scenario, where results are not dominated by fiscal stimulus. The preference in revenue recycling is to use a mechanism that minimises distortions, usually a marginal change in a significant existing tax (income, sales, or social security) or a lump-sum payment to households.

Modelling results

In S4, there is again an investment stimulus that has positive impacts on GDP and employment. The costs are borne by businesses, which will pass on as much as possible through higher product prices. The higher prices negate some of the positive benefits (lower real incomes restrict consumption) but the overall effect is still positive.

[62] Gouldson, A., Colenbrander, S., Sudmant, A., Godfrey, N., Millward-Hopkings, J., Fang, W. & Zhao, X., 2015. Accelerating Low-Carbon Development in the World's Cities. New Climate Economy, Washington, DC. Available at: https://newclimateeconomy.report/workingpapers/workingpaper/accelerating-low-carbon-development-in-the-worlds-cities-2/.

The impacts of reducing energy waste are evaluated across economic, social and environmental areas below:

GDP and Employment

The effect on GDP is different across the evaluated regions and is smaller in both size and variation compared to S2 and S3. The EU28 countries and Japan see a positive impact, whereas North America sees a negative impact. The impacts on employment are smaller, with Korea presenting the largest positive increase from the baseline scenario.

There are some differences in the impacts from S4 and S1, even though both scenarios focus on energy efficiency measures. The differences mainly reflect interactions between the different magnitudes of investments in different countries, including through trade in equipment.

Emissions

The policies in S4 substantially reduce CO_2 emissions in all regions over the projection period, compared to the baseline scenario. The difference to baseline is -9.0% in 2030, and -12.2% in 2040. This corresponds to a reduction of 942 million tonnes and 1.4 billion tonnes of carbon respectively.

Non-GHG emissions also decrease compared to the baseline scenario, but not at the same scale as in S2 or S3. Emissions of PM_{10}, $PM_{2.5}$, NO_x and SO_2 all decrease compared to baseline in the projection period. By 2040, PM_{10} emissions are -5.5% below baseline emissions, corresponding to a reduction of 5.6 million tonnes. The change compared to baseline in $PM_{2.5}$emissions is -10.9% by 2040, corresponding to 4.2 million tonnes. The change in SO2 emissions is -12.1% by 2040, corresponding to 11.6 million tonnes. The change in NO_x emissions is -8.8% by 2040, corresponding to 9.7 million tonnes.

Health impacts

S4 leads to reduced governmental spending on health due to a healthier population. In 2040, over 9,000 working years are gained across the EU countries.

4.7 S5: Innovation and industrial efficiency

Overview

Longer-term decarbonisation requires additional effort on continuing to move towards less carbon intensive production processes, improving process energy intensity, improving recycling of final products and continuing research on innovation. This scenario assesses the effects of industries being brought up to best-available-technology standards, electrification and efficiency improvements in a small number of industry sectors and those of industrial innovations and a drive to a low carbon transition coupled with faster technological progress than in the baseline. Similar analysis using CE's E3ME model was done for the European Commission, DG Energy, *Assessing the Employment and Social Impact of Energy Efficiency*[63] and DG Research H2020 *TRANSrisk case studies, for example Austria iron & steel sector study*.[64]

Data

The data used are those from the IEA Energy Technology Perspectives work. The IEA ETP provides data for fuel use, CCS, and production across three technology scenarios: (1) reference technology, (2) 2-degrees, and (3) beyond 2-degrees. Data is provided for cement, chemicals, iron and steel, pulp and paper, and aluminium. The technology scenarios include the developments which we would otherwise need to find inputs for individually: updating to best-available-technology, deployment of CCS, reductions in energy waste, and increase in resource efficiency.

The IEA ETP data provide a credible forecast for this industry scenario and replace the requirement for identifying forecasts for technology developments in individual sectors and calculating associated fuel switching and fuel savings.

This scenario also includes the additional measures:

- fuel switching in Rest of ASEAN in industries from coal to electricity (3% annual change)
- fuel switching in China in non-metallic mineral industries from coal to electricity (3% annual change)

Modelling process

S5 considers a low carbon transition across key polluting industrial sectors: cement production, iron & steel, paper & pulp, and chemicals. The two key developments modelled are industrial energy efficiency and a reduction in process emissions.

The scenario is deterministic, in the absence of dedicated technology models as used in Scenarios 2 and 3. In this scenario, we assess sectors not covered by the FTT modules, and therefore cannot study in detail technology shocks; using the IEA - ETP data addresses this issue. The underlying assumptions reflect those in the IEA Scenarios.

The economic impacts are driven by investment in new production equipment and increased industrial costs and prices. The magnitude of economic and

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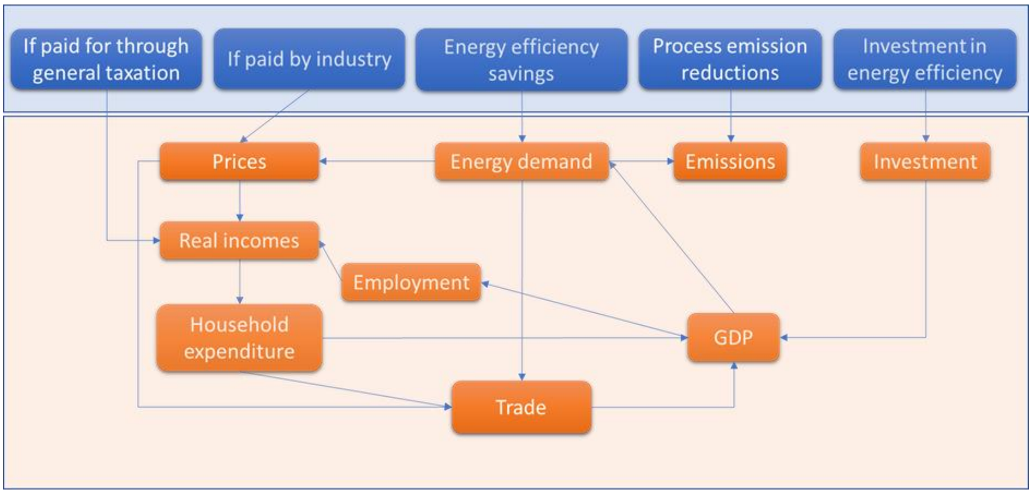
[63] Cambridge Econometrics, 2015. Assessing the Employment and Social Impact of Energy Efficiency. https://ec.europa.eu/energy/sites/ener/files/documents/CE_EE_Jobs_main%2018Nov2015.pdf.

[64] Bachner, G. Koland,O., Mayer, J., Meuller, A., Tuerk, A., Steininger, K. & Wolkinger, B., 2016. D3.2 Context of 15 case studies: Austria: Steel & Iron Sector and Energy Production. SPRU & UoS. http://www.transrisk-project.eu/sites/default/files/Documents/D3_2_CaseStudy_Austria.pdf.

environmental effects is limited when examined at the macro level, given the focused sectoral coverage. Figure 4.19 summarises the key linkages.

Figure 4.19 Key interactions for Scenario 5



Investment

The energy savings and associated investment are shared across the industrial sectors that are defined in E3ME, while remaining consistent with the IEA data. It is assumed that the energy savings are proportional to total energy consumption in each sector.

The input-output coefficients in the model determine which sectors produce the investment goods; typically, the engineering and construction sectors benefit the most from higher investment.

Modelling results

As in S4, the results from S5 show that increased investments have positive impacts on GDP and employment. The costs are borne by businesses which will pass on as much as possible through higher product prices. The higher prices negate some of the positive benefits (lower real incomes restrict consumption) but the overall effect is still positive, primarily because, in the short run at least, a reallocation of economic resources from businesses to households boosts consumption. As in the other scenarios, however, there are important differences between energy exporting and energy importing countries.

The impacts of reducing industrial energy waste and boosting innovation are evaluated across economic, social and environmental areas below:

GDP and Employment

The effect on GDP is different across the evaluated regions, and smaller in size and variation compared to S2, S3 and S4. In relative terms, the largest positive impact over time can be observed in India, while Canada, the OPEC countries (excluding Venezuela), and Oceania show negative impacts from 2030 onwards. The effect on employment is lower than 1% in all regions. Indonesia and India have the largest positive percentage differences from baseline.

Emissions

The policies in S5 reduce CO_2 emissions over the projection period compared to the baseline scenario. The difference in global emissions to baseline is -

3.9% in 2030, and -6.8% in 2040. This corresponds to absolute reductions of 410 million tonnes and 781 million tonnes, respectively. In absolute levels, CO_2 emissions still increase slightly globally over the projection period.

Emissions of PM_{10}, $PM_{2.5}$, NO_x and SO_2 all decrease compared to baseline in the projection period. By 2040, PM_{10} emissions are -1.2% below baseline emissions, corresponding to a reduction of 1.2 million tonnes. The change compared to baseline in $PM_{2.5}$ emissions is -3.1% by 2040, corresponding to 1.2 million tonnes. The change in SO_2 emissions is -4.3% by 2040, corresponding to 4.1 million tonnes. The change in NO_x emissions is -2.4% by 2040, corresponding to 2.7 million tonnes.

Health impacts

The policies in S5 lead to reduced governmental spending on health due to a healthier population. In 2040, over 1,800 working years are gained across the EU countries.

5 Conclusions

The scenarios assessed in this report show that implementing a broad range of policy measures across different sectors of the economy, with a combined focus on decarbonisation, electrification and reducing wasted energy could reduce emissions substantially without significant economic cost at global level.

In the Combined Scenario, immediate gains are expected in real value added, which are maintained throughout the forecasting period. With regards to overall employment levels, a slight increase is expected. There is also an anticipated shift away from employment in high carbon activities – oil, coal, gas extraction and manufacturing of fuels – into low carbon activities.

In order to achieve the targeted emission reductions, considerable investments are required across all the scenarios. There is also a consistent pattern in regional impacts: net fuel importer countries tend to benefit overall. This finding puts even more emphasis on the need to ensure a well-managed and just transition in net exporter countries, as is explored throughout the NCE 2018 Report.

Beyond the split between energy exporters and importers, there is small difference in the impacts between the groups of developed and developing countries. With regards to GDP and employment, there is no evidence based on the results suggesting that developing countries would face more negative impacts of decarbonisation.

The key policy challenge is to make interventions that on the one hand provide a general framework for decarbonisation (e.g. for carbon pricing or for energy efficiency measures) and on the other hand, allow for specific support for new technologies' development and early deployment stage. Proper macroeconomic and techno-economic modelling of the potential scenarios and implications can strongly support policy makers in assessing the socio-economic impacts of policy choices. It is important, however, that the modelling be closely integrated and that it interact with the real policy options available to policy makers, to arrive at solid and realistic conclusions. The modelling framework presented in this report is aimed at providing a good example of such a close interaction with real-life policy options.

6 Previous work using E3ME

A number of research papers and publications have been prepared using E3ME macroeconomic modeling tool.

Cambridge Econometrics have studied the social, employment, economic and environmental beneficial effects of energy efficiency[65,66], economic effect of decarbonising cars and vans in the UK, France and Germany[67, 68, 69], and modeled global targets for renewable energy sources[70].

Dr. Jean-Francois Mercure with co-authors researched a variety of aspects of energy sector decarbonisation and offer improved macroeconomic models for better policy design and decision-making. As shown by the authors, computable general equilibrium models may offer suboptimal guidance on capital allocation and result in negative impact on GDP and welfare. Investigated applications of non-equilibrium models include: macroeconomic impact of global adoption of low-carbon technology on investments in fossil fuel assets;[71] low-carbon technology diffusion and effects of technology lock-in;[72] future technology transformation based on market competition, induced technological change (ITC) and resource depletion in 20 world regions;[73] role of financial systems in macroeconomic modeling of climate mitigation and

[65] Cambridge Econometrics, 2015. *Assessing the Employment and Social Impact of Energy Efficiency*. [online] Cambridge: Cambridge Econometrics. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/CE_EE_Jobs_main%2018Nov2015.pdf.

[66] Cambridge Econometrics, 2017. *Beyond carbon emissions – measuring the impact of energy efficiency*. [online] Cambridge: Cambridge Econometrics. Available at: https://www.camecon.com/news/beyond-carbon-emissions-measuring-impact-energy-efficiency-policies/.

[67] Cambridge Econometrics, 2015. *Fuelling Britain's Future*. [online] Cambridge: Cambridge Econometrics. Available at: https://www.camecon.com/how/our-work/fuelling-britains-future/.

[68] Cambridge Econometrics, 2015. *En Route Pour Un Transport Durable*. [online] Cambridge: Cambridge Econometrics. Available at: https://www.camecon.com/how/our-work/en-route-pour-un-transport-durable/.

[69] Cambridge Econometrics, 2017. *Low-carbon cars in Germany*. [online] Cambridge: Cambridge Econometrics. Available at: https://www.camecon.com/how/our-work/low-carbon-cars-in-germany/.

[70] Cambridge Econometrics, 2016. *Modelling Global Renewables Targets*. [online] Cambridge: Cambridge Econometrics.

[71] Mercure, J.F., Viñuales, J.E., Edwards, N.R., Holden, P.B., Chewpreecha, U., Salas, P., Sognnaes, I., Lam, A. & Knobloch, F., 2018. 'Macroeconomic impact of stranded fossil fuel assets', Nature Climate Change, Volume 8, pp 588–593. https://www.nature.com/articles/s41558-018-0182-1.

[72] Mercure, J., Pollitt, H., Chewpreecha, U., Salas, P., Foley, A., Holden, P. & Edwards, N., 2014. *The dynamics of technology diffusion and the impacts of climate policy instruments in the decarbonisation of the global electricity sector*. [online] Cambridge, Milton Keynes: Elsevier. Available at: https://www.sciencedirect.com/science/article/pii/S0301421514004017?via%3Dihub.

[73] Mercure, J., 2012. *FTT:Power : A global model of the power sector with induced technological change and natural resource depletion*. [ebook] Cambridge: Cambridge Centre for Climate Change Mitigation Research. Available at: https://www.sciencedirect.com/science/article/pii/S0301421512005356?via%3Dihub.

carbon reduction policies[74]; and effectiveness of fiscal policy in stimulating consumers' switch to lower-emissions vehicles.[75]

A 3-year research project "Transitions Pathways and Risk Analysis for Climate Change Mitigation and Adaptation Strategies" (TRANSrisk) used the E3ME model to produce country and regional case studies in climate change mitigation and adaptation strategies. A 3-year research was conducted by a consortium of 12 organisations coordinated by the Science Policy Research Unit at the University of Sussex, was funded through the EU's Horizon 2020 research and innovation programme, and was completed in 2018. The project delivered 15 country and regional case studies, containing a new assessment framework and a toolbox aiding policy makers in transition to low-emission pathways. The case studies of Austria's steel and iron sector energy production[76] and UK's nuclear power[77] relied on E3ME models in their analysis.

[74] Pollitt, H. & Mercure, J., 2018. *The role of money and the financial sector in energy-economy models used for assessing climate and energy policy*. [online] Taylor & Francis Online. Available at: https://www.tandfonline.com/doi/full/10.1080/14693062.2016.1277685.

[75] Mercure, J. & Lam, A., 2015. *The effectiveness of policy on consumer choices for private road passenger transport emissions reductions in six major economies*. Environmental Research Letters, [online] 10(6), p.064008. Available at: http://iopscience.iop.org/article/10.1088/1748-9326/10/6/064008/pdf.

[76] Science Policy Research Unit (SPRU) & University of Sussex (UOS), 2016). *D3.2 Context of 15 case studies: Austria: Steel & Iron Sector and Energy Production*. TRANSITIONS PATHWAYS AND RISK ANALYSIS FOR CLIMATE CHANGE MITIGATION AND ADAPTATION STRATEGIES. [online] Sussex: TRANSrisk. Available at: http://www.transrisk-project.eu/sites/default/files/Documents/D3_2_CaseStudy_Austria.pdf.

[77] SPRU& UOS, 2016. *D3.2 Context of 15 case studies: UK: Nuclear Power*. TRANSITIONS PATHWAYS AND RISK ANALYSIS FOR CLIMATE CHANGE MITIGATION AND ADAPTATION STRATEGIES. [online] Sussex: TRANSrisk. Available at: http://transrisk-project.eu/sites/default/files/Documents/D3_2_CaseStudy_UK.pdf.

Appendix A Classifications in E3ME

E3ME Regions	FTT: Power Technologies	FTT:Transport Technologies	E3ME Fuel Users	E3ME Industries
1 Belgium	1 Nuclear	1 Petrol Econ	1 Power own use & transformation	1 Agriculture etc
2 Denmark	2 Oil	2 Petrol Mid	2 O.energy own use & transformation	2 Coal
3 Germany	3 Coal	3 Petrol Lux	3 Hydrogen production	3 Oil & Gas etc
4 Greece	4 Coal + CCS	4 Adv Petrol Econ	4 Iron & steel	4 Other Mining
5 Spain	5 IGCC	5 Adv Petrol Mid	5 Non-ferrous metals	5 Food, Drink & Tobacco
6 France	IGCC + CCS	6 Adv Petrol Lux	6 Chemicals	6 Text., Cloth. & Leather
7 Ireland	7 CCGT	7 Diesel Econ	7 Non-metallic minerals	7 Wood & Paper
8 Italy	8 CCGT + CCS	8 Diesel Mid	8 Ore-extraction (non-energy)	8 Printing & Publishing
9 Luxembourg	9 Solid Biomass	9 Diesel Lux	9 Food, drink & tobacco	9 Manuf. Fuels
10 Netherlands	10 S Biomass CCS	10 Adv Diesel Econ	10 Textiles, clothing & footwear	10 Pharmaceuticals
11 Austria	11 BIGCC	11 Adv Diesel Mid	11 Paper & pulp	11 Chemicals nes
12 Portugal	12 BIGCC + CCS	12 Adv Diesel Lux	12 Engineering etc	12 Rubber & Plastics
13 Finland	13 Biogas	13 LPG Econ	13 Other industry	13 Non-Met.Min.Prod
14 Sweden	14 Biogas + CCS	14 LPG Mid	14 Construction	14 Basic Metals
15 UK	15 Tidal	15 LPG Lux	15 Rail transport	15 Metal Goods
16 Czech Rep.	16 Large Hydro	16 Hybrid Econ	16 Road transport	16 Mech. Engineering
17 Estonia	17 Onshore	17 Hybrid Mid	17 Air transport	17 Electronics
18 Cyprus	18 Offshore	18 Hybrid Lux	18 Other transport services	18 Elec.Eng.& Instrum.
19 Latvia	19 Solar PV	19 Electric Econ	19 Households	19 Motor Vehicles
20 Lithuania	20 CSP	20 Electric Mid	20 Agriculture, forestry, etc.	20 Oth.Transp. Equip.
21 Hungary	21 Geothermal	21 Electric Lux	21 Fishing	21 Manuf. nes
22 Malta	22 Wave	22 motorcycles Econ	22 Other final use	22 Electricity
23 Poland	23 Fuel Cells	23 motorcycles Lux	23 Non-energy use	23 Gas Supply
24 Slovenia	24 CHP	24 Adv motorcycles Econ		24 Water Supply
25 Slovakia		25 Adv motorcycles Lux		25 Construction

E3ME Regions	FTT: Power Technologies	FTT:Transport Technologies	E3ME Fuel Users	E3ME Industries
26 Bulgaria				26 Distribution
27 Romania				27 Retailing
28 Norway				28 Hotels & Catering
29 Switzerland				29 Land Transport etc
30 Iceland				30 Water Transport
31 Croatia		**E3ME Regions (cont'd)**		31 Air Transport
32 Turkey		46 Colombia		32 Communications
33 Macedonia		47 Rest of Latin America		33 Banking & Finance
34 USA		48 Korea		34 Insurance
35 Japan		49 Taiwan		35 Computing Services
36 Canada		50 Indonesia		36 Prof. Services
37 Australia		51 Rest of ASEAN		37 Other Bus. Services
38 New Zealand		52 Rest of OPEC		38 Public Admin.&Defence
39 Russian Federation		53 Rest of world		39 Education
40 Rest of	Annex I	54 Ukraine		40 Health&Social Work
41 China		55 Saudi Arabia		41 Misc. Services
42 India		56 Nigeria		42 Unallocated
43 Mexico		57 South Africa		43 Forestry
44 Brazil		58 Rest of Africa		44 Hydrogen supply
45 Argentina		59 Africa OPEC		

Appendix B Parameters used

Table 0.1 Carbon tax by E3ME regions

Carbon tax ($/t$CO_2$)	2020	2030	2040	2050
Belgium	80.0	100.0	120.0	140.0
Denmark	80.0	100.0	120.0	140.0
Germany	80.0	100.0	120.0	140.0
Greece	80.0	100.0	120.0	140.0
Spain	80.0	100.0	120.0	140.0
France	80.0	100.0	120.0	140.0
Ireland	80.0	100.0	120.0	140.0
Italy	80.0	100.0	120.0	140.0
Luxembourg	80.0	100.0	120.0	140.0
Netherlands	80.0	100.0	120.0	140.0
Austria	80.0	100.0	120.0	140.0
Portugal	80.0	100.0	120.0	140.0
Finland	80.0	100.0	120.0	140.0
Sweden	80.0	100.0	120.0	140.0
UK	80.0	100.0	120.0	140.0
Czech Rep.	80.0	100.0	120.0	140.0
Estonia	80.0	100.0	120.0	140.0
Cyprus	80.0	100.0	120.0	140.0
Latvia	80.0	100.0	120.0	140.0
Lithuania	80.0	100.0	120.0	140.0
Hungary	80.0	100.0	120.0	140.0
Malta	80.0	100.0	120.0	140.0
Poland	80.0	100.0	120.0	140.0
Slovenia	80.0	100.0	120.0	140.0

Carbon tax ($/tCO₂)	2020	2030	2040	2050
Slovakia	80.0	100.0	120.0	140.0
Bulgaria	80.0	100.0	120.0	140.0
Romania	80.0	100.0	120.0	140.0
Norway	80.0	100.0	120.0	140.0
Switzerland	80.0	100.0	120.0	140.0
Iceland	80.0	100.0	120.0	140.0
Croatia	80.0	100.0	120.0	140.0
Turkey	60.0	75.0	90.0	105.0
Macedonia	60.0	75.0	90.0	105.0
USA	80.0	100.0	120.0	140.0
Japan	80.0	100.0	120.0	140.0
Canada	80.0	100.0	120.0	140.0
Australia	60.0	75.0	90.0	105.0
New Zealand	60.0	75.0	90.0	105.0
Russian Fed.	60.0	75.0	90.0	105.0
Rest of Annex I	40.0	50.0	60.0	70.0
China	60.0	75.0	90.0	105.0
India	60.0	75.0	90.0	105.0
Mexico	60.0	75.0	90.0	105.0
Brazil	60.0	75.0	90.0	105.0
Argentina	60.0	75.0	90.0	105.0
Colombia	40.0	50.0	60.0	70.0
Rest Latin Am.	40.0	50.0	60.0	70.0
Korea	80.0	100.0	120.0	140.0
Taiwan	60.0	75.0	90.0	105.0
Indonesia	60.0	75.0	90.0	105.0
Rest of ASEAN	60.0	75.0	90.0	105.0
Rest of OPEC	40.0	50.0	60.0	70.0

Carbon tax ($/tCO_2$)	2020	2030	2040	2050
Rest of world	40.0	50.0	60.0	70.0
Ukraine	40.0	50.0	60.0	70.0
Saudi Arabia	60.0	75.0	90.0	105.0
Nigeria	40.0	50.0	60.0	70.0
South Africa	60.0	75.0	90.0	105.0
Rest of Africa	40.0	50.0	60.0	70.0
Africa OPEC	40.0	50.0	60.0	70.0

Table 0.2 Regulation of vehicles

A.1 Please note: the value '1' indicates a regulatory ban of the given vehicle type, '0' means no regulation.

E3ME Regions 1 to 33 (EU28, Norway, Switzerland, Iceland, Turkey, & Macedonia)

Vehicle types	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1 Petrol Econ	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2 Petrol Mid	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3 Petrol Lux	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4 Adv Petrol Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 Adv Petrol Mid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 Adv Petrol Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Diesel Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 Diesel Mid	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9 Diesel Lux	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10 Adv Diesel Econ	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11 Adv Diesel Mid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 Adv Diesel Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13 LPG Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 LPG Mid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 LPG Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 Hybrid Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 Hybrid Mid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 Hybrid Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 Electric Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 Electric Mid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 Electric Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 motorcycles Econ	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23 motorcycles Lux	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

24 Adv motorcycles Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25 Adv motorcycles Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

E3ME Regions 34 to 59

Vehicle Type	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1 Petrol Econ	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2 Petrol Mid	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3 Petrol Lux	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4 Adv Petrol Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 Adv Petrol Mid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 Adv Petrol Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Diesel Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 Diesel Mid	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9 Diesel Lux	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10 Adv Diesel Econ	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11 Adv Diesel Mid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 Adv Diesel Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13 LPG Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 LPG Mid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 LPG Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 Hybrid Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 Hybrid Mid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 Hybrid Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 Electric Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 Electric Mid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 Electric Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 motorcycles Econ	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
23 motorcycles Lux	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24 Adv motorcycles Econ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

25 Adv motorcycles Lux	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 0.3 Fuel tax by E3ME regions (in 2012$)

A.2	Fuel Tax ($cents/l)	A.3	2020	A.4	2030	A.5	2040	A.6	2050
A.7	Belgium	A.8	18.4	A.9	23.04	A.10	27.64	A.11	32.25
A.12	Denmark	A.13	18.4	A.14	23.04	A.15	27.64	A.16	32.25
A.17	Germany	A.18	18.4	A.19	23.04	A.20	27.64	A.21	32.25
A.22	Greece	A.23	18.4	A.24	23.04	A.25	27.64	A.26	32.25
A.27	Spain	A.28	18.4	A.29	23.04	A.30	27.64	A.31	32.25
A.32	France	A.33	18.4	A.34	23.04	A.35	27.64	A.36	32.25
A.37	Ireland	A.38	18.4	A.39	23.04	A.40	27.64	A.41	32.25
A.42	Italy	A.43	18.4	A.44	23.04	A.45	27.64	A.46	32.25
A.47	Luxembourg	A.48	18.4	A.49	23.04	A.50	27.64		32.25
A.51	Netherlands	A.52	18.4	A.53	23.04	A.54	27.64	A.55	32.25
A.56	Austria	A.57	18.4	A.58	23.04	A.59	27.64	A.60	32.25
A.61	Portugal	A.62	18.4	A.63	23.04	A.64	27.64	A.65	32.25
A.66	Finland	A.67	18.4	A.68	23.04	A.69	27.64	A.70	32.25
A.71	Sweden	A.72	18.4	A.73	23.04	A.74	27.64	A.75	32.25

A.2	Fuel Tax ($cents/l)	A.3	2020	A.4	2030	A.5	2040	A.6	2050
A.76	UK	A.77	18.4	A.78	23.04	A.79	27.64		32.25
A.80	Czech Rep.	A.81	18.4	A.82	23.04	A.83	27.64	A.84	32.25
A.85	Estonia	A.86	18.4	A.87	23.04	A.88	27.64	A.89	32.25
A.90	Cyprus	A.91	18.4	A.92	23.04	A.93	27.64	A.94	32.25
A.95	Latvia	A.96	18.4	A.97	23.04	A.98	27.64	A.99	32.25
A.100	Lithuania	A.101	18.4	A.102	23.04	A.103	27.64	A.104	32.25
A.105	Hungary		18.4		23.04		27.64	A.106	32.25
A.107	Malta	A.108	18.4	A.109	23.04	A.110	27.64	A.111	32.25
A.112	Poland	A.113	18.4	A.114	23.04	A.115	27.64	A.116	32.25
A.117	Slovenia	A.118	18.4	A.119	23.04	A.120	27.64	A.121	32.25
A.122	Slovakia	A.123	18.4	A.124	23.04	A.125	27.64	A.126	32.25
A.127	Bulgaria	A.128	18.4	A.129	23.04	A.130	27.64	A.131	32.25
A.132	Romania	A.133	18.4	A.134	23.04	A.135	27.64	A.136	32.25
A.137	Norway	A.138	18.4	A.139	23.04	A.140	27.64	A.141	32.25
A.142	Switzerland	A.143	18.4	A.144	23.04	A.145	27.64	A.146	32.25

A.2	Fuel Tax ($cents/l)	A.3	2020	A.4	2030	A.5	2040	A.6	2050
A.147	Iceland	A.148	18.4	A.149	23.04	A.150	27.64	A.151	32.25
A.152	Croatia	A.153	18.4	A.154	23.04	A.155	27.64	A.156	32.25
A.157	Turkey	A.158	13.8	A.159	17.28	A.160	20.73	A.161	24.19
A.162	Macedonia	A.163	13.8	A.164	17.28	A.165	20.73	A.166	24.19
A.167	USA	A.168	18.4	A.169	23.04	A.170	27.64	A.171	32.25
A.172	Japan		18.4		23.04	A.173	27.64	A.174	32.25
A.175	Canada	A.176	18.4	A.177	23.04	A.178	27.64	A.179	32.25
A.180	Australia	A.181	13.8	A.182	17.28	A.183	20.73	A.184	24.19
A.185	New Zealand	A.186	13.8	A.187	17.28		20.73	A.188	24.19
A.189	Russian Fed.	A.190	13.8	A.191	17.28	A.192	20.73	A.193	24.19
A.194	Rest of Annex I	A.195	9.2	A.196	11.52	A.197	13.82	A.198	16.13
A.199	China	A.200	13.8	A.201	17.28	A.202	20.73	A.203	24.19
A.204	India	A.205	13.8	A.206	17.28	A.207	20.73	A.208	24.19
A.209	Mexico	A.210	13.8	A.211	17.28	A.212	20.73	A.213	24.19
A.214	Brazil	A.215	13.8	A.216	17.28	A.217	20.73	A.218	24.19

A.2	Fuel Tax ($cents/l)	A.3	2020	A.4	2030	A.5	2040	A.6	2050
A.219	Argentina	A.220	13.8	A.221	17.28	A.222	20.73	A.223	24.19
A.224	Colombia	A.225	9.2	A.226	11.52	A.227	13.82	A.228	16.13
A.229	Rest Latin Am.	A.230	9.2	A.231	11.52	A.232	13.82	A.233	16.13
A.234	Korea	A.235	18.4	A.236	23.04	A.237	27.64	A.238	32.25
A.239	Taiwan	A.240	13.8	A.241	17.28	A.242	20.73		24.19
A.243	Indonesia	A.244	13.8	A.245	17.28	A.246	20.73	A.247	24.19
A.248	Rest of ASEAN	A.249	13.8	A.250	17.28	A.251	20.73	A.252	24.19
Rest of OPEC			9.2		11.52		13.82		16.13
A.253	Rest of world	A.254	9.2	A.255	11.52	A.256	13.82	A.257	16.13
A.258	Ukraine	A.259	9.2	A.260	11.52	A.261	13.82	A.262	16.13
A.263	Saudi Arabia		13.8		17.28	A.264	20.73	A.265	24.19
A.266	Nigeria	A.267	9.2	A.268	11.52	A.269	13.82	A.270	16.13
A.271	South Africa	A.272	13.8	A.273	17.28	A.274	20.73	A.275	24.19
A.276	Rest of Africa	A.277	9.2	A.278	11.52	A.279	13.82	A.280	16.13
A.281	Africa OPEC	A.282	9.2	A.283	11.52	A.284	13.82	A.285	16.13

Fuel tax was in line with the carbon taxes introduced, converter is 1$/l = 434.1 $/t$CO_2$

Table 0.4 Annual investment costs (billion 2015USD)

E3ME region	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Belgium	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Denmark	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Germany	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1	45.1
Greece	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Spain	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7
France	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
Ireland	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
Italy	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9	31.9
Luxembourg	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Netherlands	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9
Austria	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Portugal	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Finland	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Sweden	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
UK	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Czech Rep.	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Estonia	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Cyprus	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Latvia	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Lithuania	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Hungary	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Malta	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Poland	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
Slovenia	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8

Slovakia	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Bulgaria	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Romania	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Norway	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Switzerland	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Iceland	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Croatia	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Turkey	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Macedonia	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
USA	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3	165.3
Japan	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3	57.3
Canada	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
Australia	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
New Zealand	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Russian Fed.	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2
Rest of Annex I	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
China	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9	253.9
India	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4
Mexico	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2
Brazil	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3
Argentina	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
Colombia	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Rest Latin Am.	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
Korea	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8
Taiwan	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Indonesia	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
Rest of ASEAN	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Rest of OPEC	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Rest of world	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7
Ukraine	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6

Saudi Arabia	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3
Nigeria	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
South Africa	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Rest of Africa	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
Africa OPEC	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
	1046.5	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**	**1046.5**

Table 0.5 Capital Investment Subsidy (% subsidy / technology)

% sub-sidy / tech-nology	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coal + CCS	0	0	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.27	-0.24	-0.21	-0.18	-0.15	-0.12	-0.09	-0.06	-0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IGCC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IGCC + CCS	0	0	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.27	-0.24	-0.21	-0.18	-0.15	-0.12	-0.09	-0.06	-0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CCGT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CCGT + CCS	0	0	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.27	-0.24	-0.21	-0.18	-0.15	-0.12	-0.09	-0.06	-0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solid biomass	0	0	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.56	-0.525	-0.4875	-0.45	-0.41	-0.375	-0.338	-0.3	-0.26	-0.225	-0.19	-0.15	-0.11	-0.075	-0.0375	0
S Biomass CCS	0	0	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.56	-0.525	-0.4875	-0.45	-0.41	-0.375	-0.338	-0.3	-0.26	-0.225	-0.19	-0.15	-0.11	-0.075	-0.0375	0
BIGCC	0	0	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.56	-0.525	-0.4875	-0.45	-0.41	-0.375	-0.338	-0.3	-0.26	-0.225	-0.19	-0.15	-0.11	-0.075	-0.0375	0
BIGCC + CCS	0	0	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.56	-0.525	-0.4875	-0.45	-0.41	-0.375	-0.338	-0.3	-0.26	-0.225	-0.19	-0.15	-0.11	-0.075	-0.0375	0
Biogas	0	0	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.19	-0.18	-0.17	-0.16	-0.15	-0.14	-0.13	-0.12	-0.11	-0.1	-0.09	-0.08	-0.07	-0.06	-0.05	-0.04	-0.03	-0.02	-0.01	0	0	0	0	0
Biogas + CCS	0	0	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.19	-0.18	-0.17	-0.16	-0.15	-0.14	-0.13	-0.12	-0.11	-0.1	-0.09	-0.08	-0.07	-0.06	-0.05	-0.04	-0.03	-0.02	-0.01	0	0	0	0	0
Tidal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Onshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Offshore	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solar PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geothermal	0	0	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.475	-0.45	-0.425	-0.4	-0.375	-0.35	-0.325	-0.3	-0.275	-0.25	-0.225	-0.2	-0.175	-0.15	-0.125	-0.1	-0.075	-0.05	-0.025	0	0	0	0	0
Wave	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Cells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

% subsidy / technology	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
CHP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0