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 "Greenhouse Gas Emissions Mitigation in G20 countries and Energy Efficiency", prepared by Enerdata, a consulting company. All reports are available for download from http://www.unepdtu.org/

Greenhouse Gas Emissions Mitigation in G20 countries and Energy Efficiency

1. Introduction

This report estimates the size of the reductions in energy use (and associated reductions in greenhouse gas emissions) that can be achieved by improving the efficiency with which energy is transformed, distributed and used. The analysis is performed at a global level and for G20 countries.

For this analysis a model-based approach has been chosen by using three global energy models, namely TIAM-ECN (run by the Energy research Centre of the Netherlands, ECN), POLES (run by ENERDATA) and the energy-econometric model E3ME (run by Cambridge Econometric). This report describes a multiple scenario analysis conducted with the POLES model, in which three carbon tax scenarios are assessed against a business as usual scenario.

2. The POLES model

POLES is a world energy-economy, partial-equilibrium, simulation model of the energy sector, with complete modelling from upstream production through to final user demand. The model combines details on key components of the energy system with a strong economic consistency, as all changes in these key components are influenced by relative price changes at the sectoral level. Moreover, the POLES model allows for dynamic technological change and takes due account of price-induced technology diffusion mechanisms such as feed-in tariffs.

For this analysis the POLES model considers 15 energy-demand sectors, corresponding to more than 40 technologies (Appendix 1.C). Unlike TIAM-ECN, the other energy-sector model used for the study, POLES does not include emissions from land use change or emissions of nitrous oxide. To increase the comparability of the estimates from both models, this synthesis report (like that summarising the findings from the TIAM-ECN model) excludes land use change and nitrous oxide.

The POLES model divides the world in 57 regions. Most of the G20 countries are represented (exceptions are Australia, Argentina and Saudi Arabia). Appendix 1.A gives additional information on the model, including its key features, input data and regional definitions.

3. Methodology: Emissions reductions and the carbon tax scenarios

Emission reduction potentials can be estimated by comparing carbon-constrained scenarios to a so-called business-as-usual (BAU) scenario, which excludes emission reduction policies. For each sector of the economy represented in the model, its emission reduction potential is analysed alongside other relevant parameters (notably energy balances, technologies deployment and activity indicators), with a view to estimating potentials at the level of individual technology options.

No emission reductions occur in the BAU scenario, beyond those attributable to already implemented policies. Nonetheless, the latter are not negligible, and are associated with the dynamic nature of certain economic sectors and the complex interactions among sectors.

Emission reductions are simulated by applying a carbon price to the baseline scenario. Each carbon-constrained scenario is the result of a supply-demand equilibrium under a different price structure, which the carbon price brings about. Emission reduction potentials are estimated by comparing the emission levels reached in the BAU scenario with those reached in the carbon-constrained scenarios.

Each emission reduction scenario is defined by a particular set of emission reduction options – those that are ‘affordable’ given the carbon price associated with the scenario. In addition to energy efficiency, those emission reduction options include other mechanisms, such as changes in the fuel mix and carbon-capture and storage. The analysis presented in this report isolates the impact of energy efficiency from the impact of all other mechanisms. Specifically, model output data are analysed for each country and sector, distinguishing between the power generation sector and the final demand sectors (namely industry, transport, buildings and agriculture).

The study considers three carbon-constrained scenarios. They are defined to simulate carbon prices starting at 0 US$/t$CO_2$ in 2013 and rising linearly to 40, 70 and 100 $/t$CO_2$ in 2030, respectively[1]. From 2030 the carbon tax level is kept constant through to 2050. The carbon price was applied to all sectors of the economy and to all greenhouse gas emissions covered by the model. No additional climate mitigation policies were implemented in the model. Appendix 1.B gives more information on the macroeconomic context of the scenarios.

4. Findings

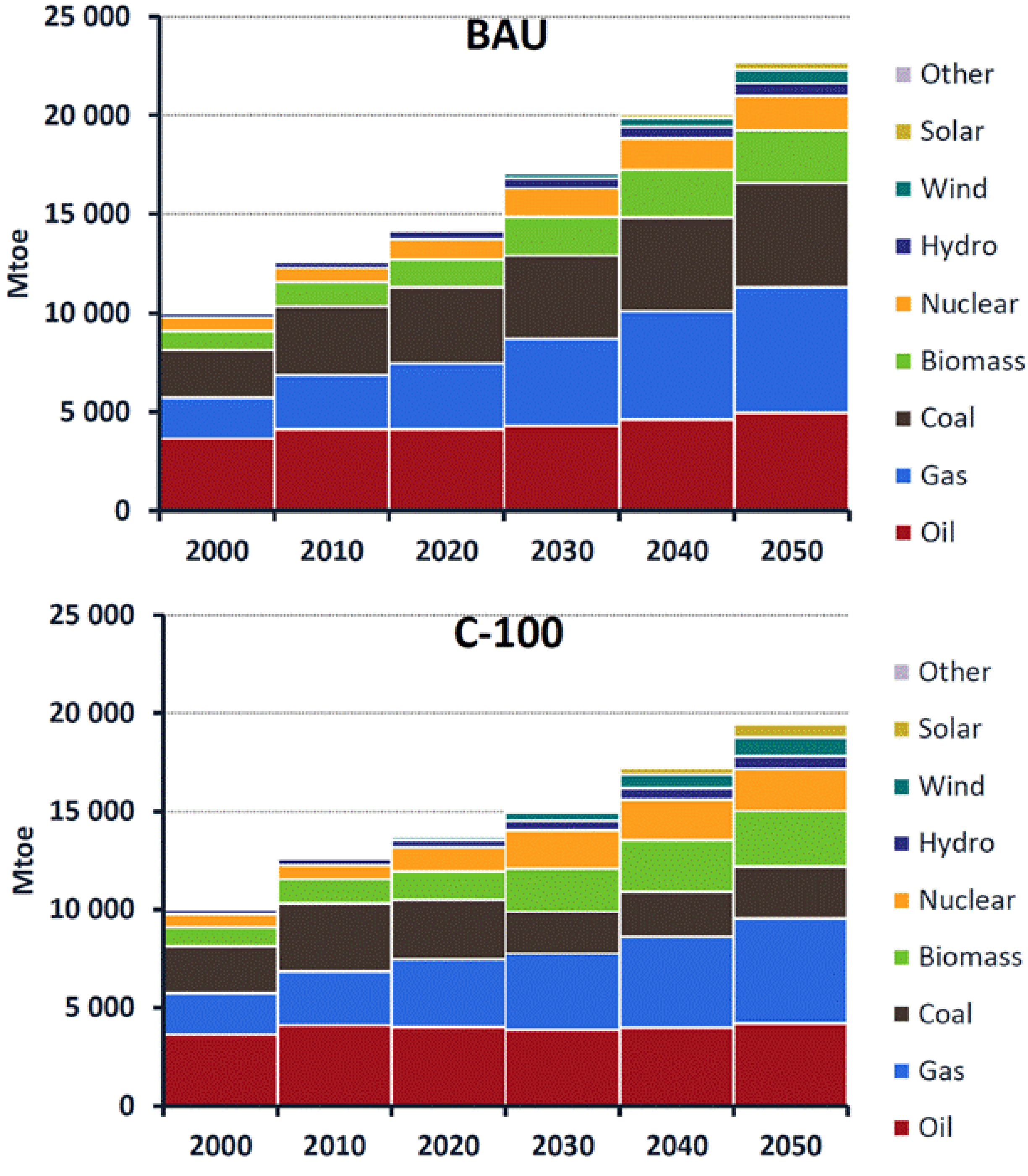
Report findings are presented in three sub-sections, outlining, respectively, changes in primary energy supply associated with the above carbon-constrained scenarios, related emission reduction potential, and the contribution of energy efficiency related to emission reductions.

4.1 Total primary energy supply

At the global level, and in the absence of additional policies, energy demand is expected to increase significantly (Figure 1). In the BAU scenario, energy demand is projected to nearly double between 2012 and 2050, reaching 22.7 Gtoe (an average increase of 1.48 percent per year). Growth rates in OECD countries (+0.59 percent per year) are lower than those in non-OECD countries (+1.92 percent per year). Conversely, energy intensity is expected to decrease significantly (by -1.4 percent per year in OECD countries and by -2.8 percent per year in non-OECD countries).

[1] Prices are given in real US dollars of 2005.

Figure 1: World total primary energy supply in the BAU and 100 US$ t/CO_2 scenarios



A price on carbon would mitigate this growth (Table 1).

Table 1: World total primary energy indicators

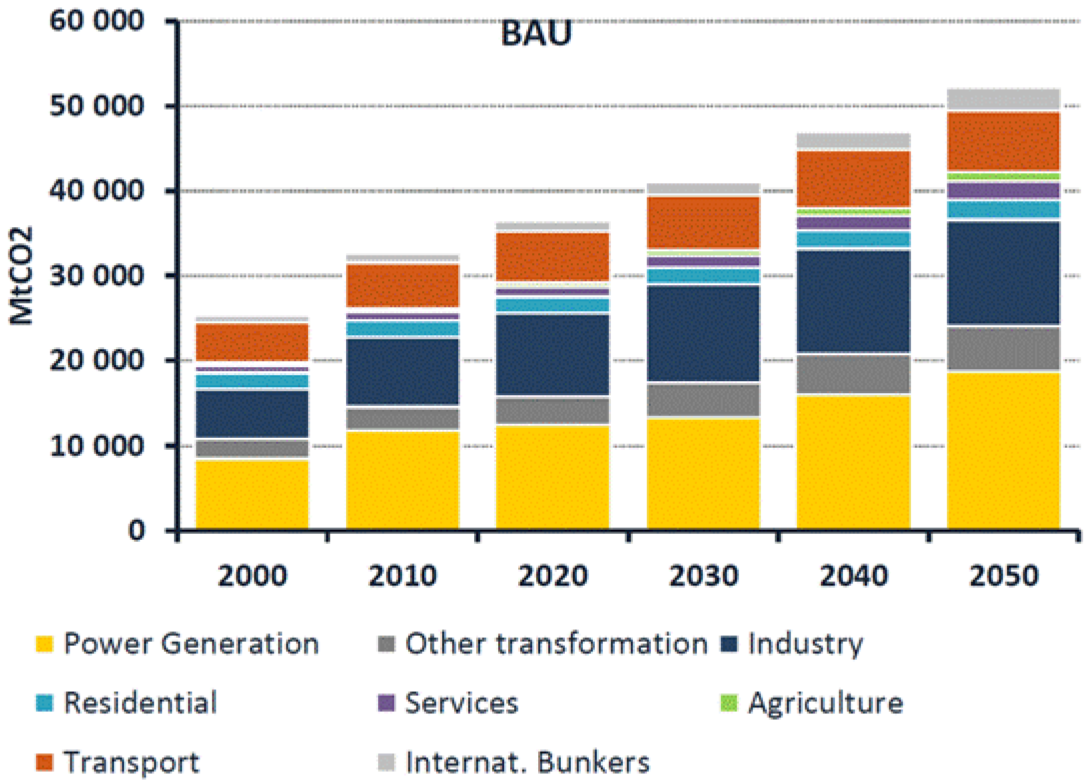
	2012	BAU	C-40	C-70	C-100
TPES (Gtoe, 2050)	13.0	22.7	20.9	20.1	19.5
Average growth, 2012-2050 (%/year)	-	1.5%	1.3%	1.2%	1.1%

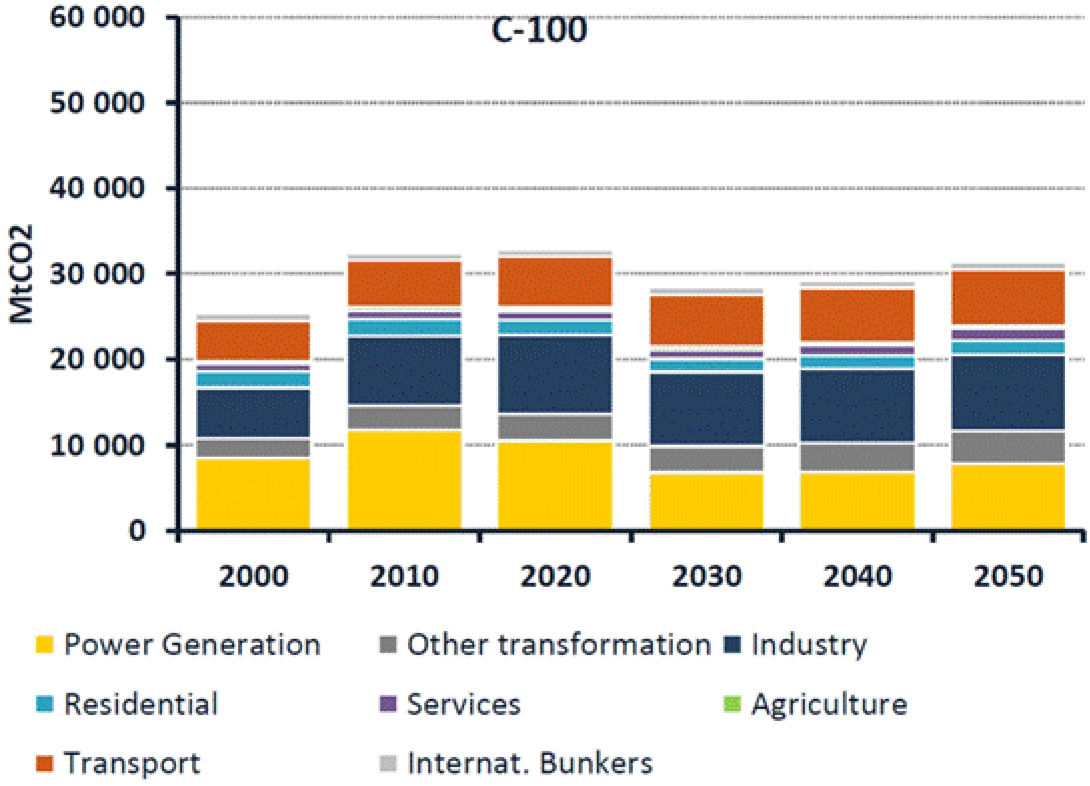
4.2 Emissions

Compared to energy demand, emissions grow at a slower pace, even in the BAU scenario. This is due to the gradual deployment of more efficient technologies. In the BAU scenario world carbon dioxide emissions reach 52.2 $GtCO_2$ in 2050, compared to 34.2 $GtCO_2$ in 2012.

A price on carbon would mitigate this growth (figure 2).

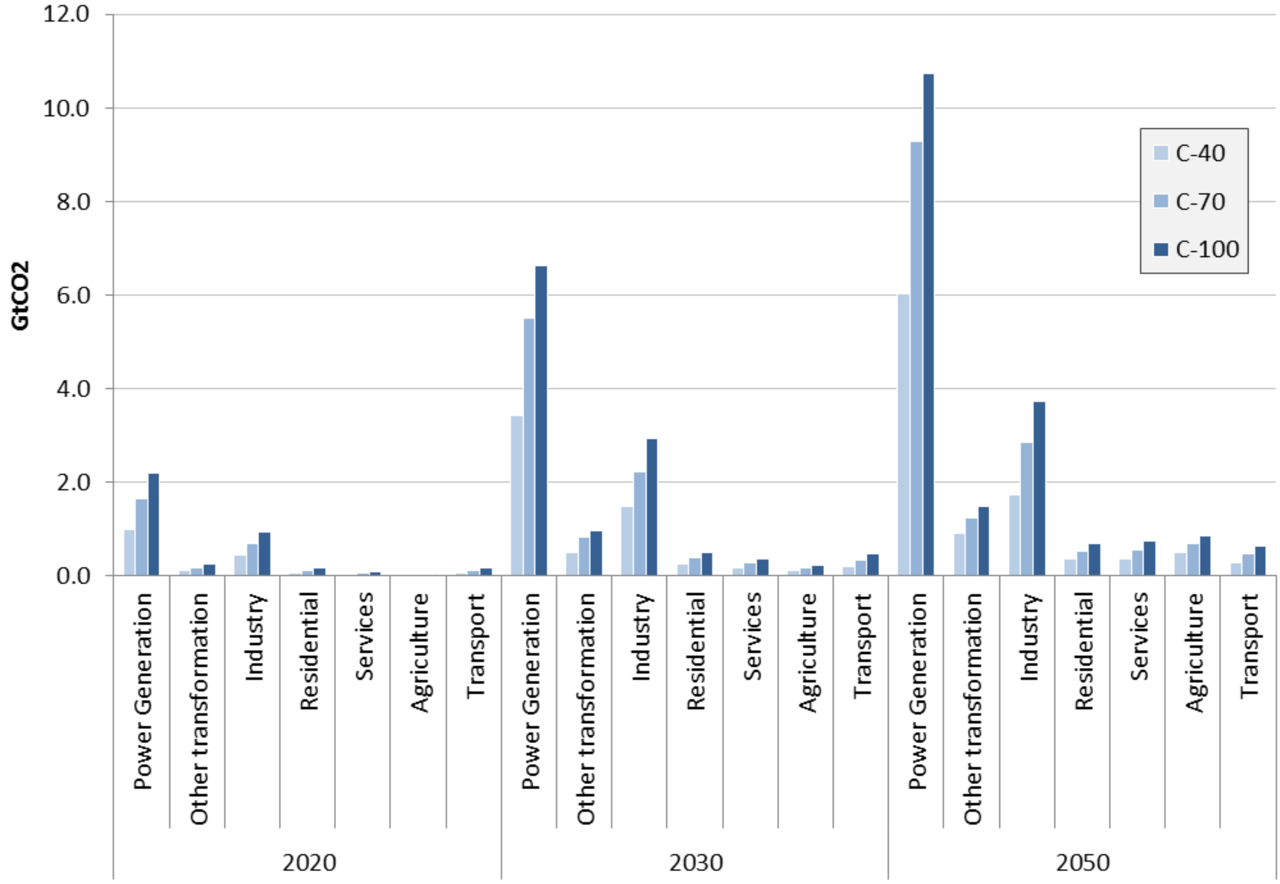
Figure 2: World carbon dioxide emissions in the BAU and 100 US$ t/CO_2 scenarios





The power sector accounts for most economic emission reductions (approximately 60 percent of the reductions in all scenarios), followed by industry (approximately 20 percent), and finally other transformation sectors (approximately 8 percent) (Figure 3). These findings are consistent with those of the TIAM-ECN model.

Figure 3: World carbon dioxide emission reductions per sector compared to BAU



4.3 Energy efficiency

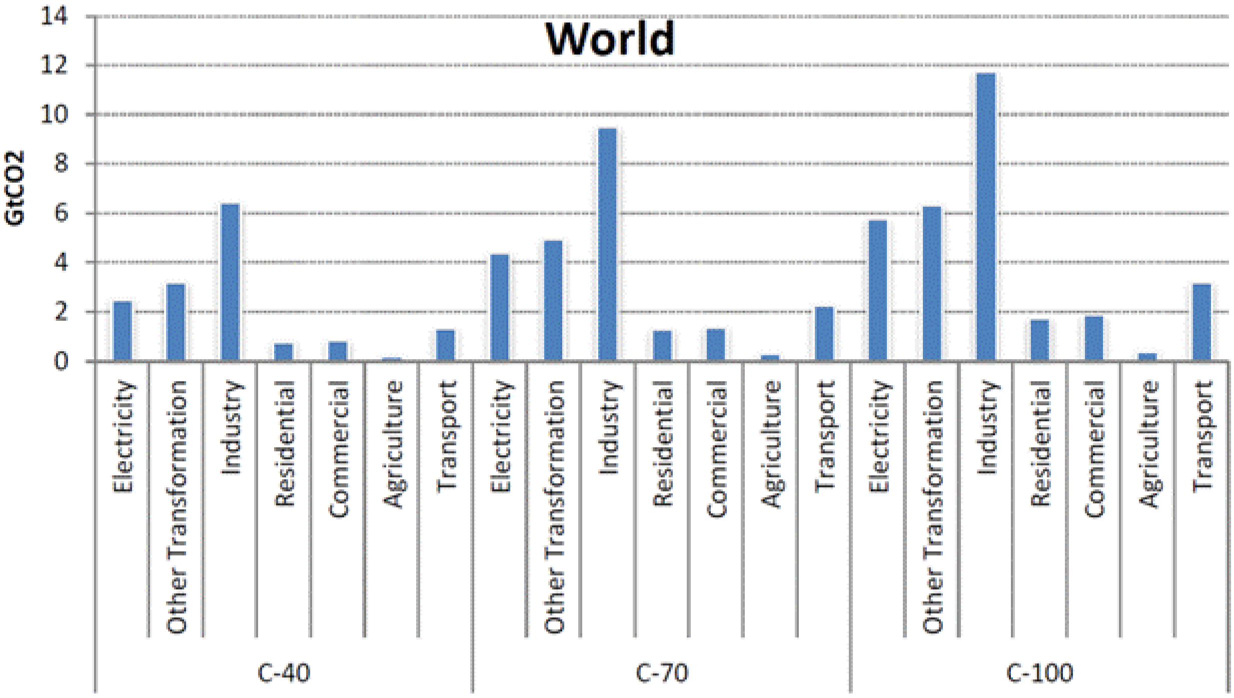
Energy efficiency plays an important role in greenhouse gas emission reductions in all regions of the world. Depending on the structure of the economy in a country and the price level on carbon, improvements in energy efficiency can account for between 10 percent and 30 percent of all emission reductions that would be economical to undertake at that price level (Table 3).

Table 3: World emission reductions and energy efficiency

	C-40	C-70	C-100
Cumulated emissions reductions, 2010-2030 (GtCO2)	78	109	134
Of which, due to energy efficiency	15	24	31
% due to energy efficiency	20%	22%	23%

Globally, the potential of energy efficiency is most significant in the industrial sectors, the upstream energy sector (including power generation), buildings, and transport (Figure 4).

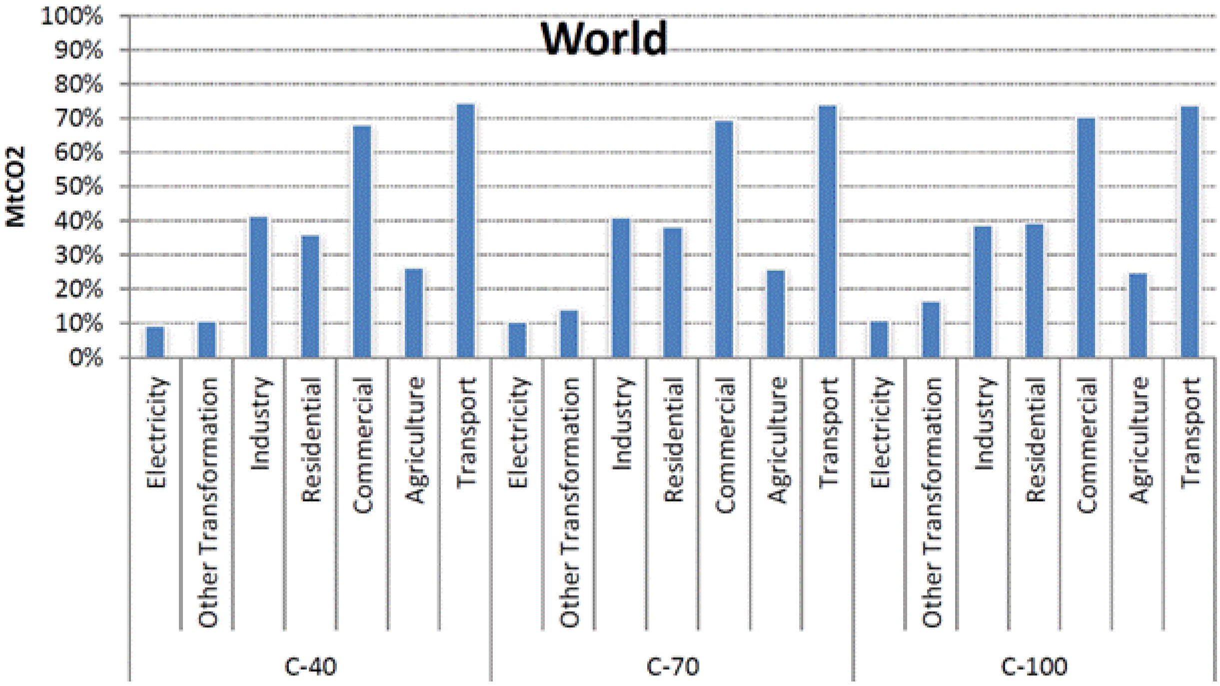
Figure 4: World emission reductions due to energy efficiency, cumulated 2010-2030



In cumulative terms, energy efficiency represents between 20 and 23 percent of total emission reductions by 2030 - a share that increases with the level of carbon taxation. In all carbon tax scenarios, G20 countries account for most emission reductions (slightly less than 90 percent of the total and a similar share of emission reductions due to energy efficiency). Two thirds of total reductions as well as of reductions due to energy efficiency are concentrated in China (more than 40 percent), USA (more than 10 percent), India (approximately 10 percent) and Russia (approximately 6 percent).

The industry sector accounts for about 42 percent of all emission reductions attributable to energy efficiency gains, followed by the upstream energy sector (37 percent), the building sector (10 percent), and the transport sector (9 percent) (Figure 5). Within each sector, energy efficiency plays the largest role in emissions reductions in transport and the commercial sector.

Figure 5: World share of emission reductions in each sector due to energy efficiency, cumulated 2010-2030



As the level of the carbon tax increases, the power sector increases its contribution to energy savings, mainly at the expense of the industry sector. The total emission reductions due to energy efficiency by 2030 at the global level are projected to reach 15.3 $GtCO_2e$ with a carbon tax of US$40/t CO_2 (the corresponding estimates for the US$70/t CO_2 and US$100/t CO_2 taxes are, respectively, 24.1 $GtCO_2e$ and 31.1 $GtCO_2e$).

5. Limitations of the analysis

As all model-based analyses, the analysis presented here has some shortcomings. Firstly, emission reductions are studied with the direct implementation of a pricing on carbon for end-user energy prices. However, the relatively high energy price levels used in the study might be outside the scope of validity of the econometric equations used to parametrise the model. This could result in patterns of energy demand that are unrealistic, either because price elasticity might no longer apply or because, whichever the price level, a minimum level of energy demand might be necessary to underpin the level of economic activity associated with the situation being modelled. In these cases, the comparison with the estimates produced with TIAM-ECN (a non-econometric, bottom-up model), helps benchmark and set realistic boundaries for energy demand and emission reduction potentials.[2]

A further limitation concerns investments in retrofitting existing power capacities or energy-consuming equipment, which are not modelled. Overall, this might impact the relative attractiveness

[2] The results of the TIAM-ECN model are synthesised in a separate report, while a summary report gives an overview of the conclusions arising from both modelling studies.

of energy efficiency as an option for emission reductions, compared to a modelling approach which would have energy efficiency as a fully explicit investment option.

Not least, energy efficiency technologies are not represented explicitly in POLES. Reductions in energy use (and the associated reductions in greenhouse gas emissions) attributable to energy efficiency gains are identified by assigning them to changes in the competitiveness of selected technologies. While POLES contains enough technological detail to undertake this kind of analysis (indeed, this is part of the strength of the model), some simplifications are unavoidable.

Appendix 1: Input data for the POLES model

Appendix 1.A: Model data

The POLES model uses a dynamic partial-equilibrium framework, specifically designed for the energy sector, but also including other greenhouse gas emitting activities. The simulation process uses dynamic year-by-year recursive modelling, with endogenous international energy prices and lagged adjustments of supply and demand by world region, which allows for describing complete economic development pathways to 2050.

The model provides technological change through dynamic cumulative processes such as combining the impacts of 'learning by doing' and 'learning by searching' on the development of technologies. As price-induced diffusion mechanisms (such as feed-in tariffs) can also be included in the simulations, the model allows for consideration of key drivers for future development of new energy technologies.

Appendix 1.A.1: Key features

Key features of the POLES model include:

- Long-term (2050) simulation of world energy scenarios/projections and international energy markets.
- World energy supply scenarios by main producing country and region, with consideration of developments in reserves (of fossil fuels) and resource constraints (80 producing countries and regions regions).
- Outlook on energy prices at the international, national and sectoral levels.
- Disaggregation into 15 energy demand sectors, with over 40 technologies (within power generation, buildings, transport, etc.).
- Detailed national and regional energy balances and emissions (for 45 countries and 12 regions), integrating primary production, primary demand, transformation and power, losses and final energy demand.
- Full power generation system (and feedback effect): 30 explicit technologies, load curve simulation with typical days, annual capacity planning and dispatch based on 'levelised cost of energy', centralised versus decentralised generation, potentials associated to renewables, and carbon-capture and storage.
- Transformation: explicit technologies for liquids from gas, liquids from coal, biofuels, and hydrogen production.
- Impacts of energy prices and tax policies on regional energy systems (including national greenhouse gas emission trends and reduction strategies).
- Energy trade: oil (global pool), gas (bilateral trade from 37 exporters to 14 importing markets), as well as import needs for coal, solid biomass, liquid biofuels and uranium, and exogenous assumptions concerning electricity.
- Costs of national and international greenhouse gas emission reduction scenarios with different regional targets and endowments and flexibility systems.
- Marginal abatement cost curves for carbon dioxide emission, and emission trading system analyses by region and/or sector, under different market configurations and trading rules.

- Technology diffusion under conditions of sectoral demand and inter-technology competition, based on relative costs and merit orders.
- Endogenous developments in energy technologies, with impacts of public and private investment in R&D and cumulative experience with ‘learning by doing’. Induced technological change of climate policies.

Table 4: POLES final energy demand sectors

Aggregate	Sector	*Remarks*
INDUSTRY	Steel Industry	*Steel tons production localization*
	Chemical industry	*Value Added*
	Chemical feedstocks	
	Non-metallic minerals	*Value Added*
	Other industries	*Value Added*
	Other non-energy uses	
TRANSPORT	Road transport	*Freight, passenger; 5 vehicle types*
	Rail transport	
	Air transport	*Domestic, international*
	Other transport	
BUILDINGS	Residential sector	*Captive electricity; 3 buildings types*
	Services sector	*Captive electricity*
AGRICULTURE	Agriculture	

Appendix 1.A.2: Model input data

In this report, the input data for the POLES model is divided into default data and data from databases that are regularly updated by Enerdata. Default input data include:

- Macroeconomic data: International Monetary Fund, the World Bank, the United Nations, and France’s Centre d'Etudes Prospectives et d'Informations Internationales.
- Historical data on energy demand, supply and prices: Enerdata databases (derived from International Energy Agency databases, harmonised and enriched through national statistics).

- Energy resources: BGR Energy Systems Limited, Energy Information Administration, Food and Agricultural Organisation, and various national sources.
- Techno-economic data (energy prices, equipment rates, and costs of energy technologies, among others): gathered both from international and national statistics.
- Power generation technologies data: multiple datasets available (notably the International Energy Agency's World Energy Model, and the Université de Grenoble's TECHPOL database).
- Forecasts: Calibration on planned power generation projects and on announced national policy objectives (for EU and for large energy consumers).

Appendix 1.A.3: Countries and regions included in the model

The POLES model divides the world in 57 regions. Most G20 countries are individually represented (Table 5).

Table 5: POLES regional representation

G20 member	POLES region
France	France
Germany	Germany
Italy	Italy
United Kingdom	United Kingdom
European Union	European Union (28)
Turkey	Turkey
United States	United States
Canada	Canada
Mexico	Mexico
Japan	Japan
South Korea	South Korea
Russia	Russia
China	China
India	India
Indonesia	Indonesia
Brazil	Brazil
South Africa	South Africa
Australia	Pacific (Australia-New Zealand-Pacific Islands)
Argentina	Rest of South America (excl. Brazil)
Saudi Arabia	Gulf countries

The last three G20 countries are not represented individually in POLES. Outputs in this study were provided for the region containing the relevant G20 country.

Appendix 1.B.: Macroeconomic context of the scenarios

The macroeconomic context (mainly, estimates of trends in gross domestic product and population) is similar across all four scenarios.

Table 6: Real GDP growth in purchasing power parities (compounded annual rate of growth, in percent)

	2000 - 2010	2010 - 2020	2020 - 2030	2030 - 2040	2040 - 2050
OECD	1.6	2.1	2.0	1.9	1.8
North America	1.6	2.7	2.0	1.9	1.9
US	1.6	2.7	1.7	1.7	1.7
Europe	1.6	1.5	1.8	1.7	1.9
Pacific	1.7	2.0	2.5	2.1	1.5
Japan	0.7	1.1	1.9	1.3	1.0
Non OECD	6.4	5.4	5.0	4.4	3.8
E Europe / Eurasia	5.0	3.6	4.4	4.2	3.8
Russia	4.8	3.6	4.1	3.8	3.4
Asia	8.1	6.5	5.5	4.6	3.9
China	10.5	7.4	5.8	4.6	3.7
India	7.6	6.0	5.9	5.3	4.6
Africa & Mid. East	4.8	4.3	4.1	4.1	4.1
Latin America	4.0	3.5	3.3	3.1	2.9
Brazil	3.6	2.9	3.0	2.6	2.4
World	3.5	3.7	3.7	3.4	3.2
EU28	1.5	1.3	1.6	1.6	1.7

Table 7: Population (millions)

	2000	2010	2020	2030	2040	2050
OECD	1138	1221	1291	1344	1380	1402
North America	413	457	499	538	568	592
US	282	309	334	359	379	397
Europe	521	552	574	586	593	594
Pacific	204	212	218	220	219	216
Japan	127	127	126	121	115	109
Non OECD	4955	5640	6356	7004	7575	8059
E Europe / Eurasia	340	339	340	334	325	315
Russia	146	142	140	134	127	121
Asia	3226	3601	3949	4207	4365	4423
China	1263	1338	1405	1425	1408	1358
India	1042	1206	1353	1476	1566	1620
Africa & Mid. East	973	1229	1545	1898	2289	2704
Latin America	416	471	522	565	597	617
Brazil	174	195	211	222	229	231
World	6094	6861	7647	8348	8955	9461
EU28	488	506	516	519	517	513

Appendix 1.C. Technologies and prices used in the POLES model

Several technologies are represented explicitly in the model, most of which within power generation. Variables used to characterise these technologies include investment costs, operation and maintenance costs, lifetime and efficiency. Data to calculate these variables are obtained from the International Energy Agency (the dataset used for the World Energy Outlook), enriched by own research and complementary sources (TECHPOL, Energy Modelling Forum and CCS Institute, among others). Other data such as running hours and full levelised cost of production are endogenous to the model.

Energy prices are calculated endogenously in the model. They are an important driver in the level of energy demand and inter-fuel substitution. The prices presented below (Table 8) are international market prices, and thus are net of any taxes and duties (including carbon dioxide prices). They are world prices (single global market modelled, or average of regional markets modelled), in constant USD of 2005 per barrel of oil equivalent.

Table 8: International prices (US$ per barrel of oil-equivalent)

	2000	2010	2020	2030	2040	2050
Oil						
BAU	32	71	114	138	155	169
C-40	32	71	113	134	152	167
C-70	32	71	113	131	148	162
C-100	32	71	112	128	144	157
Gas						
BAU	23	26	38	46	52	61
C-40	23	26	39	46	49	58
C-70	23	26	40	44	46	54
C-100	23	26	40	42	44	51
Coal						
BAU	8	19	21	23	24	26
C-40	8	19	21	22	24	25
C-70	8	19	21	22	23	25
C-100	8	19	21	22	23	25