This document is one of four non-technical summaries prepared in the context of an analysis of the multiples benefits of measures to improve energy efficiency. The document has been written by Cecilie Larsen, on the basis of a technical report entitled "The Macroeconomic Impacts Associated with Realising Energy Efficiency Improvements in the G20 Countries", prepared by Cambridge Econometrics, a research institution. All reports are available for download from http://www.unepdtu.org/

The macroeconomic Impacts Associated with Realising Energy Efficiency Improvements in G20 Countries

1. Introduction

This report summarises the key findings and methodology used in a study aimed at estimating the macroeconomic impacts associated with realising energy efficiency improvements in the G20 countries. The analysis, which was conducted using the E3ME macroeconomic model, relies on the results from two energy system models, TIAM-ECN and POLES.

The E3ME model is a global tool that links energy, environment and the economy together. One of the model's key features is its empirical foundation, with model relationships validated from past historical data. Although energy demand is endogenous in E3ME, for this project the equations have been fixed to allow detailed inputs from TIAM-ECN and POLES.

2. The E3ME Model

E3ME is a global Energy-Environment-Economy (E3) model in which behavioural relationships are estimated empirically. The structure of E3ME is based on the system of national accounts with further linkages to physical material consumption, energy use and environmental emissions, where the labour market is also covered in detail. The model consists of multiple sets of econometrically estimated equations, disaggregated by country and by sector.

The E3ME model covers 53 world regions, including explicit treatment of the G20 countries, except Saudi Arabia and South Africa.[1] The model includes 69 economic sectors, with a detailed disaggregation of the energy sector.

3. Methodology

To assess the macroeconomic impacts of energy efficiency policies, the study takes advantage of the following features of the E3ME model:

- Its non-equilibrium approach allows for the possibility that zero or negative-cost efficiency options can exist, and that they can draw on available labour and capital to boost overall production levels.
- The full integration of the economic national accounts, the energy system and emissions in E3ME allows for analysis of energy and climate policies in parallel, as well as taking into account rebound effects.
- Its modular approach allows for the incorporation of detailed inputs from external sources.
- The annual time profile of the model allows for an evaluation of the impacts in both the short and long runs, and the development of a profile over time.

[1] Estimates for Saudi Arabia and South Africa are obtained through proxy results from appropriate regions in the E3ME breakdown of the world.

3.1 Linking the E3ME top-down approach to bottom-up models

The approach in the E3ME model is top-down and econometric in nature, with energy demand determined by economic activity, relative prices and investment. This approach is suitable for policies (such as energy or carbon taxes) that entail price changes. However, a top-down approach is not suitable for estimating the macroeconomic impact of energy efficiency policies, where new technologies are developed as a result of policy. To overcome this problem, E3ME used detailed energy results from the two global engineering models, TIAM-ECN and POLES.

By combining top-down and bottom-up models, the strengths of all models are fully utilised: the detailed energy systems modelling features of TIAM-ECN and POLES, and E3ME's detailed economic analysis capabilities. Not least, all three models have a detailed regional coverage, enabling investigation of the impacts of energy efficiency in most of the G20 countries.

3.2 Scenarios and related assumptions

Carbon prices in each scenario are given in the scenario specification (Table 1). These prices are used in TIAM-ECN and POLES to stimulate the energy efficiency investment.[2] Carbon prices are not entered into the E3ME model as an additional carbon tax, since this would mean double counting the costs. There are therefore no carbon prices in the economic modelling, beyond those that are included in the baseline.

The E3ME model baseline matches that of the International Energy Agency's *World Energy Outlook* (current policies case) and includes announced policies up to 2012. However, for this study the model baseline has been set up to match the business-as-usual cases in TIAM-ECN and POLES.

Table 1: Scenario summary

Scenario	Descriptions
BAU	A business as usual case
CT40	A global carbon price of $40/tCO2 ($2005) from 2020 to 2050
CT70	A global carbon price of $70/tCO2 ($2005) from 2020 to 2050
CT100	A global carbon price of $100/tCO2($2005) from 2020 to 2050

In E3ME, the energy efficiency savings are set to match the TIAM-ECN and POLES results as closely as possible. The change in final energy demand from the two models is used as a guide for the level of energy efficiency savings in E3ME. These savings are then distributed among sectors and energy carriers.

Modelling inputs to E3ME include changes in energy demand by users and energy types, energy prices, power sector capacity and, most importantly, the necessary investment required in the electricity and non-electricity sectors. Further assumptions are made with regard to how these

[2] Recall that TIAM-ECN and POLES projections are fed into E3ME.

investments are funded. For electricity, it is assumed to be reflected in electricity prices. For industries it is added to their costs. Road transport investment is assumed to be made partially by adjustments in consumer spending patterns in passenger cars (two-thirds) and partially by the road transport industry through large commercial vehicles (the remaining third). Government is assumed to fund investment in the households and commercial sectors through revenue neutrality by adjusting income tax rates. The reader is referred to Appendix 1 for more information regarding assumptions and model input data.

In this analysis it is assumed that the amount of energy savings estimated in TIAM-ECN and POLES is fully taken up by end-users of energy. In reality, take up rates of energy efficiency programmes will vary.[3] For example, lack of access to credit or behavioural barriers can prevent users from taking up investment in energy efficiency, even in the case where it makes economic sense to do so.

3.3 Comparing TIAM and POLES model outputs

There are considerable differences between the inputs and results of the TIAM and POLES models, which affect the economic outcomes of the E3ME analysis (Appendix 1). Still, the two models do share some common ground. For instance, despite differences in the allocation of investment between the electricity and non-electricity sectors, both TIAM-ECN and POLES suggest a similar overall level of energy efficiency investment required in the scenarios. Moreover, in terms of energy results, both models produce similar outcomes in the scenarios.

4. Results

The main macroeconomic indicators are reported, namely gross domestic product and sectoral economic output, employment, income, household expenditures, trade and investment. Rebound effects to energy demand are also reported. These results are grouped in four categories: macroeconomic impacts, country specific impacts, sectoral impacts and rebound effects.

4.1Macroeconomic impacts

Table 2 provides a summary of the estimated global macroeconomic impacts of the scenarios, in both the TIAM-ECN and POLES cases. The results are presented as percentage differences from the baseline in 2030 and 2050.

[3] It follows that encouraging take up is a key issue for policy makers.

Table 2: World macroeconomic impacts in 2030 and 2050, percent difference from baseline

	TIAM-ECN inputs			POLES inputs		
2030	**CT40**	**CT70**	**CT40**	**CT70**	**CT40**	**CT70**
GDP	0.1	0.3	0.3	0.4	0.5	0.6
Consumer spending	-0.3	-0.6	-0.7	0.1	0.1	0.0
Investment	1.0	2.1	2.7	1.6	2.5	3.1
Imports	-0.2	-0.5	-0.4	0.3	0.4	0.4
Exports	0.0	-0.1	0.0	0.2	0.3	0.3
Employment	0.0	0.0	0.0	0.1	0.1	0.1
Real disposable income	-0.4	-0.7	-0.8	0.1	0.1	0.0
Consumer price	0.9	1.4	1.9	0.2	0.3	0.4
2050	**CT40**	**CT70**	**CT40**	**CT70**	**CT40**	**CT70**
GDP	0.2	0.5	0.7	0.4	0.6	0.7
Consumer spending	-0.2	-0.3	-0.4	0.0	-0.1	-0.3
Investment	1.4	2.9	3.7	2.3	3.5	4.5
Imports	0.0	0.1	0.1	0.3	0.4	0.5
Exports	0.1	0.4	0.3	0.2	0.3	0.3
Employment	0.0	-0.1	0.0	0.1	0.1	0.2
Real disposable income	-0.2	-0.2	-0.2	-0.1	-0.2	-0.3
Consumer price	0.7	0.7	0.9	0.4	0.5	0.6

Source(s): E3ME, Cambridge Econometrics.

Macroeconomic results in 2030 show a wider range of outcomes, reflecting differences in input assumptions between TIAM-ECN and POLES. The difference becomes much smaller by 2050.

4.1.1 Summary of TIAM results

The E3ME results using inputs from TIAM-ECN suggest positive GDP outcomes from the energy efficiency scenarios in all cases. The positive impacts on global GDP are driven by the additional investment in the scenarios. There are reductions in consumer demand in the scenarios due to falls in real disposable income, as many prices in the scenarios are higher. The higher price is a result of funding the additional energy efficiency investment through increased electricity prices and additional costs to industries.

There is almost no change in global employment. However, employment results vary a great deal between regions. For most regions the employment impacts are positive but employment falls in some regions where the domestic economy is affected by higher prices and trade relationships with the rest of the world.

4.1.2 Summary of POLES results

GDP impacts using the POLES inputs are also positive, and slightly more positive than the GDP results derived from TIAM-ECN inputs. The POLES model suggests slightly higher total levels of energy efficiency investment required in the scenarios:

- In POLES, the additional investment required in the electricity sector is small in all scenarios, resulting in a smaller increase in electricity prices, compared with the equivalent estimate from TIAM-ECN. In contrast, industry faces higher costs on the account of the investments they must make. Overall the results suggest higher price impacts in TIAM-ECN than in POLES.
- Additional residential and commercial investments in POLES are much larger than in TIAM-ECN. The implication of our assumptions (that government pays for residential and commercial investment, and that the scenarios are revenue neutral) is that, in the case of POLES, income taxes must be increased to fund the additional government spending. In TIAM-ECN, however, the government has additional revenues to reduce income taxes, compared to the baseline. Income taxes affect real disposable income directly and this can be seen in the E3ME results.

4.2 Country specific impacts for G20 countries

The results by region vary significantly depending on the assumptions concerning where the energy efficiency investment takes place, both in term of sectors and regions, as well as the actual level of investment. Stated differently, the differences between the TIAM-ECN and POLES scenarios can be explained by where and when these investments are assumed to take place in the economy.

Positive global gross domestic product outcomes can be expected in the energy efficiency scenarios. The positive outcomes are driven mainly by investment in the scenarios, which stimulates the economy despite higher electricity prices, costs or taxes that have to be paid to fund the investment.

Economic results for each G20 country vary depending on country-specific factors, including additional investments and changes in prices in that particular country. Since inputs are non-uniform, some countries benefit from additional investment more than others, while some lose out from competitiveness and price effects.

Net changes in total employment at the global level are very small. However, employment results at country and sector level vary more substantially. While traditional jobs in fossil fuel production fall, they are compensated by increases in employment demand in the construction and machinery sectors that benefit from these additional energy efficiency investments.

Table 3 gives expected changes in gross domestic product by G20 country, whereas Table 4 gives employment results by G20 country. Appendix 2 provides results for the specific components of GDP in each G20 region: consumer spending, investment, exports and imports.

Table 3: GDP results for 2030 and 2050 presented as percent difference from baseline

	TIAM-ECN inputs			POLES inputs		
	ct40	ct70	ct100	ct70	ct40	ct100
2030						
European Union	0.1	0.2	0.3	0.4	0.5	0.7
Germany	-0.1	0.0	-0.1	0.4	0.5	0.5
France	0.2	0.3	0.4	0.4	0.7	0.8
Italy	0.1	0.1	0.3	0.2	0.3	0.4
United Kingdom	0.1	0.1	0.1	0.1	0.2	0.3
Turkey	0.0	0.1	0.2	0.3	0.5	0.7
United States	0.3	0.1	0.2	0.3	0.5	0.6
Japan	0.0	-0.2	-0.2	0.4	0.7	0.9
Canada	0.0	0.0	-0.2	0.3	0.4	0.5
Australia	0.5	0.5	0.4	0.3	0.5	0.6
Russia	-0.7	-0.9	-0.8	0.2	0.2	0.2
China	0.5	1.6	1.6	0.8	1.2	1.2
India	0.8	1.6	1.7	0.2	0.4	0.4
Brazil	0.2	1.3	1.5	0.4	0.7	1.0
Mexico	-0.4	-1.5	-1.9	0.3	0.5	0.6
Argentina	-0.4	-0.5	-0.4	0.3	0.5	0.7
Republic of Korea	0.1	0.3	0.9	0.3	0.5	0.6
Indonesia	-0.4	-0.2	0.1	0.1	0.5	0.7
Proxy for Saudi Arabia	-1.4	-1.9	-2.3	0.2	0.2	0.0
Proxy for South Africa	-0.8	-1.3	-1.5	-0.3	-0.5	-0.6
2050						
European Union	0.3	0.5	0.7	0.6	0.8	1.0
Germany	0.1	0.3	0.5	0.4	0.5	0.5
France	0.4	0.7	0.9	0.7	0.9	1.1
Italy	0.2	0.5	0.7	0.3	0.4	0.5
United Kingdom	0.3	0.2	0.3	0.3	0.4	0.4
Turkey	0.0	0.2	0.4	0.6	1.0	1.3
United States	0.4	0.5	0.6	0.4	0.6	0.7
Japan	0.2	-0.1	-0.2	0.7	0.9	1.1
Canada	-0.2	-0.2	-0.2	0.4	0.6	0.7
Australia	0.4	0.6	0.1	0.3	0.4	0.5
Russia	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6
China	0.5	1.8	1.8	0.4	0.6	0.9
India	0.0	0.6	1.8	0.9	0.9	1.1
Brazil	0.9	1.0	0.8	0.3	0.6	0.9
Mexico	-0.1	-0.3	0.3	0.1	0.2	0.3
Argentina	-0.4	-0.2	0.0	0.3	0.4	0.6
Republic of Korea	0.4	0.7	0.7	0.4	0.7	1.0
Indonesia	2.4	3.7	3.8	-0.5	0.0	0.4
Proxy for Saudi Arabia	-0.9	-1.0	-1.1	0.4	0.4	0.2
Proxy for South Africa	-0.8	-1.5	-1.9	-0.1	-0.2	-0.3

Source(s): E3ME, Cambridge Econometrics.

Table 4: Employment results for 2030 and 2050 presented as percent difference from baseline

	TIAM-ECN inputs			POLES inputs		
	ct40	ct70	ct100	ct70	ct40	ct100
2030						
European Union	0.1	0.1	0.2	0.2	0.2	0.3
Germany	0.0	0.0	0.1	0.2	0.2	0.3
France	0.1	0.2	0.3	0.4	0.5	0.6
Italy	0.1	0.1	0.2	0.2	0.2	0.3
United Kingdom	0.0	-0.1	0.0	0.1	0.1	0.1
Turkey	0.2	0.2	0.3	0.2	0.3	0.5
United States	0.1	0.0	0.0	0.1	0.1	0.1
Japan	-0.1	-0.1	-0.1	0.0	0.1	0.1
Canada	-0.1	-0.1	-0.2	0.0	0.0	0.0
Australia	-0.1	-0.1	0.0	0.0	0.1	0.1
Russia	0.0	0.0	0.0	0.1	0.1	0.1
China	0.0	0.0	0.1	0.0	0.0	0.0
India	0.1	0.1	0.1	0.1	0.2	0.2
Brazil	0.0	0.3	0.3	0.1	0.3	0.4
Mexico	0.1	-0.3	-0.3	0.1	0.2	0.2
Argentina	-0.2	-0.2	0.0	0.3	0.6	0.7
Republic of Korea	0.0	0.1	0.2	0.1	0.1	0.1
Indonesia	0.2	0.2	0.4	-0.2	0.0	0.1
Proxy for Saudi Arabia	-0.2	-0.4	-0.5	0.2	0.4	0.5
Proxy for South Africa	-0.3	-0.5	-0.5	0.0	0.0	0.0
2050						
European Union	0.2	0.2	0.2	0.4	0.5	0.5
Germany	0.0	0.0	0.0	0.4	0.4	0.5
France	0.3	0.5	0.7	1.0	1.2	1.4
Italy	0.1	0.3	0.4	0.3	0.4	0.5
United Kingdom	-0.1	-0.2	-0.2	0.1	0.1	0.1
Turkey	0.1	0.2	0.5	0.6	1.2	1.6
United States	0.0	0.1	0.1	0.0	0.0	0.0
Japan	-0.1	-0.1	-0.3	0.2	0.2	0.3
Canada	-0.2	-0.2	-0.2	0.0	0.0	0.0
Australia	0.0	0.0	0.1	0.1	0.1	0.2
Russia	0.1	0.0	0.1	0.1	0.1	0.2
China	0.0	0.1	0.1	0.0	0.0	0.0
India	-0.1	-0.1	0.0	-0.1	-0.1	0.0
Brazil	0.0	0.0	-0.1	0.1	0.4	0.6
Mexico	-0.1	-0.3	0.1	0.1	0.2	0.2
Argentina	-0.2	-0.1	0.1	0.6	0.9	1.2
Republic of Korea	0.2	0.3	0.3	0.1	0.1	0.2
Indonesia	0.6	0.6	0.8	-0.4	-0.2	0.0
Proxy for Saudi Arabia	0.0	-0.1	-0.2	0.3	0.5	0.5
Proxy for South Africa	-0.5	-0.6	-0.7	0.1	0.2	0.3

Source(s): E3ME, Cambridge Econometrics.

4.3 Sector specific impacts

Table 5 summarises the impacts on global output by broad sector. The biggest reductions in output come from traditional mining, fossil fuels and utilities. Most of the output gains are in construction and manufacturing, which are the sectors that are expected to benefit most from the additional energy efficiency investment.

Table 5: World output by broad sector in 2030 and 2050 presented as percent difference from baseline

	TIAM-ECN inputs			POLES inputs		
	ct40	ct70	ct100	ct70	ct40	ct100
2030						
Agriculture	-0.1	-0.1	-0.1	0.0	0.1	0.1
Mining and utilities	-1.2	-2.2	-2.9	-0.3	-0.6	-1.0
Manufacturing	0.2	0.5	0.8	0.7	1.0	1.2
Construction	0.0	0.2	0.3	0.6	1.0	1.3
Distribution and retail	-0.2	-0.5	-0.6	0.2	0.4	0.4
Transport and warehousing	0.0	0.0	0.0	0.2	0.3	0.3
Hotels and catering	0.1	0.3	0.3	0.2	0.3	0.3
Communications and computing	0.1	0.2	0.3	0.4	0.6	0.7
Banking and business sectors	0.2	0.3	0.4	0.2	0.4	0.5
Real estate and other business services	0.1	0.1	0.1	0.2	0.3	0.4
Public administration	0.0	0.0	0.0	0.1	0.1	0.1
Miscellaneous	0.0	0.1	0.2	0.1	0.2	0.2
Total	0.0	0.0	0.1	0.3	0.5	0.6
2050						
Agriculture	0.1	0.2	0.3	0.0	0.1	0.1
Mining and utilities	-1.0	-2.2	-2.6	-0.4	-0.7	-0.9
Manufacturing	0.8	1.5	1.7	0.6	0.9	1.2
Construction	0.2	0.5	0.7	1.5	2.3	3.0
Distribution and retail	0.1	0.2	0.3	0.2	0.4	0.5
Transport and warehousing	0.1	0.2	0.3	0.1	0.2	0.3
Hotels and catering	0.1	0.2	0.3	0.0	0.1	0.2
Communications and computing	0.3	0.6	0.9	0.5	0.7	0.9
Banking and business sectors	0.3	0.5	0.6	0.2	0.3	0.4
Real estate and other business services	0.1	0.1	0.1	0.2	0.3	0.4
Public administration	0.0	0.0	0.0	0.0	0.0	0.1
Miscellaneous	0.1	0.2	0.3	0.1	0.1	0.2
Total	0.2	0.4	0.5	0.3	0.5	0.6

Source(s): E3ME, Cambridge Econometrics.

Table 6 summarises the global employment impacts by broad sector. Employment results follow those for sectoral output, with reductions coming from mining, fossil fuels and utilities, and employment gains in the construction and manufacturing sectors.

Table 6: World employment by broad sector in 2030 and 2050 presented as percent difference from baseline

	TIAM-ECN inputs			POLES inputs		
	ct40	ct70	ct100	ct70	ct40	ct100
2030						
Agriculture	-0.1	-0.1	-0.1	0.0	0.0	0.0
Mining and utilities	-2.5	-4.3	-4.5	-0.3	-0.4	-0.4
Manufacturing	0.1	0.1	0.2	0.2	0.3	0.4
Construction	0.1	0.2	0.3	0.2	0.3	0.4
Distribution and retail	0.0	-0.1	-0.2	0.0	0.1	0.1
Transport and warehousing	0.1	0.2	0.3	0.1	0.2	0.2
Hotels and catering	0.0	0.2	0.3	0.1	0.3	0.3
Communications and computing	0.0	0.1	0.2	0.0	0.1	0.2
Banking and business sectors	0.0	0.0	0.0	0.1	0.2	0.2
Real estate and other business services	0.0	0.0	0.0	0.1	0.2	0.2
Public administration	0.0	0.0	0.0	0.0	0.0	0.0
Miscellaneous	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.1	0.1	0.1
2050						
Agriculture	-0.1	-0.1	-0.1	0.0	0.0	0.1
Mining and utilities	-6.2	-10.4	-10.9	-1.0	-2.0	-1.4
Manufacturing	0.3	0.5	0.7	0.3	0.5	0.6
Construction	0.0	-0.1	0.0	0.4	0.8	1.0
Distribution and retail	0.1	0.2	0.3	0.0	0.0	0.1
Transport and warehousing	-0.1	-0.1	0.0	-0.1	-0.1	0.0
Hotels and catering	0.0	0.2	0.4	-0.3	-0.1	0.1
Communications and computing	0.0	0.1	0.2	0.1	0.1	0.2
Banking and business sectors	0.2	0.1	0.0	0.1	0.1	0.1
Real estate and other business services	0.0	-0.1	0.0	0.1	0.2	0.2
Public administration	0.0	-0.1	-0.1	0.0	0.0	0.0
Miscellaneous	0.0	0.0	0.0	0.0	0.0	0.1
Total	0.0	-0.1	0.0	0.1	0.1	0.2

Source(s): E3ME, Cambridge Econometrics.

4.4 Additional energy demand (rebound effects)

Rebound effects are estimated from the changes in economic activity resulting from the energy efficiency policies in the scenarios. These changes in economic activity rates include scale, composition and some technique effects. Because of this, one should not expect to see a one-to-one relationship between increases in economic output and rebounds in energy demand.

In estimating the rebound effects we have not carried out a whole new set of model scenarios. Instead we have used E3ME's estimated activity demand elasticities to estimate the impacts of higher rates of economic production on energy demand.

Table 7 provides estimates in absolute terms of the rebound effects.

Table 7: Total rebound in final energy demand (excluding non-energy uses) in G20 countries (excluding Saudi Arabia and South Africa), m toe

	TIAM-ECN inputs			POLES inputs		
	ct40	ct70	ct100	ct70	ct40	ct100
2030						
European Union	-0.3	0.6	1.8	2.2	3.0	3.7
Germany	-0.3	-0.4	-0.4	0.2	0.3	0.4
France	0.2	0.3	0.6	0.4	0.5	0.6
Italy	0.2	0.3	0.8	0.3	0.4	0.5
United Kingdom	-0.1	0.0	0.2	0.2	0.2	0.3
Turkey	0.1	0.1	0.1	0.4	0.7	0.9
United States	4.7	3.9	4.1	3.5	5.1	6.1
Japan	-0.8	-1.6	-1.7	0.2	0.4	0.6
Canada	-0.1	0.1	-0.1	0.1	0.2	0.2
Australia	0.3	0.3	0.2	0.2	0.3	0.3
Russia	-0.5	0.2	0.6	0.6	0.9	1.1
China	4.1	5.6	6.2	6.4	12.4	14.7
India	-0.6	0.1	0.6	4.2	4.2	3.4
Brazil	0.1	1.2	1.6	0.5	1.0	1.4
Mexico	-0.5	-2.6	-3.2	0.5	0.8	0.9
Argentina	0.0	0.0	0.0	0.0	0.1	0.1
Republic of Korea	0.3	0.8	1.8	0.5	0.7	0.9
Indonesia	-0.1	0.1	0.4	-0.2	0.3	0.6
2050						
European Union	1.3	4.3	6.0	3.4	4.4	5.2
Germany	-0.2	0.0	0.3	0.3	0.3	0.4
France	0.3	0.6	0.9	1.1	1.4	1.6
Italy	0.6	1.4	1.7	0.3	0.5	0.6
United Kingdom	0.0	0.1	0.2	0.1	0.2	0.2
Turkey	0.1	0.4	0.5	1.6	2.7	3.4
United States	6.8	9.6	12.6	3.4	4.6	5.7
Japan	-0.4	-1.1	-1.8	0.7	0.8	1.0
Canada	-0.1	-0.1	-0.1	0.3	0.4	0.6
Australia	-0.3	4.6	4.4	3.2	2.5	15.0
Russia	0.9	3.2	5.8	1.0	1.2	1.4
China	16.0	22.8	24.6	11.0	16.8	19.7
India	-4.2	2.9	8.2	36.4	28.9	20.6
Brazil	0.9	1.9	-0.1	0.4	1.4	2.4
Mexico	-0.7	-2.0	1.1	0.5	0.9	1.2
Argentina	0.0	0.0	0.2	0.0	0.0	0.0
Republic of Korea	1.0	1.7	2.0	0.6	1.0	1.3
Indonesia	1.1	1.8	2.0	-1.6	-0.6	0.2

Source(s): E3ME, Cambridge Econometrics.

5. Limitations of the analysis

The TIAM-ECN and POLES models have cost-optimisation assumptions, where the outcome of the scenarios represents an optimal outcome of a policy. In contrast, the E3ME macroeconomic model is a simulation-based econometric model with no prior assumption on optimisation or economic equilibrium. Nonetheless, this inconsistency in the energy and economic model properties does not represent a major disadvantage in this analysis, since a 'soft link' approach is taken, where outputs of the energy models are used as inputs to the economic model.

Additional problems arise with the estimation of employment impacts. The E3ME model allows for the possibility of spare economic capacity to exist in each country modelled. For example, the

baseline labour market projections include unemployed workers that could be moved into employment under the right economic conditions. However, due to restrictions in the availability of data, the model also assumes that, as long as there are people available to work, they can take on new jobs, regardless of the skills required.

Moreover, the development of new technologies often results in new emerging niche sectors that do not fit well to existing economic sectors. The model results represent average outcomes of each sector, but may conceal larger movements within the sectors, related to either new or existing technologies.

Finally, past relationships may not be an appropriate guide for assessing changes under different policy conditions. Nonetheless, it is argued that the E3ME approach provides a realistic estimate of future responses to policies that cannot be verified.

Appendix 1: Input data from TIAM and POLES

Table 8 and 9 summarises the key E3ME inputs from TIAM-ECN and POLES.

Table 8: Comparison of TIAM and POLES inputs to E3ME

World additional electricity investment to the baseline ($2005bn)				
	2020	2030	2040	2050
TIAM-ECN_40	48.3	189.0	327.0	377.5
POLES_40	102.6	144.1	124.0	148.3
TIAM-ECN _70	130.3	382.3	594.6	775.9
POLES_70	131.6	207.1	140.4	162.5
TIAM-ECN _100	165.1	468.3	725.1	955.1
POLES_100	160.0	209.2	153.0	171.5
World additional non-electricity investment to the baseline ($2005bn)				
	2020	2030	2040	2050
TIAM-ECN _40	15.5	-25.6	18.8	133.8
POLES_40	23.4	165.4	423.8	572.3
TIAM-ECN _70	27.2	-46.3	19.4	138.2
POLES_70	33.8	274.6	710.9	921.8
TIAM-ECN _100	35.8	-6.0	170.6	216.2
POLES_100	43.3	386.1	987.5	1237.6
World electricity price (% difference from baseline)				
	2020	2030	2040	2050
TIAM-ECN _40	14.5	35.9	34.2	26.8
POLES_40	7.0	14.9	15.0	14.0
TIAM-ECN _70	21.5	60.1	55.1	40.2
POLES_70	12.3	22.5	21.8	20.5
TIAM-ECN _100	28.3	75.2	65.4	50.6
POLES_100	17.2	28.7	27.3	26.0
Source(s): TIAM-ECN (ECN) and POLES (Enerdata).				

Table 9: Comparison of TIAM and POLES energy inputs to E3ME

World final energy demand (% difference from baseline)				
	2020	2030	2040	2050
TIAM-ECN_40	-2.0	-3.1	-3.4	-4.6
POLES_40	-1.2	-4.8	-5.6	-5.3
TIAM-ECN _70	-2.7	-5.6	-6.3	-7.2
POLES_70	-2.2	-7.9	-8.9	-8.6
TIAM-ECN _100	-3.9	-7.3	-8.5	-9.5
POLES_100	-3.1	-10.4	-11.5	-11.3
World secondary energy demand – electricity (% difference from baseline)				
	2020	2030	2040	2050
TIAM-ECN _40	-3.2	-8.9	-5.9	-5.8
POLES_40	-0.6	-3.0	-4.1	-4.6
TIAM-ECN _70	-3.9	-11.1	-8.4	-8.6
POLES_70	-1.0	-4.4	-5.5	-6.0
TIAM-ECN _100	-4.4	-12.4	-9.3	-9.4
POLES_100	-1.3	-5.5	-6.5	-7.1
Source(s): TIAM (ECN) and POLES (Enerdata).				

There are noticeable differences between the two models' results, which affect the economic outcomes from E3ME. Specifically, the following differences are observed:

- The differences in investment levels are partly explained by how investment is defined in the models. In TIAM-ECN, investments are reported as annuities, which include a technology-specific discount rate, while in POLES no foresight modelling is included. Therefore, POLES primary outputs provide economic indications on a yearly basis and not for a given time period.
- TIAM-ECN suggests higher additional investment in the electricity sector compared to non-electricity investment. POLES, in contrast, suggests lower electricity investment is required than non-electricity investment. Again this is partly due to how investment is calculated in the two models.
- Electricity prices increase more markedly in TIAM-ECN than in POLES, which partly reflects differences in assumptions about electricity investment.
- The results for other energy prices (coal, oil and gas) are also available from TIAM-ECN and POLES. However, the two models have different definitions for other energy price variables. POLES reports these prices as final consumer prices (which includes carbon taxes), while TIAM-ECN presents them as raw commodity prices. As a result, the two set of energy price results are not comparable. E3ME requires a set of raw energy prices; however, since the results from TIAM-ECN suggest that the changes in the scenarios are relatively small we have decided to exclude these price variables, to avoid biased economic outcomes.

Appendix 2: Results by G20 Country – Components of GDP

Tables 10 to 13 provide results for the components of GDP in each G20 country: consumer spending, investment, exports and imports.

Table 10: Consumer spending results for 2030 and 2050 presented as percent of difference from baseline

	TIAM-ECN inputs			POLES inputs		
	ct40	ct70	ct100	ct70	ct40	ct100
2030						
European Union	-0.3	-0.4	-0.6	0.1	0.0	0.0
Germany	-0.5	-0.7	-1.1	0.0	0.0	0.0
France	0.0	0.0	0.1	0.4	0.4	0.5
Italy	-0.2	-0.3	-0.5	0.0	0.0	-0.1
United Kingdom	-0.2	-0.3	-0.3	0.0	0.0	0.0
Turkey	-0.2	-0.2	-0.4	0.0	0.1	0.1
United States	-0.2	-0.7	-0.7	0.2	0.3	0.3
Japan	-0.5	-1.0	-1.1	-0.1	-0.2	-0.2
Canada	-0.6	-0.7	-1.2	0.0	0.0	0.0
Australia	-0.1	-0.7	-0.9	0.1	0.1	0.1
Russia	0.4	0.5	0.8	0.4	0.5	0.6
China	0.5	1.2	1.4	0.4	0.5	0.5
India	-0.4	-0.3	-0.3	0.4	0.3	0.1
Brazil	-0.1	0.1	0.0	0.1	0.3	0.5
Mexico	-1.0	-2.3	-2.9	-0.1	-0.2	-0.3
Argentina	-0.2	-0.6	-0.7	-0.2	-0.4	-0.5
Republic of Korea	-0.1	-0.2	-0.2	-0.1	-0.1	-0.1
Indonesia	-0.8	-1.1	-1.1	-1.4	-1.1	-0.9
Proxy for Saudi Arabia	-1.1	-1.7	-2.1	0.4	0.3	-0.1
Proxy for South Africa	-1.3	-2.3	-2.9	-0.8	-1.1	-1.4

2050						
European Union	-0.2	-0.2	-0.2	-0.1	-0.2	-0.3
Germany	-0.5	-0.5	-0.3	-0.2	-0.3	-0.4
France	0.0	0.1	0.1	1.0	1.3	1.4
Italy	-0.1	-0.1	-0.2	-0.2	-0.4	-0.5
United Kingdom	-0.3	-0.5	-0.6	-0.2	-0.3	-0.4
Turkey	-0.4	-0.1	-0.1	0.4	0.7	1.0
United States	0.2	0.3	0.4	0.1	0.0	0.0
Japan	-0.4	-0.8	-1.3	-0.1	-0.2	-0.2
Canada	-0.7	-0.8	-1.0	-0.1	-0.1	-0.1
Australia	-0.1	0.2	0.0	0.0	-0.1	-0.1
Russia	0.5	0.0	0.0	0.3	0.3	0.4
China	0.7	1.8	2.1	-0.1	-0.3	-0.7
India	-0.5	-0.2	0.0	1.5	1.3	0.9
Brazil	-0.2	-0.4	-0.7	-0.3	0.1	0.4
Mexico	-0.7	-1.1	-0.5	-0.3	-0.4	-0.6
Argentina	-0.4	-0.6	-0.7	-1.0	-1.7	-2.2
Republic of Korea	0.0	-0.4	-0.5	-0.1	-0.2	-0.3
Indonesia	0.1	0.2	0.3	-3.8	-3.3	-2.7
Proxy for Saudi Arabia	-1.1	-2.2	-2.1	0.7	0.6	-0.2
Proxy for South Africa	-2.0	-4.3	-5.1	-0.7	-1.0	-1.3

Source(s): E3ME, Cambridge Econometrics.

Table 11: Investment results for 2030 and 2050 presented as percent difference from baseline

	TIAM-ECN inputs			POLES inputs		
	ct40	ct70	ct100	ct70	ct40	ct100
2030						
European Union	0.3	1.0	1.8	1.7	2.4	3.1
Germany	0.1	0.3	0.5	1.3	1.8	2.2
France	0.1	0.5	1.3	1.4	1.9	2.4
Italy	0.4	1.1	2.4	1.0	1.4	2.0
United Kingdom	0.0	0.2	0.9	1.2	1.7	2.1
Turkey	0.8	0.7	1.4	1.2	2.0	2.8
United States	3.0	3.5	3.8	1.2	2.0	2.6
Japan	0.2	0.6	0.8	0.6	1.2	1.8
Canada	0.4	0.8	0.9	1.0	1.5	1.9
Australia	2.1	3.4	4.0	1.1	1.7	2.0
Russia	-2.4	-0.9	-0.5	2.5	3.8	5.0
China	1.4	4.2	4.2	2.9	4.4	4.6
India	0.8	2.4	2.6	0.5	1.1	1.1
Brazil	0.9	5.2	6.7	1.8	2.7	3.6
Mexico	2.1	1.1	1.8	2.3	3.6	4.7
Argentina	-1.5	-0.8	0.3	2.7	4.2	5.7
Republic of Korea	0.2	1.0	3.9	1.0	1.4	1.7
Indonesia	0.1	1.6	3.3	3.1	4.5	5.7
Proxy for Saudi Arabia	-0.2	1.2	1.1	2.2	3.5	4.9
Proxy for South Africa	-0.9	-0.9	-0.3	0.0	0.3	0.2

2050						
European Union	0.8	2.1	2.9	3.2	4.6	5.7
Germany	0.0	0.3	0.6	2.3	3.1	3.6
France	0.5	2.0	3.3	2.8	3.9	4.7
Italy	0.9	2.4	3.1	1.5	2.5	3.2
United Kingdom	0.1	0.7	1.3	1.9	2.7	3.3
Turkey	0.6	1.2	2.0	2.4	4.3	5.7
United States	1.6	1.9	2.4	2.3	3.7	4.6
Japan	0.6	0.7	0.8	1.8	2.4	2.9
Canada	0.9	0.7	1.1	2.3	3.6	4.7
Australia	1.7	1.8	2.3	1.8	2.5	3.0
Russia	1.3	3.3	4.7	4.1	5.8	7.0
China	2.3	5.1	5.2	1.9	2.9	4.2
India	-0.2	2.2	4.5	2.5	2.7	3.8
Brazil	1.8	3.4	2.0	2.1	3.3	4.3
Mexico	1.8	1.7	3.8	1.9	3.5	4.7
Argentina	-0.8	1.3	4.3	4.2	6.8	9.0
Republic of Korea	1.9	3.1	3.6	2.0	3.3	4.3
Indonesia	8.8	13.6	14.6	2.6	4.1	5.3
Proxy for Saudi Arabia	-0.4	0.6	4.4	2.8	4.3	5.5
Proxy for South Africa	0.2	1.0	1.3	0.2	0.3	0.4
Source(s): E3ME, Cambridge Econometrics.						

Table 12: Exports results for 2030 and 2050 presented as percent difference from baseline

	TIAM-ECN inputs			POLES inputs		
	ct40	ct70	ct100	ct70	ct40	ct100
2030						
European Union	0.2	0.2	0.2	0.3	0.4	0.5
Germany	0.4	0.5	0.6	0.4	0.6	0.7
France	0.2	0.2	0.2	0.4	0.5	0.6
Italy	0.1	0.1	0.2	0.4	0.6	0.6
United Kingdom	0.2	-0.1	-0.1	0.1	0.2	0.2
Turkey	0.0	0.0	0.2	0.7	1.0	1.2
United States	0.4	0.6	0.7	0.4	0.6	0.7
Japan	0.4	0.5	0.7	0.4	0.7	0.9
Canada	0.6	0.8	0.9	0.3	0.5	0.6
Australia	0.1	0.1	0.2	0.1	0.1	0.2
Russia	-2.3	-4.1	-4.8	-1.6	-2.5	-3.6
China	0.3	0.4	0.5	0.3	0.4	0.5
India	-0.4	-1.2	-1.4	-0.4	-0.6	-0.9
Brazil	0.3	0.5	0.7	0.2	0.3	0.4
Mexico	0.8	0.8	0.9	0.3	0.5	0.6
Argentina	0.0	-0.1	0.0	0.1	0.2	0.2
Republic of Korea	0.1	0.2	0.2	0.2	0.2	0.2
Indonesia	-0.1	-0.3	-0.2	0.0	-0.1	-0.1
Proxy for Saudi Arabia	-3.3	-5.5	-6.2	-0.8	-1.5	-2.2
Proxy for South Africa	0.0	0.0	0.1	0.3	0.4	0.5

2050						
European Union	0.2	0.3	0.5	0.3	0.4	0.4
Germany	0.2	0.4	0.7	0.4	0.5	0.5
France	0.1	0.3	0.6	0.2	0.2	0.1
Italy	0.3	0.6	0.9	0.3	0.3	0.4
United Kingdom	0.1	0.0	0.0	0.0	0.0	-0.1
Turkey	0.2	0.5	0.9	0.9	1.3	1.7
United States	0.6	0.8	0.9	0.6	0.9	1.1
Japan	0.4	0.7	1.1	0.6	0.9	1.1
Canada	0.4	0.7	0.9	0.4	0.5	0.6
Australia	0.2	0.4	0.5	0.0	0.0	0.1
Russia	-2.5	-2.5	-4.2	-4.3	-5.9	-7.1
China	0.5	0.9	1.1	0.4	0.5	0.7
India	-0.4	-0.6	-1.0	-0.5	-0.8	-1.0
Brazil	0.2	0.6	0.8	0.4	0.5	0.7
Mexico	0.4	0.4	0.5	0.5	0.6	0.8
Argentina	0.1	0.1	0.1	0.2	0.4	0.5
Republic of Korea	0.2	0.4	0.3	0.1	0.2	0.3
Indonesia	0.2	0.2	0.2	0.0	0.0	0.0
Proxy for Saudi Arabia	-1.9	-2.4	-4.9	-0.7	-1.5	-2.2
Proxy for South Africa	0.1	0.4	0.4	0.3	0.4	0.5
Source(s): E3ME, Cambridge Econometrics.						

Table 13: Imports results for 2030 and 2050 presented as percent difference from baseline

	TIAM-ECN inputs			POLES inputs		
	ct40	ct70	ct100	ct70	ct40	ct100
2030						
European Union	-0.5	-0.5	-0.1	0.4	0.6	0.8
Germany	-0.2	-0.4	-0.3	0.5	0.8	1.1
France	-1.0	-1.3	-0.8	-1.2	-1.5	-1.6
Italy	-0.2	-0.1	0.5	0.8	1.0	1.3
United Kingdom	-1.0	-1.4	-0.8	0.5	0.6	0.7
Turkey	0.0	-0.1	0.0	0.5	0.8	1.1
United States	0.9	0.6	0.4	0.5	0.6	0.6
Japan	-0.5	-0.5	-0.6	-0.6	-0.9	-0.9
Canada	0.3	0.7	0.7	0.4	0.6	0.7
Australia	0.1	0.4	0.5	0.2	0.3	0.3
Russia	-0.2	0.4	0.5	0.7	1.1	1.3
China	0.6	0.2	0.6	1.0	1.5	1.6
India	-4.2	-6.6	-6.9	0.2	-0.4	-1.0
Brazil	-0.3	-1.0	-0.9	-0.1	0.0	0.1
Mexico	0.6	-0.1	0.0	0.5	0.8	1.1
Argentina	-0.2	-0.2	0.3	0.4	0.6	0.8
Republic of Korea	-0.2	-0.3	-0.2	-0.2	-0.3	-0.4
Indonesia	-0.1	-0.1	0.2	-0.1	0.3	0.5
Proxy for Saudi Arabia	-0.3	-0.4	-0.5	0.3	0.4	0.7
Proxy for South Africa	-0.2	-0.4	-0.3	0.4	0.5	0.6

2050						
European Union	-0.8	-0.4	-0.1	0.7	1.0	1.3
Germany	-1.1	-1.1	-0.8	0.8	1.2	1.5
France	-2.5	-1.8	-1.3	0.4	0.7	0.9
Italy	0.1	0.7	0.8	0.7	1.0	1.3
United Kingdom	-2.1	-2.0	-1.8	-0.2	-0.2	-0.1
Turkey	0.1	0.5	0.6	1.1	2.0	2.6
United States	0.1	0.1	0.5	0.4	0.5	0.5
Japan	-0.5	-0.6	-0.7	-0.5	-0.4	-0.4
Canada	0.6	0.9	1.1	0.6	0.9	1.1
Australia	0.3	0.5	1.5	0.3	0.5	0.6
Russia	0.5	0.9	0.9	0.9	1.3	1.5
China	2.0	2.0	2.4	0.7	1.0	1.3
India	-1.5	-1.6	-4.7	1.1	0.3	-0.3
Brazil	-2.5	-2.1	-2.6	-0.1	0.4	0.9
Mexico	0.2	-0.5	0.5	0.5	0.9	1.1
Argentina	0.0	0.6	1.6	0.4	0.7	1.0
Republic of Korea	0.0	-0.2	-0.2	-0.1	-0.3	-0.4
Indonesia	0.9	1.2	1.5	-0.8	-0.5	-0.1
Proxy for Saudi Arabia	-0.4	-0.6	-0.3	0.4	0.6	0.6
Proxy for South Africa	0.0	0.1	0.2	0.4	0.5	0.7

Source(s): E3ME, Cambridge Econometrics.