Central Bank of Hungary – Magyar Nemzeti Bank

Climate impact assessment

Impacts of climate change scenarios on the Hungarian economy

Final report | May 2021 | Cambridge Econometrics (Hungary) Budapest | df@camecon.com www.camecon.com

cambridge econometrics
clarity from complexity

Contact person: Dóra Fazekas, df@camecon.com (Cambridge Econometrics)

Authors: Dóra Fazekas, df@camecon.com (Cambridge Econometrics)
Mary Goldman mjg@camecon.com (Cambridge Econometrics)
Zsófia Kőműves zsk@camecon.com (Cambridge Econometrics)
Alexandra Pavelka ap@camecon.com (Cambridge Econometrics)

Project director: Richard Lewney, rl@camecon.com (Cambridge Econometrics)

This study was commissioned by the Central Bank of Hungary to provide input to their internal climate stress testing analysis.

Cambridge Econometrics' mission is to provide clear and useful insights, based on rigorous and independent economic analysis, to address the complex challenges facing society.
www.camecon.com

Cambridge Econometrics Limited is owned by a charitable body,
the Cambridge Trust for New Thinking in Economics.
www.neweconomicthinking.org

Authorisation and Version History

Version	Date	Authorised for release by	Description
1.0	18/12/2020	Dóra Fazekas	Final report
2.0	10/05/2021	Dóra Fazekas	Final report

Contents

Executive Summary

Objective

This paper is the final deliverable of Cambridge Econometrics' Climate Impact Analysis' project to the Hungarian Central Bank. The research is unique in that in tackles a small country in Central Europe, which is usually not in the focus of global analysis. An open economy with strong trade links to the EU with low-hanging fruits in decarbonisation. These features create a strong need for climate-risk impact analysis tailored to the Hungarian economy, to provide a foundation for climate-risk stress-testing in the financial sector.

The objective was to calculate the impacts of climate-related scenarios with varying levels of global climate action for the Hungarian economy. In this project, we have calculated the differences between a clean energy transition to reach the global warming target set by policy makers versus the physical risks of a climate-uninformed warmer world. The model used to calculate macroeconomic variables is E3ME (e3me.com), one of the leading macro-econometric models used for climate scenario analysis.

Climate change and its effects

Climate change and its effects have gained increasing public attention. The international policy community is determined to take global action. The impact of this transition will be felt differently across economic sectors and global regions. Commitment to a low-carbon future will create opportunities for green growth but there is a risk of financial instability from stranded assets, particularly if oil and gas reserves continue to be valued at high levels that are inconsistent with the planned carbon targets.

If no further action is taken to mitigate climate change, global temperature rise is expected to reach or even exceed 4˚C above pre-industrial levels by the end of this century. Under this future scenario, there will be long-lasting effects for the global economy because of increased exposure to physical risks. For example, agricultural yields will fall and there will be increased incidence and severity of natural disasters such as wildfires, storms, and flooding.

Climate data disclosure

Informed investor decision-making and transparency on climate-related risks is essential to promoting a smooth market transition to a low-carbon economy. Several organisations have recommended the use of stress-testing to estimate climate-related risks. The Network for Greening the Financial System published recommendations for financial institutions to improve their risk management guidelines – one such recommendation is the need to integrate climate-related risks into financial stability monitoring.

Climate risk aware portfolios

Assessing the impact of different levels of climate action and global warming trajectories is key for financial institutions to develop climate risk aware portfolios. As impacts heavily depend on geographical location and economic structure, there is a clear need for detailed country and sector-specific modelling. Such detail is needed to capture the risks met by the Hungarian economy as we face the physical impacts of climate change as well as those of a transition to a less fossil-fuel intensive economy.

Cambridge Econometrics approach

Cambridge Econometrics expertise has been employed over a wide range of issues faced by clients, from policy impact assessments to climate scenario analysis. The E3ME macroeconomic model, which has been developed by Cambridge Econometrics over the past 30 years, is designed for exactly this type of analysis. Our scenarios are in line with NGFS requirements, such as:

assessing physical and transitional effects in case of different climate policies, assessing a scenario in line with the Paris Agreement, containing information about key macroeconomic variable changes and sectoral vulnerabilities on long term horizons, as well as that our scenario outputs are disaggregated on regional and sectoral levels.

This analysis

Our project started with setting up the necessary assumptions and input variables for the different global warming pathways where the global temperature increases from pre-industrial levels to 2100 may vary between below 2°C, so-called ‘Paris Transition Pathway’ and just below 4°C for the ‘Failed Transition Pathway’, which will have dramatic physical impacts. There is a wide range of possible policy and technology combinations to achieve the emissions reduction consistent with each climate pathway. Our scenario set is based on an extension to existing energy and environmental policies and represents only one of many possible pathways to different futures. We include adjustments to calibrate our forward-looking baseline projection to match published projections from official sources, usually those from the European Commission and the International Energy Agency. For this project, we have customised our standard scenario offering, such that the power sector developments are broadly in line with the targets of the latest Hungarian National Energy and Climate Plan (NEKT 2020).

In this project we modelled two transition pathways with substantially different risk levels associated with them. Transition risks and physical risk impacts were reported as a difference to a ‘climate-uninformed baseline’ which takes no account of climate change impacts at all.

Table 1-1 Narratives for the transition pathways

Pathway	Failed Transition	Paris Transition
Temperature	Below 4°C	Below 2°C
General assumptions	• EU ETS with the same carbon price • Modest biofuel blending mandates • Some support for renewables and energy efficiency	• Global ETS for most sectors with increasing carbon price • Large subsidies and feed-in tariffs for renewables • Strong EV and biofuel blending mandates • High investment in energy efficiency • Investment in CCS
Assumptions for Hungary	• EU assumptions • Power sector aligned with Hungarian energy targets (NEKT 2020)	• EU assumptions • Power sector aligned with Hungarian energy targets (NEKT 2020) • Solar PV centered power sector subsidies

Pathway	Failed Transition	Paris Transition	
Temperature	Below 4°C	Below 2°C	
Transition risk impacts for Hungary	-	• Investment stimulus boosts sectors providing the low-carbon infrastructure for the power generation and transport • Stranded fossil fuel assets lead to decline in extraction and use sectors • Reduction in the import of fossil fuels improves the trade balance • Increasing disposable incomes increase output in the agriculture, food production and consumer goods sectors	
Financial shock		**Orderly** Smooth pricing in of climate risks	**Disorderly** Abruptly priced in climate risks in 2025
Physical risk impacts for Hungary	High losses due to lower productivity and increasing prices	Moderate losses due to lower productivity and increasing prices, locked-in physical risks	

The ***Failed Transition Scenario*** captures a business-as-usual case in which climate action is limited and the warming reaches 3.5-4°C until 2100. Under this scenario physical risks related to climate change are severe. This scenario assumes the implementation of existing and announced global and EU and Hungarian policies, and for the power sector assumptions were further aligned with announced Hungarian targets and energy strategy:

- Current nuclear blocks shut down as their life cycle ends and the new nuclear blocks will be operational as planned.
- Coal and lignite capacities gradually phased out.
- Investments increased in solar capacities.
- No additional subsidies introduced for onshore wind.

The ***Paris Transition Scenario*** captures an ambitious decarbonisation which keeps the warming below 2°C. In this scenario physical risks are locked-in and their impact is weaker. Transition risks accompanying policy changes strongly affect the economy. This scenario assumes further low carbon policies announced and implemented in the analysis horizon. Hungary's low-carbon policies will be in line with European policies participating in the EU ETS and introducing renewable technology subsidies in the same spirit. For the power sector assumptions are further aligned with announced Hungarian targets and energy strategy.

- Current nuclear blocks shut down as their life cycle ends and the new nuclear blocks will be operational as planned.
- Coal and lignite capacities phased out at a faster pace.
- Investments increased strongly in solar capacities.

- No additional subsidies introduced for onshore wind.

Two variants of the Paris Scenario were modelled which differ in the financial consequences of the climate risks. In the Paris Orderly Transition Scenario, transition and physical risks are priced in smoothly over the period of 2021-2025. In the Paris Disorderly Transition Scenario, however, climate risks are abruptly priced in in 2025, which leads to a confidence shock to the financial system in 2025. This shock has a demand and supply side impact on the real economy as well.

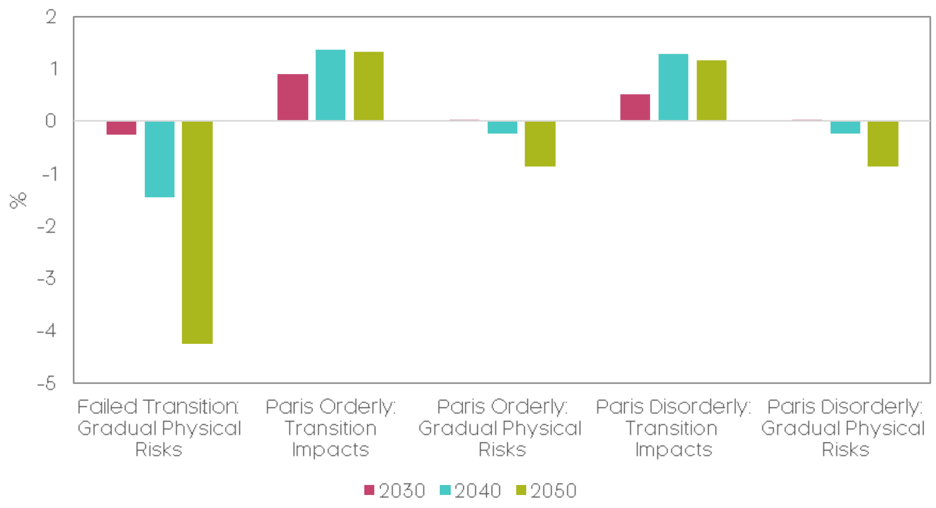
Running the model

Then, using E3ME as a 'translation tool', climate-related physical and transition risks were quantified as shocks to macroeconomic indicators per year, per sector, for each of the scenarios. These quantified climate risk shocks represent the difference between the transition scenarios and the climate-uninformed baseline.

Key results

Results show that in the Paris Transition scenarios fossil fuels are phased out from power generation, transport, and the whole economy, while energy-efficiency grows. Investment in the low-carbon infrastructure, growing incomes, employment and improving trade balances boost the GDP compared to the Failed Transition scenario. The modelling results of the disorderly scenario show a short-run negative GDP shock compared to the Paris Orderly scenario. While gradual physical risks are kept at a 1% level in the Paris Transition scenarios until 2050, in the Failed Transition scenario they can exceed a negative 4% impact.

Figure 1 GDP impacts for Hungary, percent difference



Key sectoral impacts of such a low-carbon transition are seen in agriculture, food services and consumer goods – these benefit from higher household incomes. The output of construction, metals, and electronics sectors increase to meet increased demand for the low-carbon infrastructure. In motor vehicles, there is a fleet change to more efficient or electronic vehicles, which keeps investment and trade high. In the long run, once the fleet is replaced demand for vehicles falls. Demand for fossil fuels in the transport sector declines, which improves Hungary's trade balance and drives an increase in household incomes and consumer spending on other goods. As expected, fossil fuel extraction and related sectors decline.

1 Introduction

This paper is the final deliverable of Cambridge Econometrics' Climate Impact Analysis' project to the Hungarian Central Bank. The objective was to calculate the impacts of climate-related scenarios with varying levels of global climate action for the Hungarian economy.

There is a growing consensus and emerging requirements from central banks and supervisory agencies to assess the impact of climate risks. These systemic risks include transition risks, stemming from climate policies implemented, and physical risks, from climate change itself.

Assessment reports by the Intergovernmental Panel on Climate Change (IPCC) document unprecedented warming since the 1950s strongly linked to anthropogenic emissions of greenhouse gases (e.g. (IPCC, 2014) (IPCC, 2018)). As the global temperature is rising compared to its pre-industrial levels, climate-related physical risks increasingly impact economic productivity and human living conditions. To mitigate those risks and keep global warming at a manageable level substantial policy changes are needed to cut back emissions. Strong transition policies also affect economic productivity. Different countries may face markedly different physical risks based on their geographic location and substantially different transition risks depending on their economic structure and reliance on fossil fuels.

Organisations, and financial institutions specifically, are facing an increasing pressure to consider climate change and the risks related to it in their investment decisions. Pension funds, sovereign wealth funds, and various other institutional investors need to secure income streams aware of the risk profiles of these investments in the coming years and decades. These risks profiles are expected to be altered by both climate change and climate action. For instance, investments in fossil fuels had high returns historically which drew capital to the related sectors and infrastructure. In the coming years, these high emission sectors are expected to be impacted by significant realignment towards a low carbon economy. Each region and country will be affected differently by the restructuring of the industry during a low-carbon transition. Producers and importers of fossil fuel resources will face radically different risks under the changing circumstances.

As both climate change and climate action pose risks to the financial system, more and more institutions advocate for climate-related risk assessments. Reliable information is needed for financial markets to price climate-related risks and opportunities correctly. This is key for keeping the stability of the financial system, for making informed, efficient capital-allocation decisions and adjust to potential risks. The Task Force on Climate-related Financial Disclosures (TCFD) recommends that private companies disclose their climate-related financial risks to lenders, insurers, and other stakeholders (Task Force on Climate-related Financial Disclosures, 2017). Government leaders, supervisors and regulators also announce policies to endorse and support climate risk disclosures to ensure the resilience of the economy. The Network for Greening the Financial System (NGFS) consists of Central Banks and Supervisors and created guidelines in order to improve the climate risk management of financial institutions (see Network for Greening the Financial System (2020)).

NGFS recommends scenario analysis as a tool for climate-stress testing. Developing alternative futures with different level of climate action and climate change allows assessing the risks associated with each pathway. Constructing standard scenarios aims to reduce the uncertainty inherent in such analysis.

This report presents Cambridge Econometrics' approach to modelling both transition and gradual physical risks. The research is unique in that in tackles a small country in Central Europe, which is usually not in the focus of global analysis. An open economy with strong trade links to the EU with low-hanging fruits in decarbonisation. These features create a strong need for climate-risk impact analysis tailored to the Hungarian economy, to provide a foundation for climate-risk stress-testing in the financial sector.

Section 2 gives a brief introduction to the science behind climate change and policy developments. Section 3 presents climate stress-testing and compares our approach to that of the NGFS. Section 4 presents our methodology for quantifying transition risks in detail: the E3ME model and our approach to quantify gradual physical risks. Section 5 introduces the modelled climate-risk scenarios and their underlying assumptions. Section 6 presents the key results from the modelling, while Section 7 concludes.

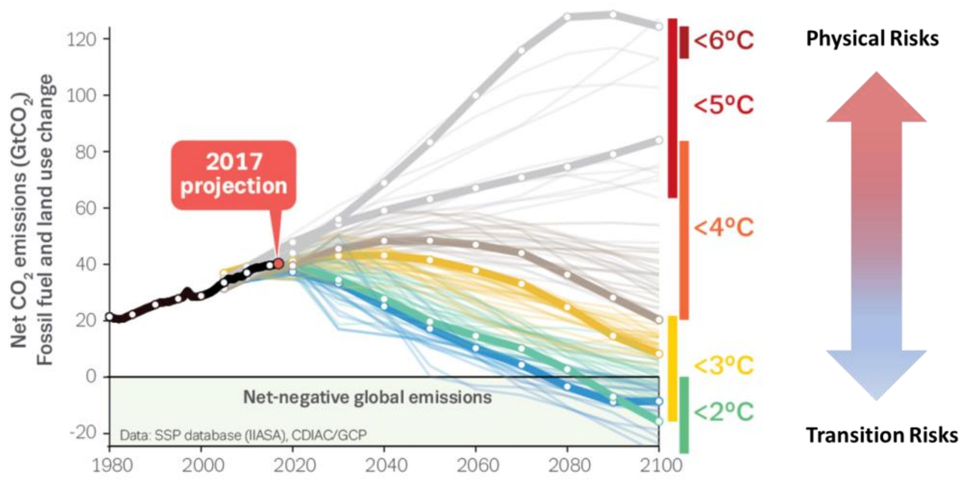
2 Global Warming Pathways

Climate science

Assessment reports by the Intergovernmental Panel on Climate Change (IPCC) provide an integrated view on the current state and prospects of climate change. Their recent reports show a continuous and unprecedented warming since the 1950s strongly linked to anthropogenic emissions of greenhouse gases (IPCC 2014) (IPCC 2018).

The cumulative amount of greenhouse gases in the atmosphere and continuing emissions will further warm the planet. Increasing the global average temperatures and the incidence of extreme weather events are likely to cause 'severe, pervasive and irreversible impacts for people and ecosystems' (IPCC 2014). To mitigate climate change, to prevent and to 'lock-in' the physical risk impacts of associated with it, substantial and sustained policy actions are needed.

Figure 2-1 Potential global warming pathways, Global Carbon Budget 2017



Source: Global Carbon Budget 2017, Le Quéré, C. & al. (2017) and own elaboration

Figure 2-1 from the Global Carbon Budget 2017 (Le Quéré, C. & al. (2017)) illustrates the average global warming achieved by 2100 compared to the pre-industrial levels, for given carbon-dioxide emission pathways. The emission pathways depend on the economic activity and the introduced policies to mitigate emissions. With the current commitment to climate action and economic trends the warming is expected to be kept just below 4°C by 2100. However, it is possible that current pollution trends exacerbate or that the climate system of Earth reacts more sensitively to emissions and reaches tipping points which accelerate the warming. In such cases the global average warming may reach 5 or even 6°C. For the global warming to be kept well below 2°C, preferably at 1.5°C, substantial and urgent climate action needed. This requires a high level of economic and social transformation, which was committed to in the Paris Agreement in 2015 (UNFCCC 2015) by several countries, including all Central Eastern European countries. Despite the commitments, the actual level of climate action and emission trends makes it likely that the warming will already reach 1.5°C between 2030 and 2052 (IPCC 2018), therefore temperature will rise even higher by 2100.

Small changes in the global average temperature mean very severe changes to our living environment. Warming will be uneven globally, being higher on land than sea and reaching two to three times the average as we move toward Arctic regions. There, it brings the melt of the permafrost and sea ice, which will impact seaside regions across the globe (IPCC 2018). The higher the average temperature gets; the intensity and severity of extreme weather events increase. These include heavy precipitation with tropical cyclones bringing floods, severe droughts in other regions causing wildfires, extreme hot days and cold nights in other areas (IPCC 2018). Even a 2°C projected warming means a severe increase of climate-related risks to economic growth, human health, food and water security (IPCC 2018). These risks grow steeply as we reach higher temperature pathways, approaching an increasingly uninhabitable Earth by the end of the century with the highest temperature pathways. The locality specific nature of those risks calls for modelling focusing on specific regions and countries separately

3 NGFS and climate-risk stress-testing for financial institutions

Recommendations

Several organisations have recommended the use of stress-testing to estimate climate-related risks. In 2016, the European Systemic Risk Board recommended to include a disruptive energy transition scenario into stress-testing. In 2017, the Taskforce on Climate related Financial Disclosures (TCFD) recommended long-term forward-looking scenario analysis to better understand the likely impacts of climate change and related policy on investment portfolios. In 2019, the Network for Greening the Financial System (NGFS) published recommendations for financial institutions to improve their risk management guidelines (NGFS (2020)). One such recommendation is the need to integrate climate-related risks into financial stability monitoring. NGFS recommends taking into account for all risk types associated with different global warming pathways:

- ***Physical risks*** refer to the impacts of climate change on physical capital and economic performance. In most analysis there is a distinction between gradual and extreme weather-related risks. Gradual physical risks are slow-onset impacts, such as increasing temperature which gradually decreases agricultural yields and economic productivity. Extreme weather events refer to the increase in severity and frequency of meteorological, hydrological, and climatological events causing physical damages and high costs. The impacts of both types of physical risks are highly uneven at a global scale and increasing with the average temperature.
- ***Transition risks*** capture the impacts of all decarbonisation policies, which aim to mitigate climate change. Keeping the global average warming well below 2°C requires a high level of economic and social transformation. The severity of the transition risks associated with decarbonisation policies depends on the economic structure and resource intensity of production. A global phase out of fossil-fuel reliant technologies from all segments of the economy could severely hurt some countries. Other regions may benefit from the restructuring, becoming suppliers of sustainable technologies.

As shown in Figure 2-1 physical risk impacts increase severely the higher the warming becomes, while transition risks grow with the strength of the mitigation policies. For fully quantifying local physical risks and economy-specific transition risks, a highly disaggregated yet global modelling is needed.

Developing climate-scenarios and building a climate-risk stress testing framework is the recommended tool of the risk assessment. In the next sections we describe the steps of undertaking such analysis with the E3ME model of Cambridge Econometrics, which is in line with the recommendations of NGFS. However, there are some differences between the modelling of NGFS and our approach.

Comparison of our approach to NGFS

Our approach uses a top-down forward-looking scenario-based modelling approach, similarly to the NGFS, but uses different type of macroeconomic model. E3ME is macro-econometric model (see Section 4) based on historical relationships and econometrics. Our approach allows for spare capacities and technological transitions.

Second, both approaches use scenario analysis to assess the impacts of green policies and climate change under different states of the world. There are three main pathways built on IPCC scenarios covered in NGFS and our approach as well, the SSP2, RCP 2.6 and RCP 6.0 (IPCC 2014).

Assumptions are quite similar in both methodologies. Both approaches calculate the gradual physical damages based on literature (Table 4-1, which links the average temperature change and decrease in economic productivity. There is difference in that our approach goes beyond the global level results and provides extra components in analysing the climate risks -e.g., sectoral and regional breakdown of results are available as well.

It is widely recognised that these guidelines will rise to regulation in the near future. Therefore, it is key for supervisors and financial institutions to start developing their climate-risk stress testing methodologies to prepare for forming regulations and potential climate-risks.

4 Modelling approach

Modelling transition risks with E3ME model

For capturing the full impact of global climate action, a large-scale is needed which is able to link economy, energy and environment, in a so-called E3 system. The model also needs to have a global coverage and sufficient sectoral and fuel use detail to capture the policies. There are a few of such models which are commonly used for policy analysis. In this report we present the E3ME model developed by Cambridge Econometrics, which can be used to capture transition risk impacts in climate risk modelling (Cambridge Econometrics 2019).

General description E3ME model

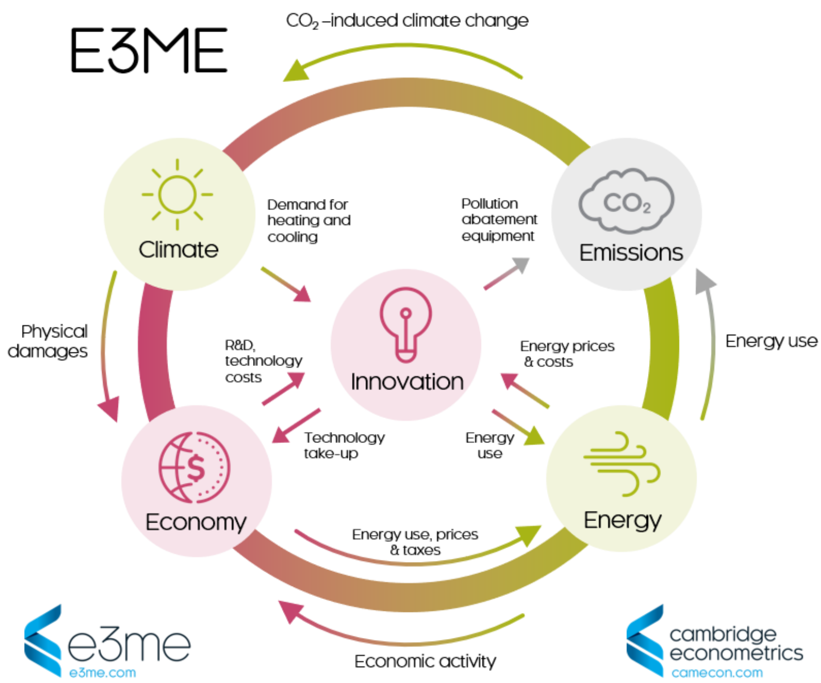
E3ME is a macroeconometric model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programs and is now widely used in Europe and beyond for policy assessment, for forecasting and for research purposes. Key features of E3ME include:

- the close integration of the economy, energy systems and the environment, with two-way linkages between each component
- the detailed sectoral disaggregation in the model's classifications, allowing for the analysis of similarly detailed scenarios
- its global coverage, while still allowing for analysis at the national level for large economies
- the econometric approach, which provides a strong empirical basis for the model and means it is not reliant on some of the restrictive assumptions common to Computable General Equilibrium (CGE) models (e.g.: equilibrium on the labour market).
- the econometric specification of the model, making it suitable for short and medium-term assessment, as well as longer-term trends

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.

Figure 4-1 represents how E3ME operates as a translation tool for investigating linkages across the four key dimensions of the model (climate, emissions, economic performance, and the energy sector) under various climate scenarios. 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 to the environment module, which in turn can give measures of damage to health and buildings. 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. Emissions are determined by economic activity and the energy modules, by the technologies used for production. Emissions affect the pace of global warming and the level of climate risks, which impact the economy through productivity impacts and physical damages. Innovation is modelled in separate submodules affecting all pillars of the model.

Figure 4-1 The broad structure of E3ME model



Source: Cambridge Econometrics (2019)

Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each pillar of the model. The set of assumptions describing these exogenous factors are the set of policy assumptions per climate pathway to model the transition and gradual physical risks in E3ME. 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 energy policies (including regulation of the energy industries). The linkages between the components of the model are shown explicitly by the arrows that indicate which values are transmitted between components.

E3ME's historical database goes back to 1970 and the model projects forward annually to 2050. The main data sources are Eurostat, the OECD (both the National Accounts section and STAN), World Bank, UN statistics, IMF, and I LO, supplemented by data from national sources. Energy and emissions data are sourced from the IEA and EDGAR[1].

FTT: the technology innovation modules in E3ME

The econometric relationships and accounting identities in the model determine total demand for manufactured products, services, and energy carriers. While long time series may capture well the behaviour of economic indicators, they cannot be used to model the innovation and the spread of new technologies.

[1] The full model manual and a list of peer-reviewed publications in which it has been applied is available from www.e3me.com.

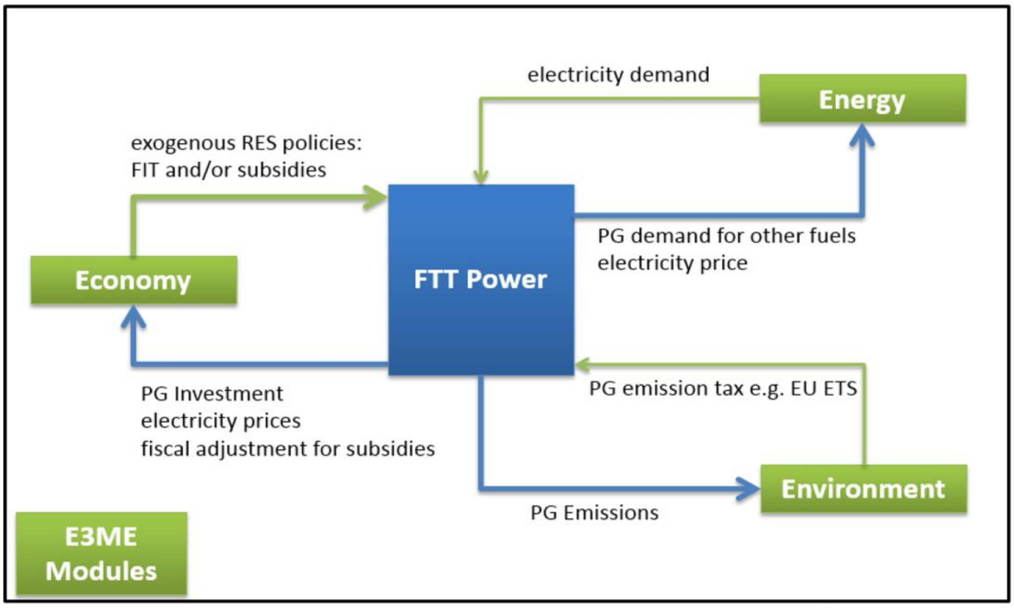
Future Technology Transformation (FTT) modules represent bottom-up simulations of technology diffusion in E3ME for several sectors building on the same principles. Technology diffusion determines changes in the environmental intensity of economic processes, including changes in amounts of energy required for transport, electricity generation and household heating. Greenhouse gas emissions are produced by the combustion of fuels and by other industrial processes, which interfere with the climate system.

FTT:Power is the energy system submodel of the E3ME, developed by Mercure et al. (2012), represents the power sector using an advanced framework for the dynamic selection and diffusion of innovations. It uses a decision-making core for investors wanting to build new electrical capacity, facing several technologically feasible options with different costs. The resulting diffusion of competing technologies based on investor choices is constrained by the globally available renewable and non-renewable resources. The decision-making takes place by pairwise levelized cost (LCOE) comparisons, conceptually equivalent to a binary logit model, parameterised by measured technology cost distributions. Costs include reductions originating from learning curves, as well as increasing marginal costs of renewable natural resources (for renewable technologies) using cost-supply curves. The diffusion of technology follows a set of coupled non-linear differential equations, sometimes called ‘Lotka-Volterra’ or ‘replicator dynamics’, which represent the better ability of larger or well-established industries to capture the market, and the life expectancy of technologies.).

For given energy demand calculated based on the needs of the economy FTT calculates how that energy demand is met depending on the available technologies and their costs in a bottom-up modelling framework. FTT:Power determines a technology mix by region given a scenario of detailed electricity policy: carbon prices, investment subsidies, feed-in tariffs and forced phase-out regulations by technology. Changes in the power technology mix result in changes of production costs, reflected in the price of electricity and emissions. Figure 4-2 captures these links between the FTT:Power submodule and the core of E3ME.

Source: Cambridge Econometrics (2019)

Figure 4-2 FTT:Power in the E3ME model



Source: Cambridge Econometrics (2019)

FTT:Transport models the passenger car transport sector, which accounts for by far the largest share of transport emissions and is described in detail in Mercure, Lam, Billington, & Pollitt (2018). FTT:Transport assesses the types of vehicles that are purchased in three size bands (small, medium and large) and several technology classes (including basic and advanced forms of ICE, hybrid and electric cars). The policy options cover ways of differentiating costs between the different vehicles (either in terms of capital costs through variable taxation or fuel/running costs) or regulations on the sales and operation of certain types of vehicles (e.g., phasing out inefficient cars, biofuel mandates).

FTT:Heat models the technology changes in the residential heating sector (for a detailed description see Knobloch (2019)). Rather than assuming that the energy efficiency improvement happens (e.g., due to public mandate), it provides a range of policy options for heating appliances (e.g., boilers, heat pumps) including subsidies, specific taxes or phase-out of old products. It thus assesses the take-up rates of the different technologies around the world.

The FTT module family is continuously expanding, FTT:Steel being the most recent addition and the FTT:Agri capturing full land use dynamics is currently under development.

Representation of transition policies in E3ME

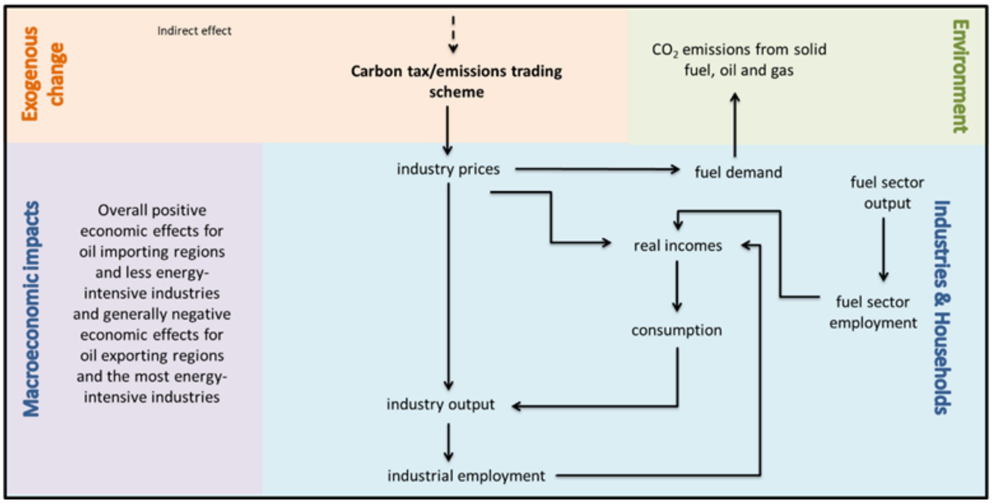
There are wide range of possible policy and technology combinations to achieve the emissions reduction consistent with each climate pathway. The following sections represent how three core types of policies and their effects feed through the economy in E3ME.

Carbon tax in E3ME

The ETS scheme and energy taxes are similar policy mechanisms because they increase the price of fossil-fuel, or energy-intensive inputs to production. Industry can pass the costs on to consumers, but this reduces real incomes and reduces aggregate consumption. In cases where industry adjusts other inputs to production to keep prices faced by consumers constant, less output may be produced requiring fewer employees. Reductions in employment also has negative effects on real incomes and feeds into further reductions in aggregate demand.

In response to the price increase, industry might reduce demand for fossil fuels, which leads to reductions in emissions. In regions where fossil fuels are a large part of industrial production, a reduction in demand for these products could lead to decreases in output and employment in fossil fuel producing sectors. This would have additional negative effects on real incomes, consumption, and total output. Figure 4-3 summarises the main economic impacts when an energy tax or ETS scheme is introduced and how these effects feed through the economy.

Figure 4-3 Overview of economic linkages for a carbon tax policy in E3ME

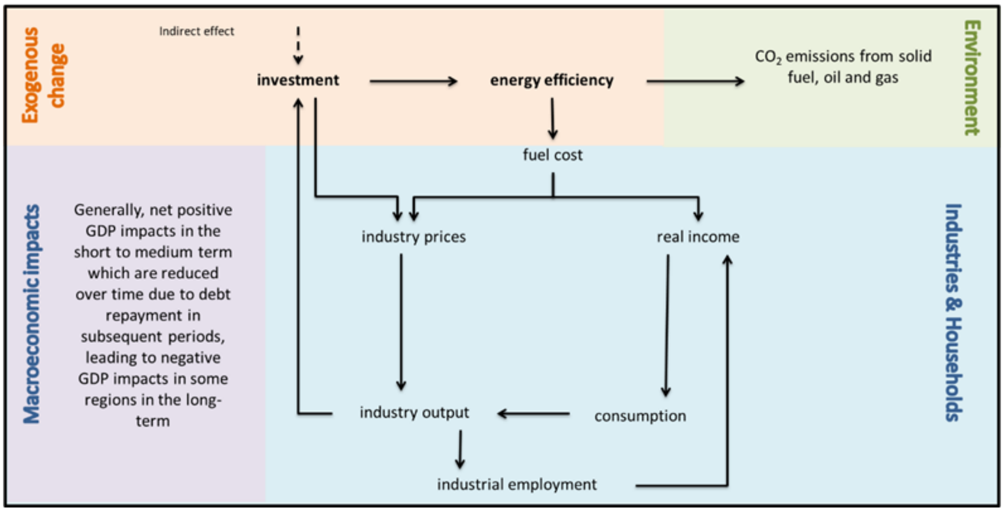


Source: Cambridge Econometrics (2019)

Energy efficiency improvement policies in E3ME

Energy efficiency investments reduce fuel costs for households, which has positive impacts on real incomes and consumption. At the same time, investment in energy efficiency reduces industry costs. With massive investments in energy efficiency measures, there is an increase in industry output to meet this demand along with increases in employment. This has further positive impacts on income and consumption. Energy efficiency improvements have generally positive GDP impacts while reducing total fuel demand and total emissions. Energy efficiency gains in different sectors are modelled through reduction in fuel demand. The higher energy efficiency is achieved through energy efficiency investments. Figure 4-4 summarises the main economic impacts when energy efficiency policies are introduced and how these effects feed through the economy.

Figure 4-4 Overview of economic linkages for an energy efficiency improvements policy



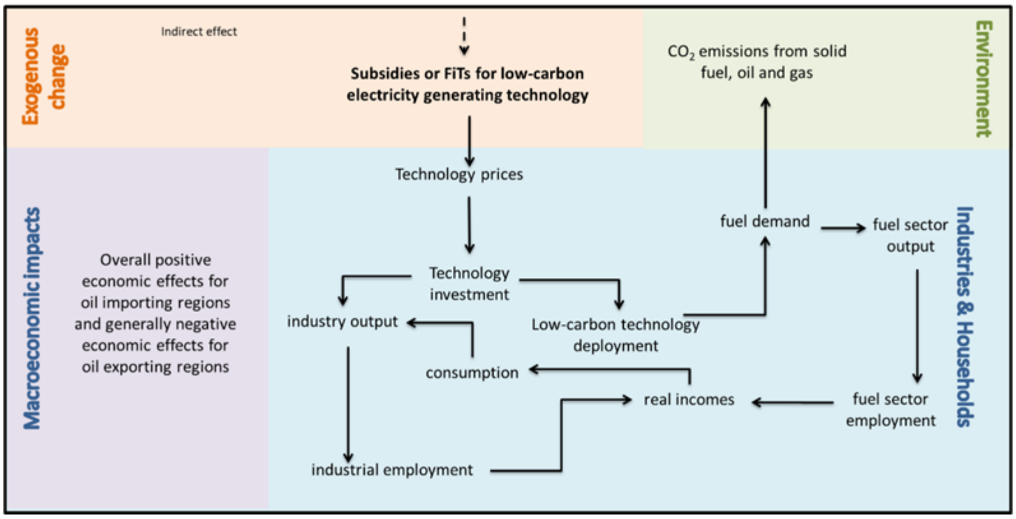
Source: Cambridge Econometrics (2019)

Subsidies of Feed-in-tariffs for low-carbon energy technology

Feed-in-tariffs and technology investment subsidies both act to lower the cost of investment in low-carbon electricity generation technologies. With greater investment and deployment of these technologies, there is a reduction in fuel demand and total emissions.

Given increased investment in these technologies and the electricity sector more generally, there is an increase in output and employment. This has a positive impact on real incomes, which drives increases in consumption. As consumers have more income to spend on goods and services this creates additional demand, additional output is produced to meet this demand, which engenders additional employment and so on.

Figure 4-5 Overview of economic linkages for a feed-in-tariff or technology subsidy policy



Source: Cambridge Econometrics (2019)

At the same time, with reduced demand for fossil fuel inputs for electricity generation, there is a decrease in output and employment in fossil fuel related sectors. This has negative macroeconomic impacts in regions that are fossil fuel exporters and experience the double effects of reduced output and employment in these sectors and reductions in government spending due to reduced fossil fuel extraction royalties paid to government. Figure 4-5 summarises the main economic impacts when feed-in tariffs are introduced and how these effects feed through the economy.

Modelling physical risks

Understanding the macroeconomic consequences of climate change is an issue that is pervaded by huge levels of uncertainty. As an unprecedented challenge, this uncertainty exists both in the link between emissions to temperature change and in assessing the wider economic effects of temperature change itself.

Application of Integrated Assessment Models (IAMs) and econometric analysis have previously been used to estimate the impact of climate change on future economic growth. The literature reflects a wide range of estimated GDP impacts associated with future temperature and climatic change (as shown in Table 4-1. Many of these approaches have been criticised for underestimating the likely scale of future climate damages, since the estimates are often based on the impact of temperature on GDP at much lower levels of temperature change, as historically observed.

Table 4-1 Global GDP impact of climate change across different studies

Source	Model, approach	Scenario	Global GDP impact in 2100
Burke, Hsiang, & Miguel (2015)	Econometric study (national-level data)	5-6˚C	-23%
Burke, Davis, & Diffenbaugh (2018)	Econometric study (national-level data)	1.5˚C 2˚C 3˚C	-11% -16% -25%
OECD (2015)	IAM (DICE)	1.5˚C 4.5˚C	-2% -10%
Nordhaus & Moffat (2017)	IAM (DICE)	6˚C	-8.16%
Hsiang, et al. (2017)	Spatial Empirical Adaptive Global-to-Local Assessment System (SEAGLAS)	1.5˚C 4.5˚C 8˚C	-1. to -1.7% -6.4 to -15.7% -1.5 to -5.6%
Kahn, et al. (2019)	Econometric analysis	1.5˚C 4˚C	-1.07% -7.22%
Zenghelis, D. (2006)	IAM (PAGE)	5-6˚C	-5% to -20%

Source: Own elaboration

In our modelling approach, systemic gradual physical risks are represented as aggregate productivity (GDP) impacts due to increasing temperatures (controlling for the effects of precipitation). Such impacts thus represent temperature impact on agricultural, industrial and worker productivity. The approach draws from the work of Burke and Tanutama (2019), which builds on earlier work by Burke, Hsiang, & Miguel (2015) and Burke, Davis, & Diffenbaugh (2018).

Burke and Tanutama (2019) econometrically estimate the relationship between temperature and GDP growth rates at a sub-regional level. In their paper, a district-level panel dataset was used on climate and GDP across 37 countries and multiple decades, which confirmed that also on a district level, economic production is concave in temperature exposure, with a negative slope throughout nearly all the observed temperature distribution and increasingly steep at warmer temperatures.

The regional change in temperature is used with the marginal effects of +1°C increase in temperature on GDP growth rates estimated by Burke and Tanutama (2019) to estimate an adjusted GDP growth rate in each year in each region. The temperature-adjusted GDP growth rate is used to calculate a climate-adjusted GDP in each year in each region.

Using this damage function, combined with regional-specific temperature impacts, we find much higher GDP impacts related to temperature change, than other literature sources. The country level impacts could range from -18% on GDP by 2100 in the Paris scenario to -60% GDP impact by 2100 in the Failed Transition scenario.

The approach also takes account of regional differences in the impact of temperature change on GDP growth. For example, under this approach, countries with temperatures below 5°C initially (such as Finland and Iceland) experience positive GDP growth impacts from warming, while countries with initially high average temperatures experience large negative impacts on GDP growth (e.g., India and Saudi Arabia). Strengths and limitations of this approach:

- This approach has been updated to use the most recent literature on estimating the economic impacts of climate change – Burke and Tanutama (2019).
- The approach explicitly accounts for the difference in warming that occur in different regions and for regional differences in the impact of temperature change on GDP growth.
- The impacts are consistently implemented across the different pathways and does not require any down-scaling or up-scaling of results based on published impacts for any one temperature pathway.
- The econometric approach captures some of the effects of extreme weather events, but only to the extent that warming has increased the incidence and severity of extreme weather events over the historical period. It is highly likely that this relationship is non-linear, with extreme weather events (such as wildfires, flooding, and tropical storms) increasing in frequency and severity as temperatures increase. As such, this method is likely to underestimate the full impacts of future temperature change on future GDP growth.

- The approach cannot capture potentially devastating climate tipping points, or the potential knock-on effects of complex political and social processes hastened by the stresses of climate change (i.e., mass migration, war, political and social instability).

Modelling extreme weather risks (non-E3ME)

In the E3ME model, we incorporate findings from Burke and Tanutama (2019) to estimate the economic impacts of climate change, but not the effects of extreme weather events. Extreme weather events are not evenly distributed across time, unlike the economic impacts of decreased productivity due to gradual temperature change. Incorporating the effects of extreme weather events such as flooding, tropical cyclones, or forest fires, would require making assumptions about what time period these events occurred in, which would then impact results in subsequent periods. This is too large an assumption to make without additional research about the distribution of these events, and additional data on the economic impacts of extreme weather. Instead, we use implied productivity losses from mean temperature change over time. It is possible to add the layer of extreme weather events to the transition and gradual physical risk shocks of E3ME. Ortec Finance[2] uses PALGamma, a proprietary catastrophe model (see Ortec Finance (2019)).

Incorporating COVID-19 impacts in the modelling

After June 2020, Cambridge Econometrics revised the modelling approach to account for some of the observed impacts and possible future implications of the ongoing COVID-19 pandemic. Using GDP growth assumptions based on expert publications of the potential macroeconomic impacts of the pandemic, the scale of the reduction in spending and GDP and the timing and extent of the subsequent recovery, with variation by country. This data was used to adjust the short-term GDP and sectoral output projections in E3ME and to re-calibrate E3ME GDP growth assumptions.

Additional adjustments were made to fuel demand, to account for global declines in transportation and commercial activity that might persist until at least 2025, with large impacts on the demand for oil products in particular.

It is currently not known what the medium- or long-term impacts of the ongoing COVID-19 pandemic will be. There will likely be structural transformations of the economy and reorientation of supply chains given the changes necessary to safeguard public health until effective treatments and vaccines become widely available. There is great uncertainty around the length and severity of the crisis. There are several views of how the COVID-19 crisis could play out. Cambridge Econometrics implemented one of the more conservative narratives, including a one-year shock to GDP growth.

[2] Ortec Finance: https://www.ortecfinance.com/

5 Scenarios

There are wide range of possible policy and technology combinations to achieve the emissions reduction consistent with each climate pathway. Our scenario set is based on an extension to existing energy and environmental policies and represents only one of many possible pathways. We do not provide a standalone forecast for the economic outcomes of these potential future scenarios, but always provide results under selected, specific scenario assumptions consistent with each climate pathway.

In this report we introduce two transition scenarios with substantially different risk levels associated with them:

- ***Failed Transition Scenario*** assumes a business-as-usual pathway in which climate action is limited and the warming reaches 3.5-4°C until 2100. Under this scenario physical risks related to climate change are severe.
- ***Paris Transition Scenarios*** capture an ambitious decarbonisation which keeps the warming below 2°C. In these scenario physical risks are locked-in and their impact is weaker. Transition risks accompanying policy changes strongly affect the economy. Two variants of the Paris Transition were modelled which differ in the financial consequences of the climate risks, whether those risks are smoothly or abruptly priced in by markets.

Table 5-1 provides a broad overview of the key characteristics of the two transition pathways, while the following sections describe the detailed assumptions used. Note that by default the main macro-economic results do not include any physical risks. Gradual physical risk adjusted results are only available for a subset of the macro-economic indicators for both scenarios. Extreme weather risks are provided by our partner Ortec Finance and are out of the scope of this report.

Table 5-1 E3ME's standard climate risk scenarios

	Paris Transition	Failed Transition
Temperature	Below 2°C	Below 4°C
Key risks	Transition risks & locked-in physical impacts	Dramatic physical impacts
Key policies	• Global ETS for most sectors & increasing carbon price • Large subsidies and feed-in tariffs for renewables • Strong EV and biofuel blending mandates • High investment in energy efficiency in all sectors • Investment in CCS	• EU ETS with same carbon price • Modest biofuel blending mandates • Some support for renewables and energy efficiency

Key impacts	• Transition impacts:
	  • Investment stimulus:
	    • positive for some sectors
	  • Stranded fossil-fuel assets:
	    • negative for resource intense sectors
	• Physical damages:
	  • negative but smaller than in the Failed Transition Scenario
		• No transition impacts
		• Physical damages:
		  • negative and different magnitude for each sector

cambridge econometrics
camecon.com

The results of our scenarios are compared to a climate uninformed baseline, which by default does not take into account any climate change impacts, so no physical risks.

Failed Transition Scenario

The Failed Transition scenario reflects a 'business as usual' case assuming a continuation of current policies, leading to around a global average 3.4°C of warming above preindustrial levels by 2100. In our model, these current global policies are essentially consistent with the IEA's World Energy Outlook Current Policies scenario (IEA 2019). In this scenario policy makers do not implement radical policies to mitigate climate change.

It is assumed that Hungary's key climate-energy policies will be in line with EU policies. Additionally, the projected energy mix has been adjusted to be broadly consistent with the announced Hungarian energy targets and strategies as much as the possible in the modelling (Innovációs és Technológiai Minisztérium 2020).

Data calibration

Long term GDP projection of this scenario is calibrated to published official forecasts. We combine the IMF(2017-2024), the European Commission Ageing Report (2025-2050, EU regions), the IEA World Energy Outlook (2025-2040, non-EU regions) and the IIASA SSP2 (2040-, non-EU regions) projections to create a long-term view on GDP growth, with smoothing applied from 2030-2050 (for sources see IEA (2019), IMF (2019), Riahi et al. (2017), Cuaresma (2017), (Commission 2018). Economy wide variables are also calibrated to the last available data in Eurostat for Hungary (from 2018), to ensure that the projections use an up-to-date starting point.

Global Assumptions

Global policies in the Failed Transition scenario are broadly consistent with the IEA's World Energy Outlook Current Policies scenario (IEA 2019) and include:

- Phase out of fossil-fuel subsidies in the US, China and Japan, mandates in some countries (e.g., China) on the share of total electricity generated by renewable sources
- Feed-in-tariffs for some low-carbon energy technologies (limited to offshore and onshore wind and solar power in China and India)
- Subsidies for Carbon Capture and Storage (CCS) in the US
- In the transportation sector there are subsidies for hybrid and electric vehicles in China and modest biofuel blending mandates in most regions

In the baseline scenario, population growth and GDP growth projections are consistent with the IEA's World Energy Outlook (IEA 2019). World GDP grows at around 3% per year and the global population grows to just over 9 billion by 2050 and then starts to stabilize. Population assumptions are exogenous in the E3ME model and therefore are identical across scenarios.

European Union Assumptions

Policy assumptions for the European Union in the baseline scenario are broadly consistent with the IEA's World Energy Outlook Current Policies scenario (IEA 2019) and include:

- Phase out of fossil-fuel subsidies in the European Union, mandates in some countries (Germany, UK) on the share of total electricity generated by renewable sources

- EU Emission Trading System (ETS) is implemented as is today, covering the power sector, the iron and steel industry, non-ferrous metals, chemicals, non-metallic minerals, and the paper and pulp industries
- Continuation of the EU emissions trading scheme with conservative price increases (a modest 3-4% year-on-year increase in carbon prices is assumed)
- Feed-in-tariffs for offshore and onshore wind and solar power
- Subsidies for Carbon Capture and Storage (CCS) in the European Union

Hungary specific assumptions

It is assumed that Hungary's main climate-energy policies will be in line with EU policies. For the power sector assumptions are further aligned with announced Hungarian targets and energy strategy.

- Current nuclear blocks to be shut down as their life cycle ends and the new nuclear blocks (Paks 2) will be operational as planned – this leads to an increase in the share of nuclear around 2030 when both current and new blocs will be operational.
- Coal and lignite capacities will be gradually phased out.
- Investment is increased in solar capacities.
- No additional subsidies will be introduced for onshore wind and CCS technologies
- Renewable support is not technology neutral in Hungary. Some technologies (e.g., solar) are preferred to others (e.g., wind). This difference across technologies, as described in the Hungarian energy targets, will be taken into account in the modelling as much as the power sector model (FTT:Power) allows the imposition of such constraints.

Figure 5-1 shows the power generation mix for Hungary in the Failed Transition scenario. Electricity generation is expected to slightly increase, with a growing share of solar PV and other renewables (e.g., biomass) in the mix complementing the nuclear generation. Figure 5-2 presents the fuel use of the Hungarian economy. Although, total fuel demand is expected to decrease due to efficiency improvements, the share of oil and gas remains important part of the mix. Changes in the power generation technology and fuel mix follow from the scenario assumptions and are key drivers of the economic impacts.

Figure 5-1 Power generation in the Failed Transition scenario

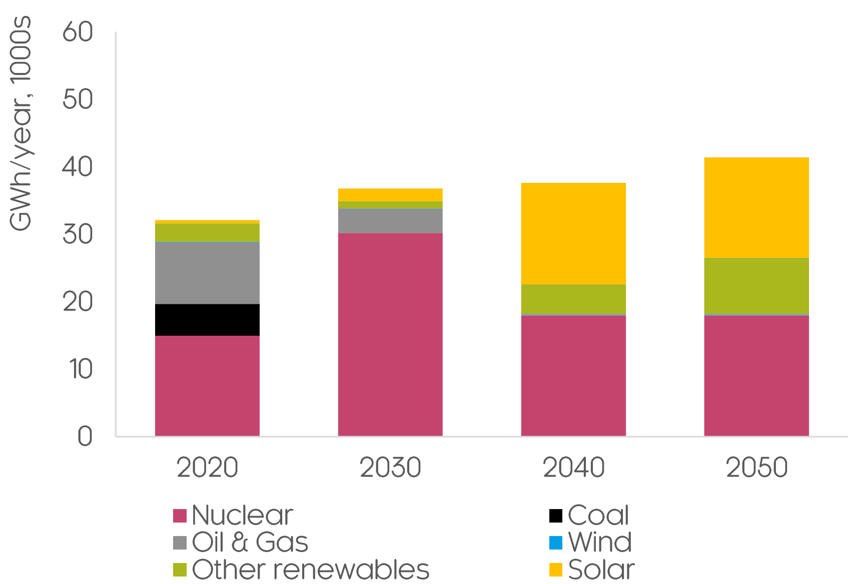
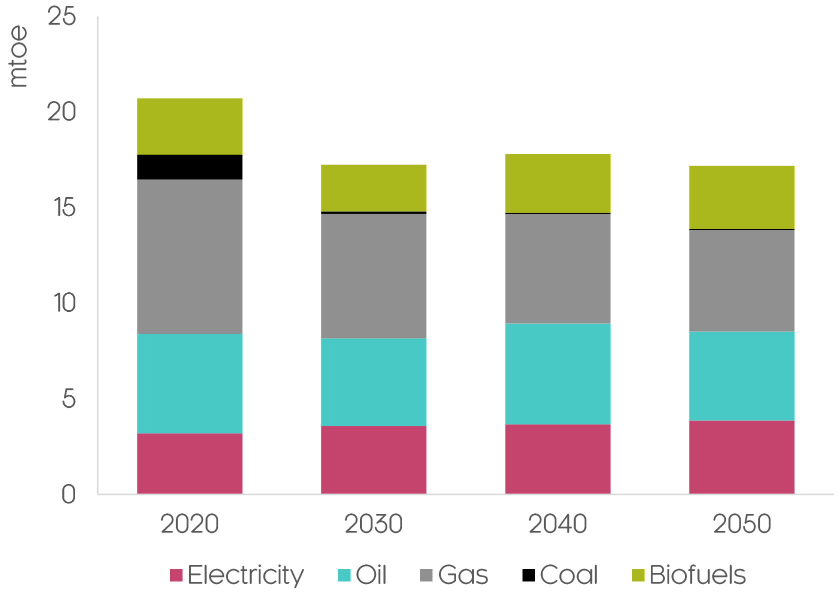


Figure 5-2 Fuel use in the Failed Transition scenario (million tonnes of oil equivalent)



So

Source: Cambridge Econometrics own calculation

Paris Transition Scenario

In the Paris Transition scenarios, political and social organisations act quickly to implement the recommendations of the Paris Agreement. With rapid and aggressive decarbonisation, global CO_2 emissions start to fall almost immediately. Financing to meet ambitious decarbonisation investment goals is made available in all world regions.

We have done two model runs: one scenario representing an 'orderly' transition without sudden sentiment and pricing-in shocks. And another one: a ‘disorderly’ transition to represent a case where the transition is not linear, climate risks are abruptly priced in in 2025.

By default, this scenario does not include physical risk adjustments

Global Assumptions

The Paris Transition scenarios includes a more ambitious policy set to generate the emissions reductions necessary for an increased probability of staying ‘well-within’ 2-degrees of warming.

- Emissions trading covers all world regions and all energy users except for road transport and domestic fuel-users
- Renewable electricity generation increases to almost 60% of total generation by 2050
- Global energy efficiency improvement is 3% globally in all sectors. For high greenhouse gas emission sectors this brings a significant emission reduction.
- Technology subsidies are available for CCGT, biogas and geothermal technologies
- Feed-in-tariffs are implemented for offshore wind, onshore wind, solar PV, and CSP
- Regional energy tax implemented from 2021 onwards in several large economies, such as the US, Canada, Japan, Brazil, India

- To further reduce emissions from the road transport sector, more aggressive biofuel blending mandates are pursued

In both scenarios assumptions about population growth are exogenous and are consistent with the IEA's World Energy Outlook. GDP and GDP growth are impacted by the effects of large exogenous investments to fund the transition to the low-carbon economy and the sectoral restructuring.

European Union Assumptions

The Paris Orderly and Disorderly Transition scenarios includes a more ambitious policy set for the European Union as well, to generate the emissions reductions necessary for an increased probability of staying 'well-within' 2-degrees of warming.

- EU ETS extended to include engineering, construction, agriculture, fishing activities, ore extraction, food and drink, textiles, hydrogen production, as well as rail transport and other transportation services
- Extensive technology subsidies are available for CCGT, biogas, geothermal, solar PV and nuclear technologies
- Feed-in-tariffs are implemented for offshore wind, onshore wind, solar PV, and CSP
- Heavy investments in energy efficiency
- Regional energy tax implemented from 2021 onwards

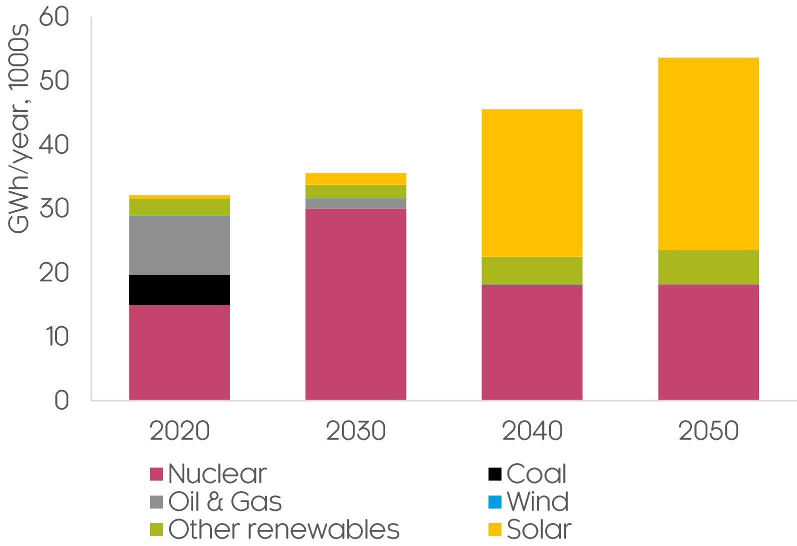
Hungary specific assumptions

Hungary's low-carbon policies will be in line with European policies, participating in the EU ETS and introducing renewable technology subsidies in the same spirit. For the power sector assumptions are further aligned with announced Hungarian targets and energy strategy.

- Current nuclear blocks to be shut down as their life cycle ends and the new nuclear blocks (Paks 2) will be operational as planned– this leads to an increase in the share of nuclear around 2030 when both current and new blocs will be operational.
- Coal and lignite capacities will be phased out at a faster pace.
- No additional subsidies will be introduced for onshore wind and subsidies for CCS technologies will be limited.
- Renewable support is not technology neutral in Hungary. Some technologies (e.g., solar) are preferred to others (e.g., wind). This difference across technologies, as described in the Hungarian energy targets, will be taken into account in the modelling as much as the power sector model (E3ME-FTT: Power) allows the imposition of such constraints.

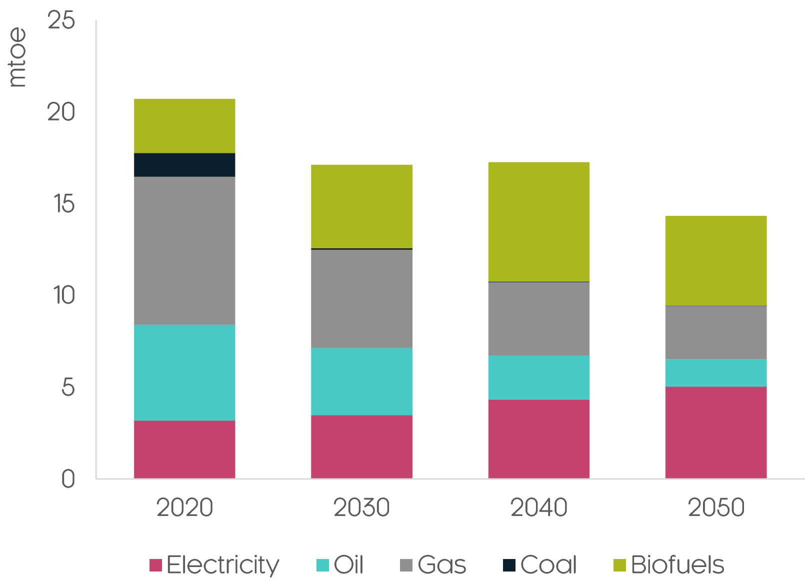
Figure 5-3 shows the power generation mix for Hungary in the Paris Transition scenarios. Paris Transition scenarios have higher electricity demand than the Failed Transition scenario as the low-carbon economy is more electrified. The excess demand is mostly met by solar and other renewable sources. Figure 5-4 presents the fuel use for the Hungarian economy in the Paris Transition scenarios. The fuel use is lower than it is in the Failed Transition scenario, due to the high investments in energy efficiency. Besides the higher rate of electrification, the share of biofuels also grows in this scenario at the cost of fossil fuels. Changes in the power generation technology and fuel mix follow from the scenario assumptions and are key drivers of the economic impacts.

Figure 5-3 Power Generation in the Paris Transition Scenarios



Source: Cambridge Econometrics own calculation

Figure 5-4 Fuel use in the Paris Transition scenarios (million tonnes of oil equivalent)



Source: Cambridge Econometrics own calculation

Emission and warming pathways under the two scenarios

In the Failed Transition and Paris Transition scenarios, the emission trajectories of the modelled global warming pathways correspond roughly to RCP2.6 and RCP6.0 from the IPCC (IPCC 2014). A relatively high climate sensitivity is applied (TCRE of 2.5°C/Tt C), which leads to a temperature well below 2°C by 2100 for the Paris Transition and just below 4°C for the Failed Transition Scenario.

The transient climate response to cumulative carbon emissions (TCRE) is the ratio of the globally averaged surface temperature change per unit carbon dioxide (CO2) emitted. This is also called 'climate sensitivity'. TCRE implicitly captures a unique relationship between CO_2 emissions, non-CO2 emission and total warming, although there is large uncertainty about the extent to which this relationship will continue in the future.

Table 5-2 Emission and warming pathways under the standard scenarios

Scenarios:	Cumulative emissions (2019-2100 in Gt CO2)	Cumulative emissions (2019-2100 in Tt C)	TCRE (°C/Tt C)	Reference time	Warming 2050 (°C)	Warming 2100 (°C)
Failed Transition	4163	1.1	2.5	1850-1900	1.9	3.8
Paris Transition	682	0.2	2.5	1850-1900	1.4	1.5

Source: Cambridge Econometrics own calculation

Paris Orderly and Disorderly Transition Pathways

Two variants of the Paris Scenario were modelled which differ in the financial consequences of the climate risks. In the Paris Orderly Transition Scenario, transition and physical risks are priced in smoothly over the period of 2021-2025. In the Paris Disorderly Transition Scenario, however, climate risks are abruptly priced in in 2025, which leads to a confidence shock to the financial system in 2025. This shock has a demand and supply side impact on the real economy as well.

6 Results

This section presents the modelling results for the Failed Transition and Paris Transition pathways, as well as the gradual physical risk analysis for the Hungarian economy. First, we present transition and physical risk impacts for GDP and inflation, our key indicators. Then we decompose the full transition impact to its key drivers, presenting it at a sector and product level detail.

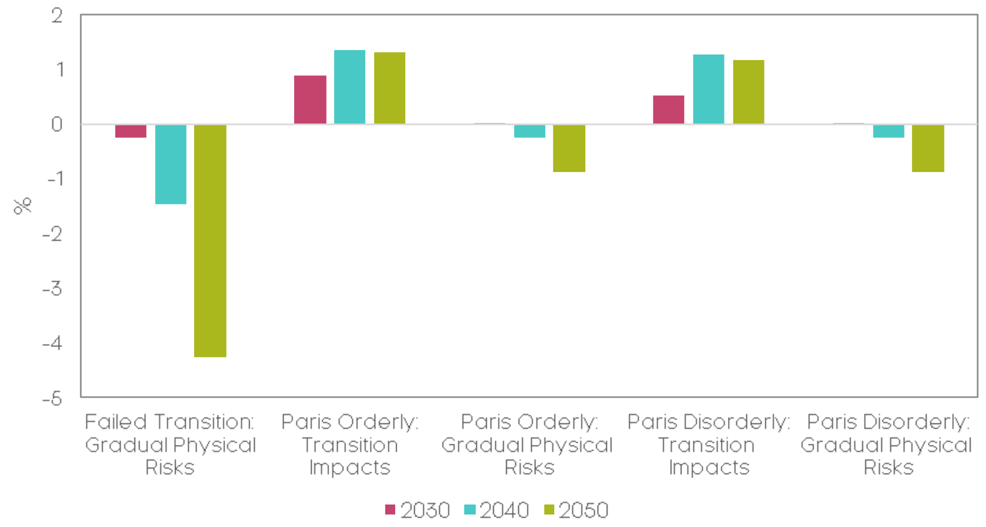
This section presents the results of the Transition scenarios as differences from the baseline as core modelling outputs. Additionally, physical risk analysis is available for all scenarios for a subset of the macroeconomic indicators. Note that the Paris Transition scenario has two variants representing different assumptions about the pricing in of climate risks.

Transition and gradual physical risk impacts on output and inflation

Figure 6-1 shows the transition and gradual physical risks impacts on GDP compared to the baseline scenario. The Paris Transition scenarios find positive transition impacts for the whole timeframe. This shows that the Hungarian economy benefits from the decarbonisation investments and the fossil-fuel phase out, as an importer of fossil resources. The Paris Disorderly scenario variant includes a negative pricing in shock in 2025 which slightly lowers the positive impacts for the whole time frame. Note that in the Failed Transition scenario, due to the low level of climate action there is no transition to a low-carbon economy. Therefore, there are no specific transition risks.

Gradual physical risk impacts reduce GDP due to falling economic productivity in both scenarios. Gradual physical risks are expected to lower the GDP of the Failed Transition scenario by 4.25% by 2050. In the Paris Transition scenarios, strong climate action mitigates and locks in gradual physical risks. The negative physical risk impacts are smaller and are more than counterbalanced by the positive effect of transition policies on the Hungarian economy.

Figure 6-1 Transition and physical risk impacts on GDP

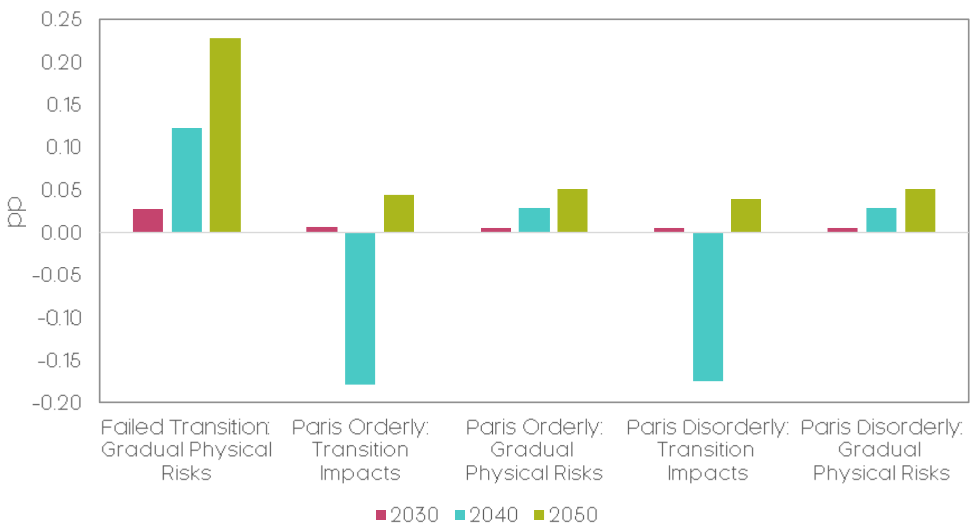


Source: Cambridge Econometrics own calculation, % diff from baseline

Figure 6-2 presents the transition and gradual physical risk impacts on the Hungarian inflation. The Paris Transition scenarios find that transition risks have a small effect in inflation, with the sign of the impact changing over time. Inflation impacts are largely driven by the revenue recycling mechanisms of the model. Assuming revenue neutrality, the government recycles carbon revenues and reduces VAT rates. This slows down price increase in the Paris Transition scenarios in the 2040s compared to the Failed Transition scenario. Towards the end of the period, increasing incomes and outputs of the Paris Transition scenarios push prices up, outweighing the impacts of the revenue recycling. There is no large difference in the trends of the Orderly and Disorderly Paris Transition variants. As described above, there are no transition impacts in the Failed Transition Scenario.

Gradual physical risks have a positive impact on inflation, primarily by squeezing supply chains and increasing the costs of economic activity. Gradual physical risks put pressure on supply chains by reducing labour and agricultural productivity and thus, increasing the cost of goods and services. There is no difference in the trends of the Orderly and Disorderly Paris Transition variants. This inflationary impact is higher in the Failed Transition scenario, where the low-level of climate action is unable to mitigate such physical risks.

Figure 6-2 Transition and physical risk impacts on Inflation

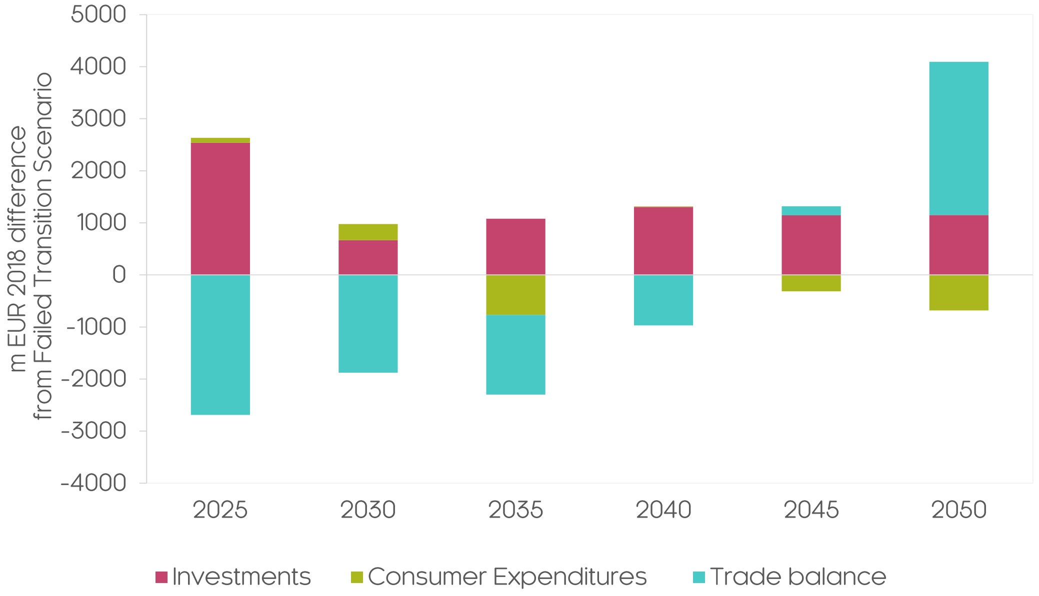


Source: Cambridge Econometrics own calculation

Transition risks: the main drivers of the GDP impacts

As shown in Figure 6-1 transition policies have a sustained positive impact on the Hungarian GDP over the 2020 to 2050 timeframe. Output in the Paris Transition scenarios is 1.3% higher by 2050 than in the Failed Transition scenario. Figure 6-3 shows the key drivers of the GDP shock, to understand the mechanisms behind the overall effect economic impact of the transition.

Figure 6-3 Key drivers of the transition impacts for Hungary in the Paris Orderly Transition



Source: Cambridge Econometrics own calculation

The figure presents clearly, that the investment stimulus is one of the key drivers of the positive transition impacts over the whole timeframe. Achieving the targets committed to in the Paris Agreement requires high investments into low-carbon technologies and energy efficiency. Power generation and transport are the key areas of the decarbonisation where phasing out fossil fuels and increasing the use of renewables requires new infrastructure.

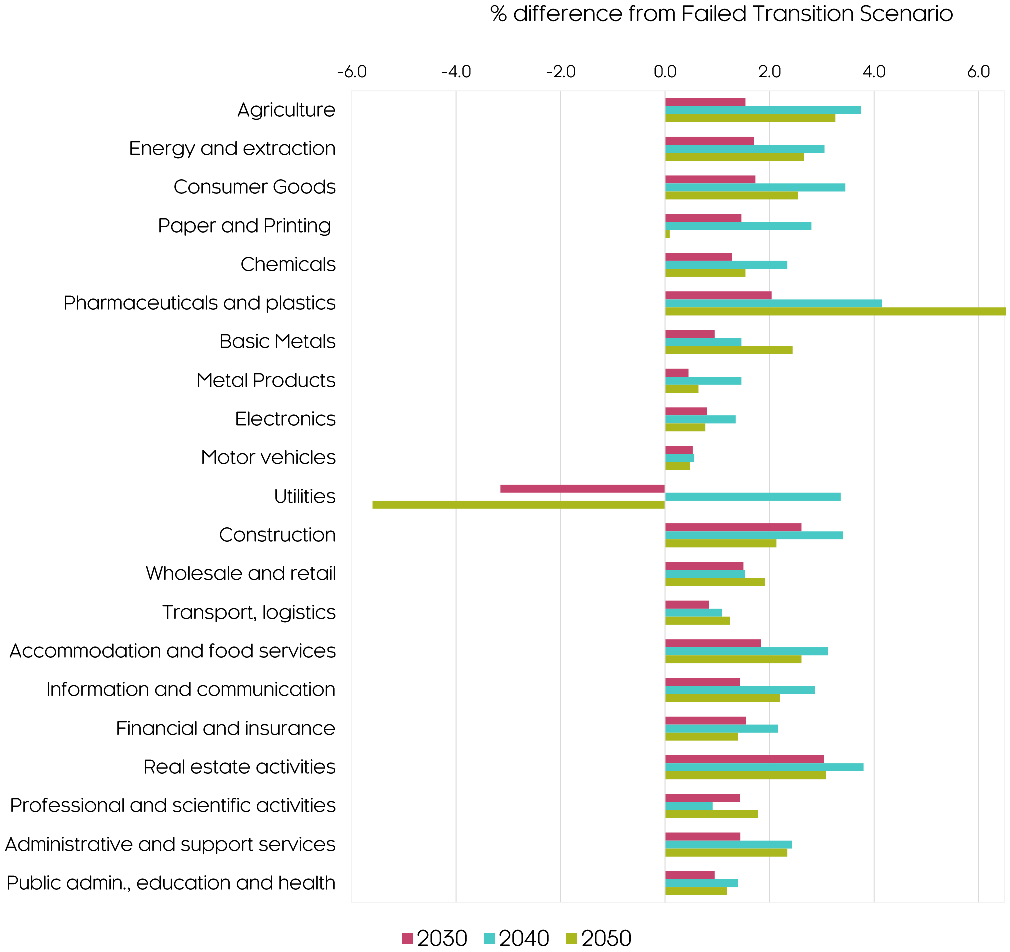
Overall trade balance improvement compared to the Failed Transition scenario is also a key component of the 2050 positive impact. Trade balance dynamics are strongly connected to the transformation of the transport sector in Hungary. As internal combustion engine vehicles are phased out, exports of those reduces with growing imports of electric and hybrid vehicles. As the economy and the vehicle fleet becomes more electrified, trade balance improves with reducing imports of fossil fuels. Consumption impacts account for a smaller fraction of the overall positive transition effect. Recovering from the COVID-19 shock, household incomes initially grow due to increasing employment driven by the investment stimulus and new infrastructure building. Disposable income the primary determinant of consumption is also supported by lower tax rates. The modelling assumes revenue neutrality for the government, which means that increasing carbon tax revenues in the Paris Transition scenarios are recycled, make tax cuts possible. Over time these impacts are outweighed by that energy efficiency investments are becoming increasingly expensive after picking the low-hanging fruits and the debt repayment starts for the early low-carbon investments.

Transition risks: sectoral investment

Figure 6-4 presents the impacts of transition policies on sectoral investment in the Paris Transition scenarios compared to the Failed Transition scenario.

The overall positive effect of the investment stimulus is clear from the chart. The only mixed sign impacts are seen in the utilities sector, which includes the electricity sector a key driver of the impact. Initially, energy efficiency improvements reduce electricity use and investment demand to electricity production. Then as fossil fuels are phased out from residential heating and the transport sector, electricity demand grows pulling investment to the sector. This happens parallel to shutting down the existing blocks of the Paks nuclear power plant, which creates a need for building more renewable capacities. After the investment spike, as additional capacities are built, investment decreases to the sector. Improving energy efficiency in residential heating and cooling further reduces the investment needs to the power sector.

Figure 6-4 Sectoral investment: transition impacts in the Paris Orderly Transition Scenario



Source: Cambridge Econometrics own calculation, detailed table in the Appendix

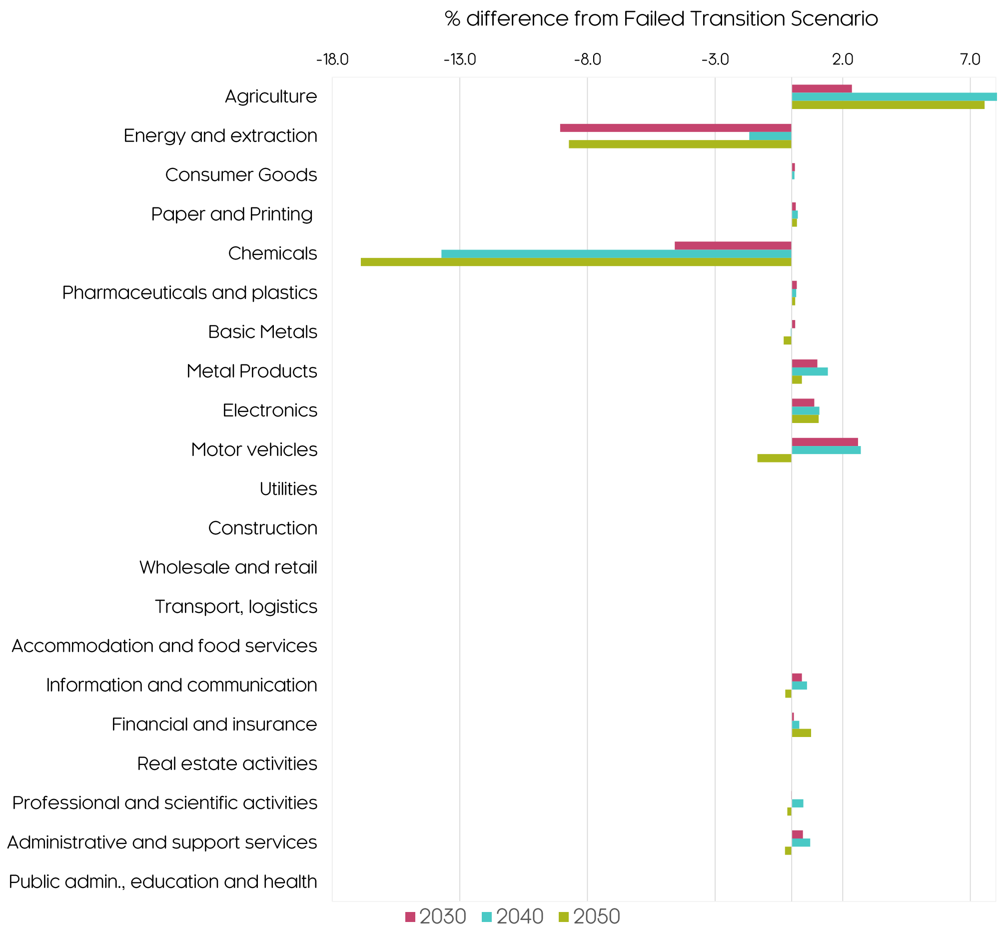
It is important to note, that as this graph shows percentage changes, some of the spikes are economically unimportant as happen in relatively small sectors. On the other hand, investment increase in transport, construction, metal, and electronics sectors are sizeable and serve building the infrastructure for the low-carbon economy. As the national and household incomes grow fuelled by the investment stimulus, spending increases on consumer goods and food. This draws investment to those sectors, related services, and wholesale-retail.

Note that transition impacts are aligned in the Disorderly and Orderly scenario variants.

Transition risks: sectoral imports

Figure 6-5 shows the impacts of transition policies on sectoral imports in the Paris Transition scenarios compared to the Failed Transition scenario.

Figure 6-5 Sectoral import: transition impacts in the Paris Orderly Transition Scenario



Source: Cambridge Econometrics own calculation, detailed table in the Appendix

The sectoral import impacts have quite different dynamics. Phasing out fossil fuels from power generation and transport is the key driver of the negative sectoral impacts as Hungary is a net importer of fossil fuels. Falling demand for lignite, oil and gas in the power sector lowers imports of the energy and extraction sectors. Phasing out internal combustion engine vehicles from passenger road transport substantially reduces demand and imports of manufactured fuels, which is accounted for as products of the chemical sector.

Impacts in the motor vehicles, metals and electronics sectors also relate to the decarbonisation of the power generation and transport. The import of motor vehicles increases initially with the growing demand for electric vehicles. As the vehicle fleet is replaced and the domestic sector shifts its production to electric and hybrid vehicles, the import demand lowers. Meeting the infrastructural demands of the decarbonizing power and transport sectors increases import demand for metals and electronics. Although, these impacts seem small in percentage terms, they are sizable and economically important.

Agriculture import also increases under the Paris Transition scenarios thanks to the increasing household income channel, which raises demand for agriculture and related food products. Note that transition impacts are aligned in the Disorderly and Orderly scenario variants.

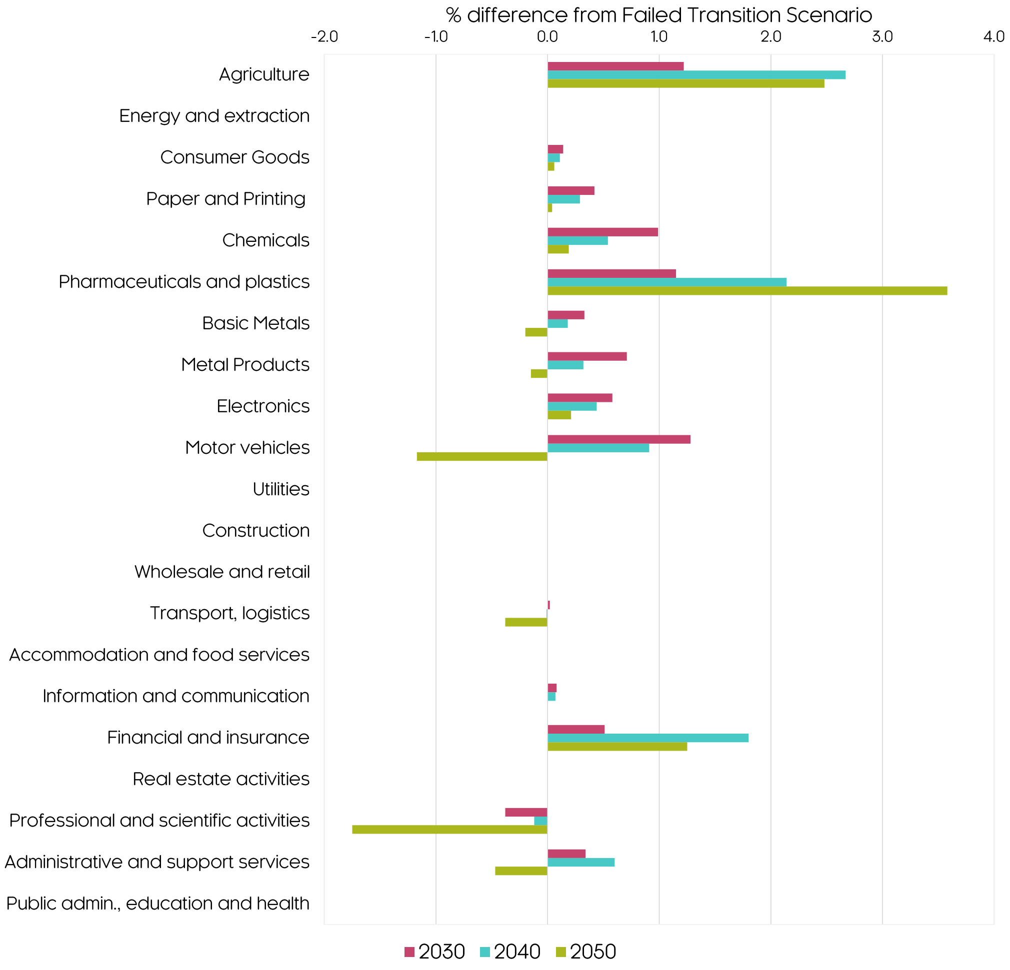
Transition risks: sectoral exports

Figure 6-6 shows the impacts of transition policies on sectoral exports in the Paris Transition scenarios compared to the Failed Transition scenario.

It is important to emphasize that although the focus of this analysis is Hungary, the policy assumptions of the Paris Transition scenarios are global ones affecting all trade partners of Hungary. The dynamics of the export impacts reflect this. The rapid decarbonization of power generation and transport creates a high global demand for metals, electronics, and new electric motor vehicles parts, which increases Hungarian exports as well. Once the vehicle fleet is replaced and the power sector is in alignment with the committed targets, the demand reduces.

As in Hungary, demand for agriculture also increases at a global scale under the Paris Transition scenarios thanks to the growing household incomes which raise demand for agriculture and related food products. Note that transition impacts are aligned in the Disorderly and Orderly scenario variants.

Figure 6-6 Sectoral export: transition impacts in the Paris Orderly Transition Scenario



Source: Cambridge Econometrics own calculation, detailed table in the Appendix

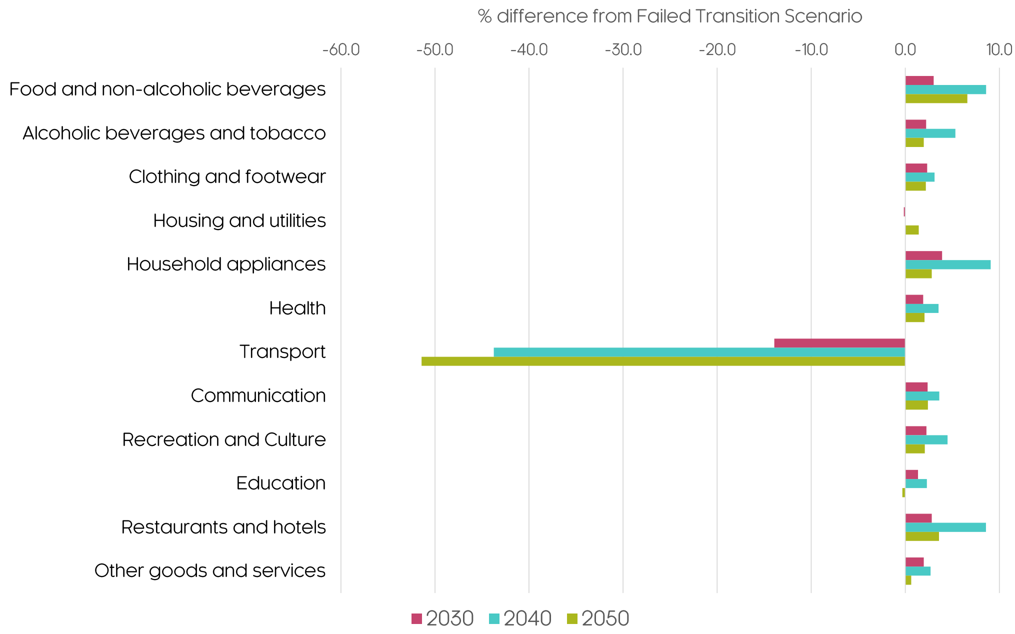
Transition risks: consumption

Figure 6-7 shows the impacts of transition policies on household consumption in the Paris Transition scenario compared to the Failed Transition scenario.

Household consumption impacts in the Paris Scenario are dominated by the lower transport expenditures. The reduced spending on petrol and diesel outweighs the high costs of changing the vehicle fleet. The one other product category with lower than baseline spending is gas in residential heating, which is counterbalanced by increased household spending on electricity. These trends disappear with the aggregation of product categories in the figure.

In the Paris Transition scenarios growing household incomes and lower VAT increase household expenditures, especially the spending on food and various other consumer goods. Note that transition impacts are aligned in the Disorderly and Orderly scenario variants.

Figure 6-7 Consumption: transition impacts in the Paris Orderly Transition Scenario



Source: Cambridge Econometrics own calculation, detailed table in the Appendix

Transition risks: labour market impacts

Focusing on employment impacts instead of GDP drivers, broadly similar economy-wide and sectoral trends emerge. The Paris Transition scenario has higher employment rate for the 2020 to 2050 period than the Failed Transition scenario. The number of employees is higher by 0.5% by 2050, while the number of unemployed is lower by 8% at the same time leaving the participation rate mostly unchanged. The spikes in employment growth are often related to capacity building in the power sector, for instance to the retirement of the existing Paks nuclear blocks and quick renewable capacity building to meet high electricity demand.

Sectoral employment dynamics are strongly correlated with sectoral output changes. The highest growth can be observed in sectors covering the infrastructure needs of the low carbon economy (e.g., construction, metals, and electronics). High employment gains are also observed in the wholesale and retail, consumer good, agriculture and food production sectors which serve the higher consumer demand.

Large scale capital investment into the power, transport and the agriculture sector increase the productivity of the economy. Such investments also make the economy less labour and more capital intensive.

7 Conclusion

This project funded by the Hungarian National Bank aimed at determining both the physical impacts of climate change, the locked-in physical impacts of our past polluting activity, even if we now embark on a decarbonisation pathway, as well as those future physical impacts should we decide not to take a more ambitious approach to reducing our emissions. Cambridge Econometrics' scenario approach is suitable to analyse what would happen if global policymakers do indeed take on more aggressive targets and more ambitious policies to get us on a cleaner pathway, we can quantify what are the so-called transition risks entailed in such a transition scenario. We have also assessed the impacts of physical changes of a scenario where no further action is taken.

Developing climate-scenarios and building a climate-risk stress testing framework is the recommended tool by the Network for Greening the Financial System. For capturing the full impact of global climate action, a macro model is needed with global coverage and sufficient sectoral and fuel use detail to capture the impact of policies. The E3ME model is designed for analysing how macro-economic variables evolve under different climate-scenarios and decarbonisation policies. Modelling results can help the better understanding of portfolio exposure to climate risks and informed decision making for the financial sector.

This final report of the project described the steps of undertaking such analysis with Cambridge Econometrics' E3ME model – in line with the recommendations of NGFS. We have undertaken this analysis globally, but assumptions were customised with a special focus on the Hungarian economy. Results were also focused on Hungary: with the E3ME model we have analysed the economic output of the whole economy, the labour market impacts, and emissions. We also looked at how different sectors in Hungary are expected to be affected by the low-carbon transition.

This paper describes a Failed Transition Scenario assuming the continuation of current policies (those already implemented or announced) and a decarbonisation scenario where the global temperature increase does not reach 2°C by 2100. This is called the Paris Transition scenario, as the implemented policies and the global warming pathway achieved is in line with the commitments of the Paris Agreement. The transition and physical risks in these pathways were compared to a 'climate uninformed baseline' scenario to account for the differences. Two variants of the Paris Transition were modelled which differ in the financial consequences of the climate risks, whether those risks are smoothly or abruptly priced in by markets.

Our modelling for the Hungarian economy reveals that the Paris Transition scenarios have overall positive impacts. Investment in the low-carbon infrastructure, growing incomes, employment and improving trade balance boost the GDP. The decarbonisation of the economy creates a demand for new infrastructure, which increases output and employment of the construction, metals, and electronics sectors. We observe a fleet change in the transport sector as internal combustion engine cars are replaced by hybrid and electronic vehicles, which keeps investment and trade high. In the long run, once the fleet is replaced demand for these cars falls. With the electrification of transport demand for fossil fuels declines, which improves Hungary's trade balance and drives an increase in consumer spending on other goods. Agriculture, food services and consumer goods benefit from higher household incomes and lower spending on manufactured fuels. Fossil fuel extraction and related sectors decline, being the only losers of the transition.

Focusing on the impacts of gradual physical risks my we find large losses in the Failed Transition scenario and moderate, locked-in physical risks in the Paris Transition scenarios. Physical risks have a negative impact on GDP by damaging economic productivity and positive inflationary impact due to the pressure on supply chains and increasing input prices. The substantial difference in the level of physical risks in the scenarios underlines the importance of mitigation policies.

Our methodology for quantifying climate-risks is a continuously improving approach, with several planned developments on the way. Physical risks are often categorised into gradual (slow onset) impacts and extreme weather events' impacts. Gradual impacts are modelled currently, while climate-related extreme weather events follow a separate methodology and input data (offered by our partner Ortec Finance). In the upcoming model update we are working on integrating a better treatment for gradual climate impacts in response to the updates in the literature and new, cutting-edge econometric techniques.

8 References

Burke, M, S. M. Hsiang, and E. Miguel. “Global non-linear effect of temperature on economic production.” *Nature* 527, no. 7577 (2015): 235.

Burke, M., and V. Tanutama. “Climatic Constraints on Aggregate Economic Output.” Stanford Working Paper No. 1044, 2019.

Burke, M., W. M. Davis, and N. S Diffenbaugh. “Large potential reduction in economic damages under UN mitigation targets.” *Nature* 557, no. 7706 (2018): 549.

Cambridge Econometrics. *Climate-related scenario analysis for the Hungarian Central Bank (forthcoming).* Working Paper, 2020.

Cambridge Econometrics. “E3ME Technical Manual v6.1.” 2019.

Commission, European. “The 2018 Ageing Report. Economic and Budgetary Projections for the EU Member States (2016-2070).” 2018.

Cuaresma, Jesús Crespo. “Income projections for climate change research: A framework based on human capital dynamics.” *Global Environmental Change* 42 (2017): 226-236.

Environment Agency. “Climate change agreements - Guidance.” Aug 2017.

European Commission. “A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.” 2018.

Hallegatte, S., J. C. Hourcade, and P. Dumas. “Why economic dynamics matter in assessing climate change damages : illustration on extreme events.” *Ecological Economics* 62, no. 2 (2007): 330-340.

HM Government. “A Green Future: Our 25 Year Plan to Improve the Environment.” 2018.

Hsiang, S., et al. “Estimating economic damage from climate change in the United States.” *Science* 356, no. 6345 (2017): 1362-1369.

IEA. “World Energy Outlook 2019.” 2019.

IMF. “World Economic Outlook (WEO), October 2019 Database.” 2019.

Innovációs és Technológiai Minisztérium. “Nemzeti Energia- és Klímaterv.” 2020.

Innovációs és Technológiai Minisztérium. “Nemzeti Energiastratégia 2030, kitekintéssel 2040-ig.” 2020.

IPCC, Intergovernmental Panel on Climate Change. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Edited by R.K. Pachauri and L.A. Meyer (eds.) Core Writing Team. Geneva: IPCC, 2014.

IPCC, Intergovernmental Panel on Climate Change. “Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to.” 2018.

Kahn, M. E., et al. “Long-term macroeconomic effects of climate change: A cross-country analysis.” 2019.

Knobloch, F., H. Pollitt, U. Chewpreecha, V. Daioglou, and J.-F. Mercure. “Simulating the deep decarbonisation of residential heating for limiting global warming to 1.5 °C.” *Energy Efficiency*, 2019: 521–550.

Le Quéré, C., and et al. “Global Carbon Budget 2017.” 2017. https://www.globalcarbonproject.org/global/images/carbonbudget/Infographic_Emissions2017.png.

Mercure, J.-F., A. Lam, S. Billington, and Pollitt. “Integrated assessment modelling as a positive science: private passenger road transport policies to meet a climate target well below 2 ∘C.” *Climatic Change*, 2018: 109–129.

Mercure, Jean-François. “FTT:Power : A global model of the power sector with induced technological change and natural resource depletion.” *Energy Policy* 48 (2012): 799-811.

Network for Greening the Financial System. “Guide for Supervisors Integrating climate-related and environmental risks into prudential supervision.” 2020.

Nordhaus, W. D., and A. Moffat. *A survey of global impacts of climate change: Replication, survey methods, and a statistical analysis.* National Bureau of Economic Research, 2017.

OECD. “The Economic Consequences of Climate Change, OECD Publishing.” 2015.

Ortec Finance. *Full recording and presentation of the Ortec Finance webinar on Predict Ability Ltd (PAL) - 19 March 2020.* 2019.

Riahi, K, and et al. “The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview.” *Global Environmental Change* 42 (2017): 153-168.

Task Force on Climate-related Financial Disclosures. “Recommendations of the Task Force on Climate-related Financial Disclosures.” 2017.

UNFCCC, United Nations Framework Convention on Climate Change. *What is the Paris Agreement?* 2015. https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement.

Zenghelis, D. *The Economics of Climate Change: The Stern Review.* HM Treasury, London., 2006.

Appendix: Detailed Sectoral impacts

The below tables hsow detailed sectoral impacts.

Sectoral investment impacts in the Paris Orderly Transition Scenario

Paris Transition Scenario % difference from Failed Transition Scenario Sectors	Investment		
	2030	2040	2050
Agriculture	1.5	3.8	3.3
Energy and extraction	1.7	3.1	2.7
Consumer Goods	1.7	3.5	2.5
Paper and Printing	1.5	2.8	0.1
Chemicals	1.3	2.3	1.5
Pharmaceuticals and plastics	2.0	4.2	6.7
Basic Metals	1.0	1.5	2.4
Metal Products	0.5	1.5	0.6
Electronics	0.8	1.4	0.8
Motor vehicles	0.5	0.6	0.5
Utilities	-3.2	3.4	-5.6
Construction	2.6	3.4	2.1
Wholesale and retail	1.5	1.5	1.9
Transport, logistics	0.8	1.1	1.2
Accommodation and food services	1.8	3.1	2.6
Information and communication	1.4	2.9	2.2
Financial and insurance	1.6	2.2	1.4
Real estate activities	3.0	3.8	3.1
Professional and scientific activities	1.4	0.9	1.8
Administrative and support services	1.4	2.4	2.3

Source: Cambridge Econometrics own calculation

Sectoral import impacts in the Paris Orderly Transition Scenario

Paris Transition Scenario % difference from Failed Transition Scenario Sectors	Imports		
	2030	2040	2050
Agriculture	2.4	8.1	7.6
Energy and extraction	-9.1	-1.7	-8.7
Consumer Goods	0.1	0.1	0.0
Paper and Printing	0.2	0.2	0.2
Chemicals	-4.6	-13.7	-16.9
Pharmaceuticals and plastics	0.2	0.2	0.1
Basic Metals	0.1	0.0	-0.3
Metal Products	1.0	1.4	0.4
Electronics	0.9	1.1	1.1
Motor vehicles	2.6	2.7	-1.3
Utilities	0.0	0.0	0.0
Construction	0.0	0.0	0.0
Wholesale and retail	0.0	0.0	0.0
Transport, logistics	0.0	0.0	0.0
Accommodation and food services	0.0	0.0	0.0
Information and communication	0.4	0.6	-0.3
Financial and insurance	0.1	0.3	0.8
Real estate activities	0.0	0.0	0.0
Professional and scientific activities	0.0	0.5	-0.2
Administrative and support services	0.4	0.7	-0.3

Source: Cambridge Econometrics own calculation

Sectoral export impacts in the Paris Orderly Transition Scenario

Paris Transition Scenario % difference from Failed Transition Scenario Sectors	Exports		
	2030	2040	2050
Agriculture	1.2	2.7	2.5
Energy and extraction	0.0	0.0	0.0
Consumer Goods	0.1	0.1	0.1
Paper and Printing	0.4	0.3	0.0
Chemicals	1.0	0.5	0.2
Pharmaceuticals and plastics	1.2	2.1	3.6
Basic Metals	0.3	0.2	-0.2
Metal Products	0.7	0.3	-0.2
Electronics	0.6	0.4	0.2
Motor vehicles	1.3	0.9	-1.2
Utilities	0.0	0.0	0.0
Construction	0.0	0.0	0.0
Wholesale and retail	0.0	0.0	0.0
Transport, logistics	0.0	0.0	-0.4
Accommodation and food services	0.0	0.0	0.0
Information and communication	0.1	0.1	0.0
Financial and insurance	0.5	1.8	1.3
Real estate activities	0.0	0.0	0.0
Professional and scientific activities	-0.4	-0.1	-1.8
Administrative and support services	0.3	0.6	-0.5
Public admin., education and health	0.0	0.0	0.0

Source: Cambridge Econometrics own calculation

Sectoral consumption impacts in the Paris Orderly Transition Scenario

Paris Transition Scenario % difference from Failed Transition Scenario Product categories	Consumption		
	2030	2040	2050
Food and non-alcoholic beverages	3.0	8.6	6.6
Alcoholic beverages and tobacco	2.2	5.3	2.0
Clothing and footwear	2.3	3.1	2.2
Housing and utilities	-0.2	0.0	1.4
Household appliances	3.9	9.1	2.8
Health	1.9	3.5	2.0
Transport	-13.9	-43.8	-51.4
Communication	2.4	3.6	2.4
Recreation and Culture	2.3	4.5	2.1
Education	1.4	2.3	-0.3
Restaurants and hotels	2.8	8.6	3.6
Other goods and services	2.0	2.7	0.6

Source: Cambridge Econometrics own calculation