Greenhouse Gas Emissions Mitigation in G20 countries and Energy Efficiency

Final Report

November 2014

Report on the methodology and main results for the provision of data for UNEP Risoe

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1. Introduction

This report has been compiled for UNEP Risø (project KEBMIN-EE_for_GAP2014) and studies energy efficiency impacts on greenhouse gas (GHG) emission reductions, on a global level and for G20 member countries.

The outputs of this work were used by other project partners (ECN, Cambridge Econometrics) in a harmonisation process and to assess the macro-economic impacts of the energy scenarios. This work was conducted to inform activities around the UN's *Emissions Gap Report*.

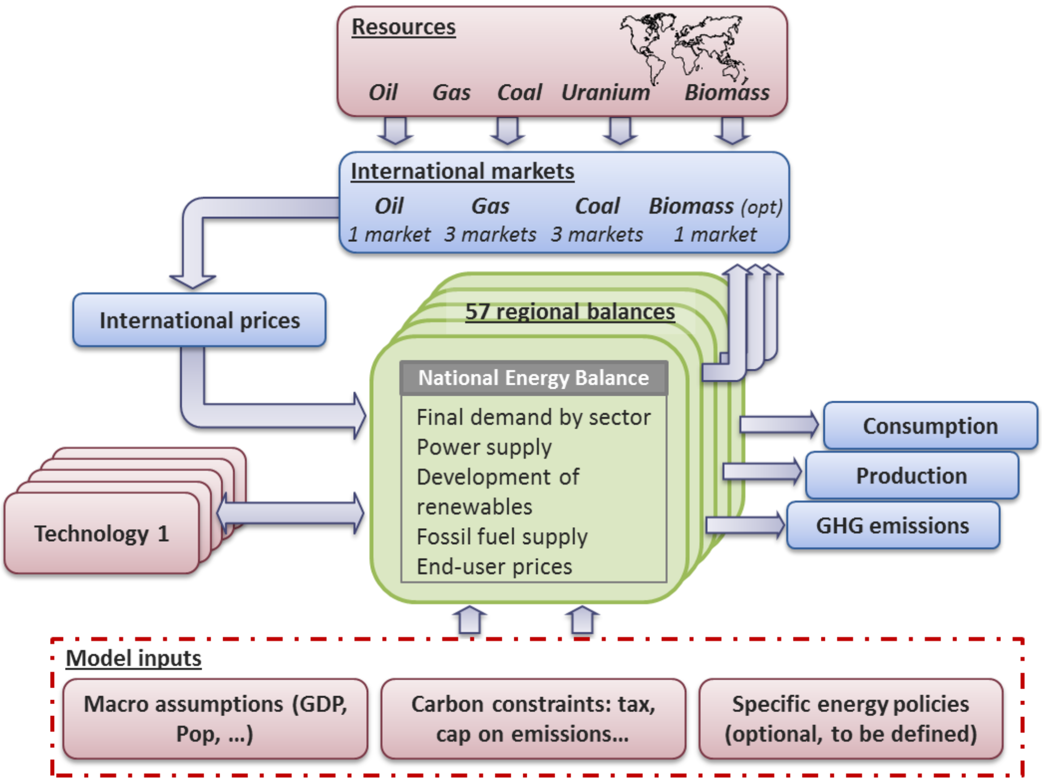
This report describes the methodology used and the main aspects of the energy-economy model POLES; the main assumptions for the scenarios developed for this work; and a discussion of the main findings; more detailed result tables can be found in the Annexes.

2. Methodology

The estimation of the energy efficiency potential for GHG emissions reduction was done based on energy-economy scenarios developed on the world energy model POLES.

2.1. The POLES model

POLES (Prospective Outlook on Long-term Energy Systems) 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 POLES model uses a dynamic partial equilibrium framework, specifically designed for the energy sector but also including other GHG emitting activities (e.g., the six GHG's of the "Kyoto basket"). 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 full development pathways to 2050.



The use of the POLES model combines a high degree of detail for key components of the energy system and a strong economic consistency, as all changes in these key components are influenced by relative price changes at the sectoral level.

The model provides technological change through dynamic cumulative processes such as the incorporation of Two Factor Learning Curves, which combine the impacts of "learning by doing" and "learning by searching" on technologies' development. 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 to future development of new energy technologies.

One key aspect of the analysis of energy technology development with the POLES model is indeed that it relies on a framework of permanent inter-technology competition, with dynamically changing attributes for each technology.

POLES is used and developed by JRC IPTS, Université de Grenoble CNRS, and Enerdata.

Key Features

- Long-term (2050) simulation of world energy scenarios/projections and international energy markets.
- World energy supply scenarios by main producing country/region with consideration of reserve development and resource constraints (80 producing countries/regions).
- Outlook for energy prices at international, national and sectoral level.
- Disaggregation into 15 energy demand sectors, with over 40 technologies (power generation, buildings, transport). EU Member States: Estimates of ETS and Non-ETS splits.
- Detailed national/regional energy balances and emissions, integrating primary production, primary demand, transformation & power, losses and final energy demand. 45 consuming countries + 12 regions; including all individual 28 EU Member States and EU surroundings (Norway, Iceland, Switzerland, Turkey).
- Full power generation system (and feedback effect on other energies): 30 explicit technologies, load curve simulation with typical days, annual capacity planning and dispatch based on LCOE, centralized vs decentralized, potentials associated to renewables, CCS.
- Transformation: Explicit technologies for liquids from gas, liquids from coal, biofuels, hydrogen production.
- Impacts of energy prices and tax policies on regional energy systems. National greenhouse gas emissions and abatement strategies.
- Energy trade: Oil (global pool); Gas (bilateral trade from 37 exporters to 14 importing markets); import needs for coal, solid biomass, liquid biofuels, uranium; exogenous for electricity.
- Costs of national and international GHG abatement scenarios with different regional targets/endowments and flexibility systems.
- CO2 emission Marginal Abatement Cost curves 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.

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	

Input data

Default input data in the model include:

- Macroeconomic data: IMF, World Bank, UNPD, CEPII.
- Historical data on energy demand, supply, prices: Enerdata databases (derived from IEA, harmonized and enriched by national statistics). Energy resources: BGR, EIA, FAO, national sources.
- Technico-economic data (energy prices, equipment rates, costs of energy technologies …): gathered both from international and national statistics. Power generation technologies data: multiple datasets available (IEA's WEM; Université de Grenoble's TECHPOL).
- Forecasts: Calibration on planned power generation projects and on announced national policy objectives (EU and for large energy consumers).

Regular updates of the database (currently twice a year) are provided by Enerdata.

Regions definition

The POLES model splits the world in 57 regions. Most of the G20 countries are individually represented. The table below provides correspondences between G20 members and POLES regions.

Table 1: 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 members are not represented individually in POLES. Outputs in this project were provided for the region containing the relevant G20 country.

2.2. Emissions reduction and energy efficiency measures in POLES

Emissions reductions are obtained by comparing the carbon-constrained scenario to a so-called business-as-usual (BAU) scenario, in which the policies to reduce emissions have not been implemented. For each sector of the economy represented in the model, its emissions reductions are interpreted alongside other modelling results (energy balances, technologies deployment, activity indicators) to break down the total sector reductions into individual options. The sector's energy efficiency option is the result of comparing emissions between the two scenarios once the effects of identified technologies (e.g. renewables, CCS) and switches between fossil fuels have been taken into account.

Emissions in the BAU scenario

Emissions in the BAU scenario are considered as baseline; no abatement occurs in these scenarios and emissions change over time via dynamic effects that are attributable to current policies and not attributable to additional climate-related policies that might be implemented in the future.

The BAU scenario does not operate at a frozen efficiency: some policies and technological improvements that are considered to happen independently of climate-related policies are included in the BAU. Such changes in the baseline will occur at an abatement cost considered to be zero; in a scenario with carbon pricing, the abatement cost will represent changes that deviate further from these baseline figures. Beyond these non-climate related dynamic changes, POLES does not propose zero-cost abatement options.

Emissions reductions

Emissions reduction potentials are produced by observing the abatement incurred 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 that includes a carbon price; emissions abatement is the comparison of the emissions reached in both BAU and carbon-constrained scenario.

Within each scenario, a number of options are chosen to reduce emissions. As POLES operates in a “top-down” manner, we do not propose the “lump” adoption of the cheapest technology followed with a “threshold” effect by the “lump” adoption of the next more expensive technology (as in more “bottom-up” modelling and marginal abatement cost curves). Instead, several technological options are adopted simultaneously in a lesser or greater degree in a dynamic process.

Emissions reductions options

The model output data is analysed to estimate the sub-sectoral options adopted in each country to reach the emissions reductions, using a Kaya-type decomposition method. The possible options are the following:

For the Power Generation sector:

- Production change: change in the level of demand for electricity (result of changes in the final demand sectors); could be interpreted as electrification (increase) or efficiency (decrease)
- Fossil fuel switch (excluding CCS)
- Carbon Capture and Storage: typically emerges in the late 2020s
- Nuclear: by default takes into account national policies for the foreseeable future as of 2011-2012
- Wind: combined onshore and offshore
- Solar: combined photovoltaic and concentrated solar thermal power
- Other renewables (geothermal, hydro)

For this project, the item “production change” was taken to account for reductions due to energy efficiency.

Table 2: Sub-sectoral options for the Power Generation sector

Sector / Option	Production change	Fossil fuels switch (no CCS)	CCS	Nuclear	Wind	Solar	Other Renewables
Power generation	X	X	X	X	X	X	X
Counted in EE for UNEP Risoe	**X**						

For the Final Demand sectors (and the Energy transformation excluding the Power Generation sector):

- Activity change: demand response, change in the level of activity due to the shifting price environment (e.g. industrial production change, mobility change)
- Energy efficiency: decreased energy use for the same level of activity (e.g. investment in more efficient buildings)
- Fossil fuels switch (excluding CCS): shifts in the fossil fuels mix between oil, gas and coal
- Carbon Capture and Storage: typically emerges in the late 2020s (Industry and Energy Transformation)
- Renewables: increased use of biomass or biofuels
- Electricity: increased penetration of electric processes or of substitutable uses of electricity
- Process emissions (Industry)
- Other options: Behaviour change (e.g. changes in buildings consumption not attributable to efficient buildings), …

These options are not applicable to all sectors. The table below details which sectors can feature which of these options.

Table 3: Sub-sectoral options for the Final Demand sectors

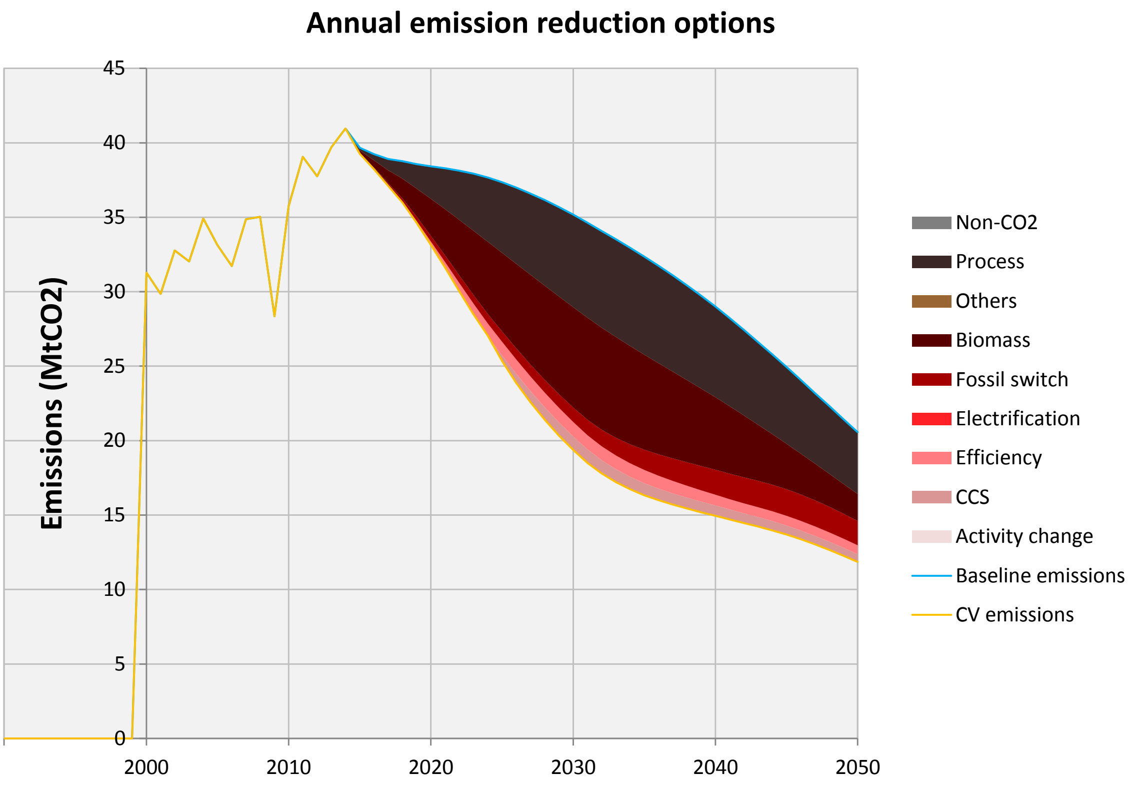
Sector / Option	Activity change	Energy efficiency	Fossil fuels switch (no CCS)	CCS	Renewables	Electricity	Process emissions
Other Energy transformation		X		X			
Industry: Non-Metallic Minerals	X	X	X	X	X	X	X
Industry: Steel Industry	X	X	X	X	X	X	X
Industry: Chemicals Industry	X	X	X	X	X	X	X
Industry: Other Industries	X	X	X	X	X	X	
Buildings: Residential		X	X		X	X	
Buildings: Services		X	X		X	X	
Agriculture		X	X		X	X	
Transport: Road	X	X			X	X	
Transport: Domestic Aviation	X	X			X		
Transport: Rail & Other		X				X	
Counted in EE for UNEP Risoe	**X**	**X**					

For this project, the items "activity change" and "energy efficiency" were taken to account for reductions due to energy efficiency.

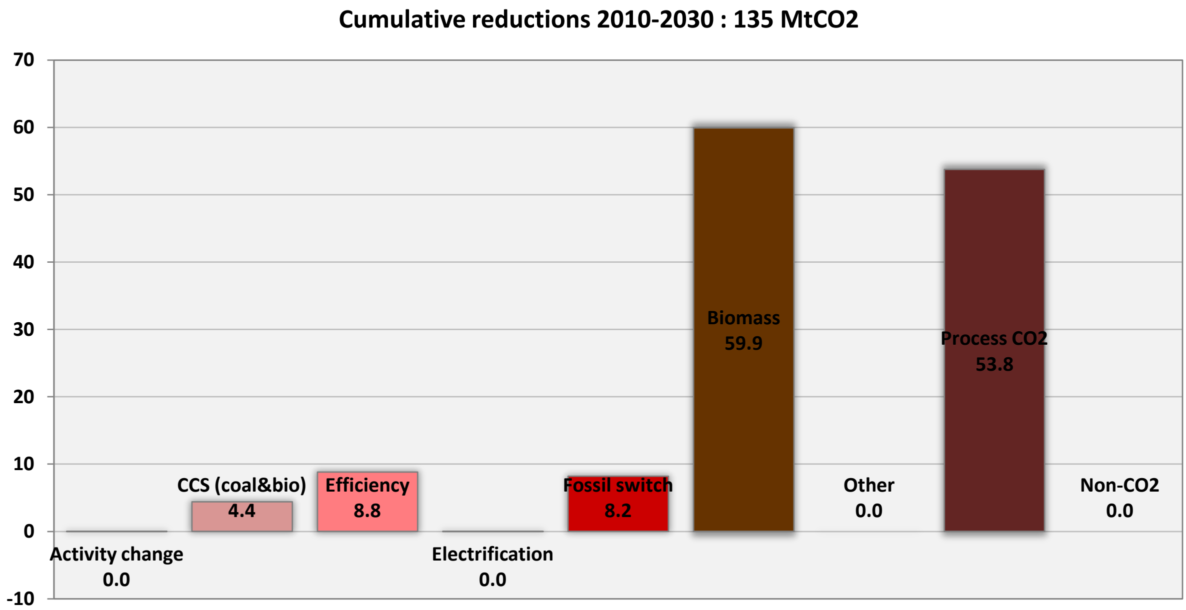
Efficiency is thus one of the options that is adopted by the model when it is exposed to a carbon price.

In the example below, we have studied the steel sector of Brazil in 2030 in one of the scenarios modelled (C-100; see below).

Over the entire modelling period, we observe a reduction of emissions compared to the BAU scenario which can be broken down into different options ("wedge diagram").



In 2030, the difference in emissions between BAU and carbon-constrained scenario amounts to 135 MtCO2. They can be broken down to the following contributions:



These contributions are detailed in the following table; the breakdown follows a similar logic in other sectors.

Table 4: Example of sectoral abatement options and methodology

Option	Contribution in 2030 (MtCO2)	Contribution in 2030 (% of sector)	Comment
Activity change	0	0%	Changes in activity between scenarios studied (e.g. demand of electricity in power sector). For the steel industry, demand of steel was set at the same level between scenarios.
Process emissions	53.8	40%	Changes in the emissions of industrial processes due to the implementation of a carbon price (price-induced emission reductions based on an endogenously recreated marginal abatement cost curve).
CCS	4.4	3%	Implementation of CCS with coal or biomass technologies, based on the relative costs of technologies with and without CCS. CCS technologies capture emissions with a certain efficiency; emissions not captured are emitted fatally.
			Once the effects of the above options are taken into account, the following options are calculated on the remaining envelope by using relevant distribution keys.
Fossil fuel switch	8.2	6%	Emissions over Consumption of fossil fuels Changes in the average carbon content of the sector's fossil fuel mix (coal + gas + oil). This pertains to the change of the mix, not the decrease of emissions due to the decrease of the total level of fossil fuel consumption (which is treated in other options).
Electricity	0	0%	Consumption of electricity over Activity indicator Increase of the role (share) of electricity in the sector's energy mix (electrification). For the steel industry, this corresponds to an increase in electric arc processes compared to the baseline due to lower per ton costs; for the considered scenarios, electric arc tons were set the same between scenarios.
Renewables	59.9	44%	Consumption of renewables over Activity indicator Increase of the role (share) of renewables in the sector's energy mix for heat and processes (i.e. biomass, solar). For the steel industry, this corresponds to an increase in the use of biomass compared to the baseline due to an increase in competitiveness because of carbon pricing (biomass end use considered to be carbon-neutral).
Efficiency	8.8	7%	Consumption of fossil fuels over Activity indicator Changes in emissions due to the implementation of a carbon price not explained by above effects (price-induced reductions

			not explained by explicitly represented by the above technologies and options). For buildings (residential, services), this includes emissions reductions due to the penetration of medium- and low-consumption buildings (explicitly represented in the modelling).
Total	135.1	100%	Difference between BAU and carbon-constrained.

2.3. Scenarios

The scenario used as reference or BAU was derived from the EnerFuture scenario *Balance* [1], which corresponds to a moderate return to economic growth within this decade and a continuation of currently adopted policies. *Balance* uses very recently updated databases on energy consumption, electricity capacities and production, energy prices and primary energy production: 2012 for nearly all data, certain 2013 data for key variables (economic growth). For the reference for this project, climate-related policies (carbon prices) were removed from *Balance*. The resulting reference is relatively close in definition to the IEA's World Energy Outlook Current Policies Scenario 2013, in the sense that no future intensification of energy and climate policies are implemented beyond what has already been decided in main energy consuming countries; GDP and population figures differ, but not significantly so.

For this project, three carbon-constrained scenarios were derived from the reference scenario.

These three scenarios considered carbon prices starting at 0 in 2013 and rising linearly to 40, 70 and 100 $/tCO2 in 2030, respectively (values are in constant US$ of 2005); the carbon price level was then constant throughout 2050.

The carbon pricing was applied to all sectors of the economy and to all GHG emissions covered by the model (i.e. fossil fuels combustion & industry). No other climate mitigation policies were implemented additionally to that.

Sectors where the EU ETS is in place followed a slightly different trajectory over 2013-2020, to account for the presence of a carbon price in the historical data (linear increase over 2013-2020 based on the last historical value for the ETS price). The impact of this difference on the outputs is minimal (0-2% difference in EU-28 emissions compared to a case where the same carbon price trajectory was used as in non-ETS countries/sectors).

[1] EnerFuture energy forecasting service by Enerdata, last updated in January 2014

3. Main assumptions and drivers

3.1. Macroeconomic context

The macroeconomic context (GDP, population) is similar across all four scenarios.

Table 5: Real GDP Growth (ppp) – CAGR (%)

	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 6: Population (M)

	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

3.2. Technologies

Several technologies are represented explicitly in the model. Among the main ones are technologies in power generation. Data used for these is derived from the IEA (dataset used for the WEO 2013), enriched by own research and complementary sources (TECHPOL, Energy Modelling Forum, CCS Institute, ...): investment cost, operation & maintenance cost, lifetime, efficiency. Other data such as running hours and full levelized cost of production (LCOE) are an endogenous result of the modelling.

Data presented below correspond to parameters from the scenario with a 40 $/tCO2 carbon price, for the USA; differences between scenarios and regions are to be found in the energy and carbon prices.

Table 7: Data on power generation technologies

	2010	2020	2030	2050
Coal	Pulverized Fluidized Bed			
Investment costs ($/kW)	2194	2125	2112	2094
Efficiency	46%	46%	46%	47%
Running hours per year	5500	7032	7015	7068
LCOE ($/MWh)	64	53	51	51
Coal CCS	Pulverized Fluidized Bed + CO2 removal from flue gas			
Investment costs ($/kW)	3833	3577	3428	2779
Efficiency	37%	38%	39%	39%
Running hours per year	5500	5500	7015	7092
LCOE ($/MWh)	105	102	78	70

Gas	CCGT			
Investment costs ($/kW)	885	781	732	661
Efficiency	54%	57%	58%	60%
Running hours per year	2822	3358	3818	4361
LCOE ($/MWh)	66	69	76	84
Gas CCS				
Investment costs ($/kW)	1559	1479	1432	1373
Efficiency	51%	53%	54%	56%
Running hours per year	5500	5500	5500	5500
LCOE ($/MWh)	64	73	86	100
Nuclear	Generation III PWR			
Investment costs ($/kW)	4814	4462	4075	3765
Efficiency	33%	33%	33%	33%
Running hours per year	8293	8110	8112	8128
LCOE ($/MWh)	67	70	77	82
Hydro large				
Investment costs ($/kW)	2767	2757	2751	2742
Efficiency	100%	100%	100%	100%
Running hours per year	2848	3155	3155	3155
LCOE ($/MWh)	99	89	89	89
Solar PV	PV power plant			
Investment costs ($/kW)	3175	2642	2074	1447
Efficiency	100%	100%	100%	100%
Running hours per year	1669	1696	1712	1731
LCOE ($/MWh)	197	162	140	101
CSP	CSP + storage (smooth 24-h production)			
Investment costs ($/kW)	5639	4929	3926	3440
Efficiency	100%	100%	100%	100%
Running hours per year	3942	3942	3942	3942
LCOE ($/MWh)	179	152	123	109
Wind onshore				
Investment costs ($/kW)	1760	1600	1498	1318
Efficiency	100%	100%	100%	100%
Running hours per year	2361	2480	2500	2499
LCOE ($/MWh)	88	81	77	71
Wind offshore				
Investment costs ($/kW)	2739	2013	1803	1632
Efficiency	100%	100%	100%	100%
Running hours per year	0	2998	3027	3084
LCOE ($/MWh)	111	95	88	79

3.3. Prices

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 are international market prices, and thus are net of any taxes and duties (including CO2 prices); they are world prices (singe global market modelled, or average of regional markets modelled), in constant USD of 2005 per barrel of oil equivalent.

Table 8: International prices ($/boe)

	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

3.4. Caveats and limitations

The results of this study were produced with the POLES model. Like any model, POLES presents strong points and drawbacks. Certain modelling results stem from the modelling principles themselves; other results may be due to only a partial representation of real-world processes, which could be enhanced given proper modelling developments. For the purposes of this study, of particular importance are the following points:

- **Assumptions quality**: Results of emissions reductions and reduction potentials are always as compared to a BAU, thus the definition of the BAU is very important. The assumptions used in the BAU are key to establish the level against which reductions will be measured, and a level of uncertainty remains in the definition of these uncertainties – mainly for per country GDP growth, fossil fuel resources size, renewables technologies learning.

- **Hybrid modelling and reduction options**: In most sectors represented, POLES is a hybrid model of top-down econometric representations and bottom-up technological aggregation. Whilst top-down modelling is adapted to long-term simulation-based modelling of large economic units (country-level or international region-level), a bottom-up approach detailing individual technologies would be more suited to the study of the adoption of specific technologies.

- **Hybrid modelling and reduction potentials**: For sectors where a top-down econometric representation plays a large role (final demand sectors), energy demand and emissions are largely the results of price-induced effects on the level of demand and fuel substitution. Emission reductions are studied with the direct implementation of a pricing on carbon for end user energy prices. However, a context of high energy prices might be outside of the scope of validity of the econometric equations, resulting in patterns of energy demand that might be deemed unrealistic (either because price elasticities might no longer apply or because whichever the prices a minimum level of energy demand might be physically necessary to underlie the desired economic activity). In these cases, a proper comparison with a more bottom-up modelling might be necessary to benchmark and set boundaries within which energy demand and emissions reduction potentials might realistically be.

- **Hybrid modelling and investments**: Where detailed technological representations exist, it is possible to track CAPEX investments that the model chooses (power generation technologies, road transport vehicles). Also, investments in retrofitting existing power capacities or energy consuming equipment are not modelled; the model can choose to decommission them and have them replaced by new equipment. Where energy demand is modelled in a top-down econometric way, model choices are based on that year's energy prices, and investments in new equipment are not explicit; investment figures provided are based on estimates of energy expenditure savings and abatement costs. Overall, this might impact the relative attractiveness of energy efficiency as an option for emissions reductions as compared to a modelling approach which would have energy efficiency as a fully explicit investment option.

- **Energy efficiency technologies**: More specifically, energy efficiency technologies are not represented explicitly in POLES. Efficiency-related emissions reductions pertain to:

    - price-induced reductions not explained by other factors in sectors with a top-down econometric representation;

    - or emissions reductions due to changes in competitiveness of explicit technologies not explained by other factors to in sectors with a bottom-up representation. The enhancement of a technology represented explicitly can be attributed to one option for energy efficiency (e.g. increase in efficiency of internal combustion engine in road transport) or can impact the overall supply-demand balance and thus impact several options simultaneously, energy efficiency option included (e.g. increase in efficiency of gas-fuelled power plants might result in increased fuel switch towards gas, or a decreased penetration of CCS, or energy efficiency).

Whilst these interactions are part of the richness of the model, this also makes it complex to identify energy efficiency as an output of POLES. Thus, we developed a methodology to distinguish between options chosen by the model by re-treating POLES modelling outputs in a separate tool (detailed in Table 4: Example of sectoral abatement options and methodology above).

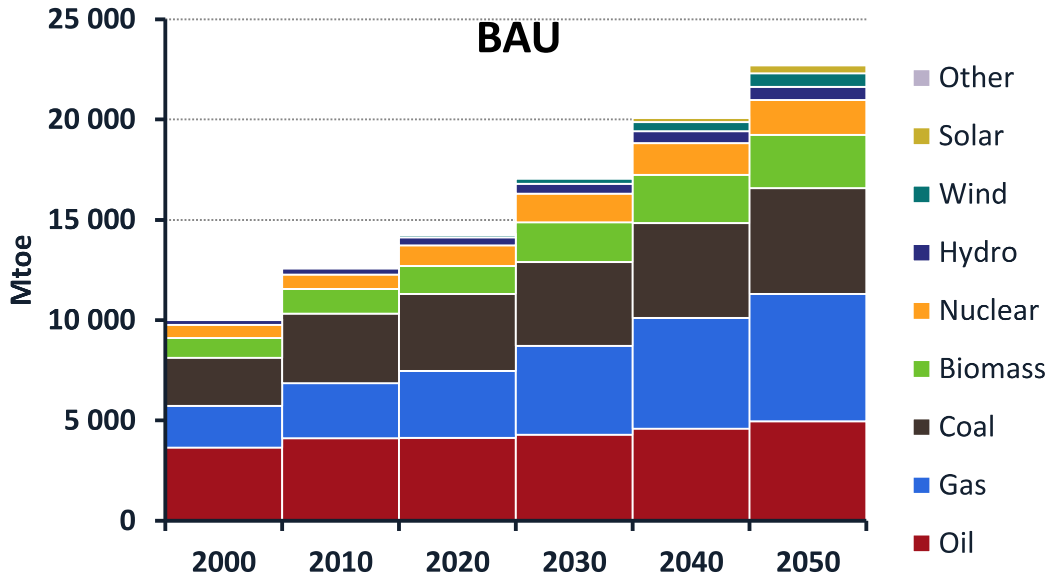
4. Main results

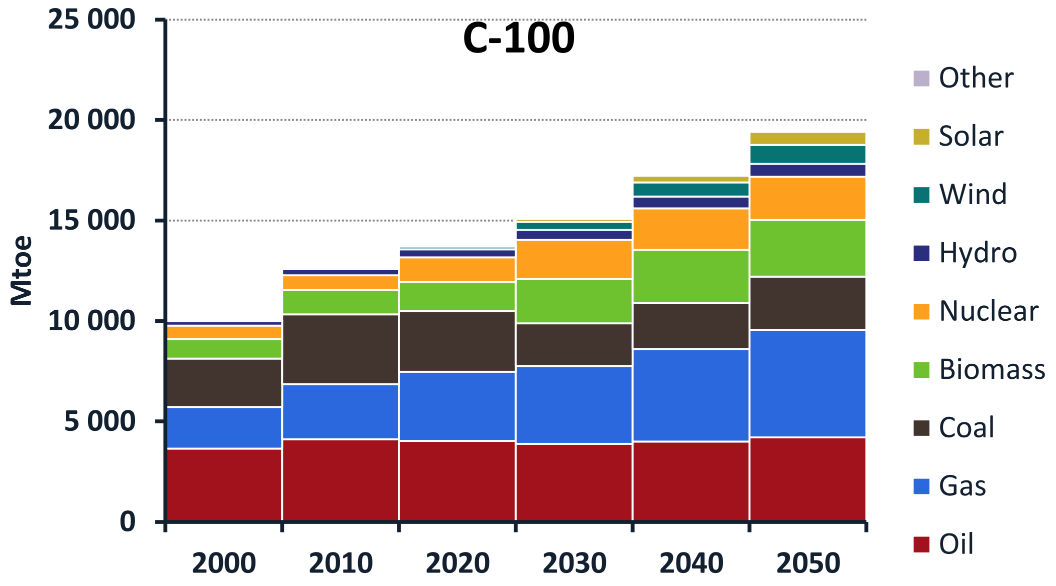
4.1. Total Primary Energy Supply

At the global level, energy demand is expected to increase significantly if no additional policies are implemented to curb that growth and decrease emissions. In the BAU scenario, energy demand is expected to nearly double between 2012 and 2050, reaching 22.7 Gtoe, an average increase of 1.48%/year (compared to 1.79%/year over 1990-2012).

The tendencies are different between OECD (+0.59%/year) and non-OECD countries (+1.92%/year); the values for 1990-2012 were 0.66 and 2.77%/year, respectively. Energy intensity is expected to decrease significantly, by -1.4%/year for OECD and -2.8%/year in non-OECD (compared to -1.4 and -2.0%/year for 1990-2012, respectively).

Figure 1: Total Primary Energy Supply, World, BAU and C-100 (Mtoe)





With the implementation of a pricing on carbon emissions, this growth is tempered.

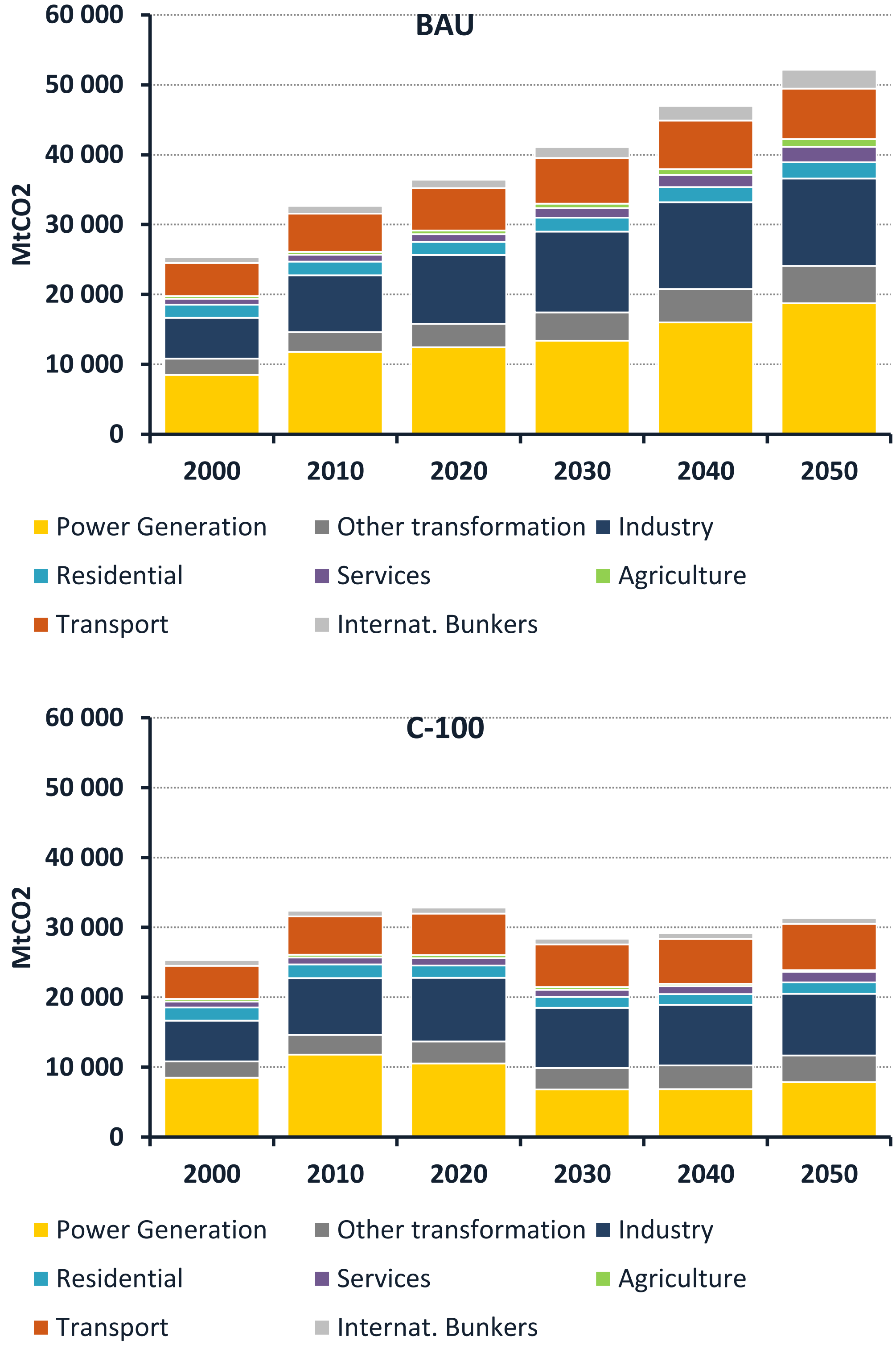
Table 9: Total Primary Energy indicators, World

	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%
% Renewables (2050)	12.9%	19.6%	23.7%	25.2%	26.4%

4.2. Emissions

On emissions, the combination of economic growth and technological learning results in different trends. Emissions grow at a slower trend compared to energy demand even in the BAU, reflecting an increasingly efficient world and the deployment of low-carbon technologies as a result of their direct competition with carbonated energy sources. World CO2 emissions reach 52.2 GtCO2 in 2050, compared to 34.2 GtCO2 in 2012 (including international bunkers).

Figure 2: CO2 emissions, World, BAU and C-100 (MtCO2)



The implementation of a pricing on carbon goes a long way on constraining the growth of these emissions, with a price of 100 $/tCO2 being necessary to make them decrease on the 2050 time horizon (32.5 GtCO2 in 2050 for the C-100 scenario).

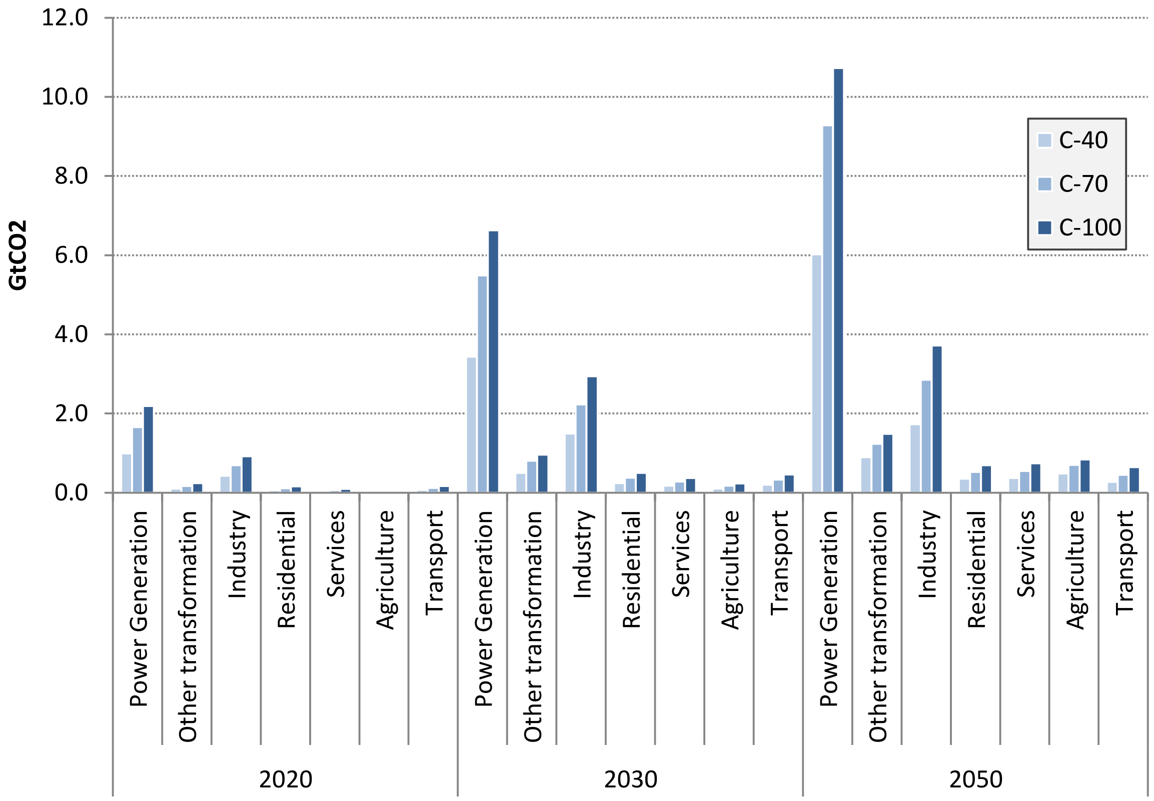
The role of OECD countries in these emissions is bound to decrease with time, however that decreasing share is more a result of the growing importance of non-OECD in terms of economic growth, and the share of OECD ends up being similar in all carbon price scenarios.

Table 10: World CO2 emissions in 2050 (GtCO2)

	2012	BAU	C-40	C-70	C-100
World	34.2	52.2	41.4	35.8	32.5
Of which OECD	*36%*	*25%*	*26%*	*27%*	*27%*

The sector largely most responsible for the reduction in emissions is the power sector (about less than 60% of the reductions across all scenarios), followed by industry (about less than 20%) and the other transformation sector (i.e. fuel transformation, fuels production, transport and distribution; about 8%).

Figure 3: CO2 emissions reductions per sector compared to BAU, World (GtCO2)



The volumes of these reductions should be put in perspective with the level of emissions remaining despite the implementation of these carbon prices, and where these emissions take place. Notably, by 2050 and in the most ambitious scenario (C-100), OECD will have reduced its emissions by 23% compared to 1990 (and non-OECD increased them by 127%).

4.3. Emissions and energy efficiency

Energy efficiency plays a large role in emissions reductions, in all world regions. Depending on the structure of the economy of each country and the level of carbon constraint, it can be responsible for anywhere between 10% and 30% of the reductions of a country's economy. Energy efficiency can go a long way to reducing emissions worldwide and helping each economy contribute to long-term climate stabilization goals.

As an example, for the EU-28 not only is the volume of reductions due to energy efficiency increasing with the carbon price considered, but efficiency's importance in the overall reductions increases as well.

Table 11: Emissions reductions and energy efficiency, World

	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%

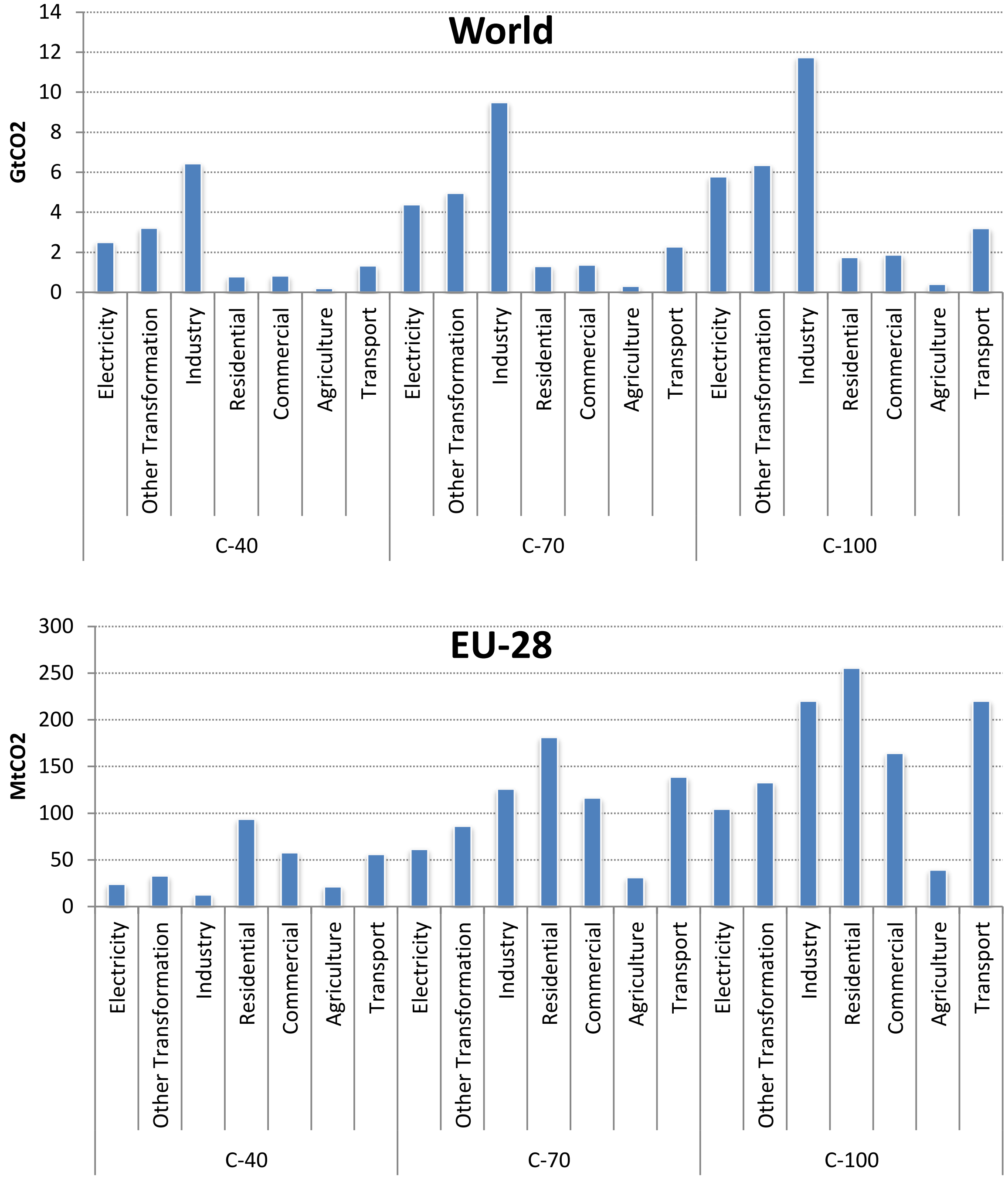
Table 12: Emissions reductions and energy efficiency, EU-28

	C-40	C-70	C-100
Cumulated emissions reductions, 2010-2030 (GtCO2)	2.53	3.75	5.05
Of which, due to energy efficiency	0.30	0.74	1.14
% due to energy efficiency	12%	20%	22%

Globally, energy efficiency potentials are to be found most significantly in the industrial sectors, the upstream sector (including power generation), buildings, and transport.

In the EU-28, energy efficiency plays an important role in the reductions of buildings, followed by industry and transport.

Figure 4: Emissions reductions due to energy efficiency, cumulated 2010-2030, World and EU-28



Total reductions via energy efficiency represent 20-23% of total reductions cumulated to 2030 (a share increasing with the level of carbon taxation). In all carbon tax scenarios, G20 countries represent the essential part of total emission reductions (slightly less than 90%) and of emission reductions due to energy efficiency (90%).

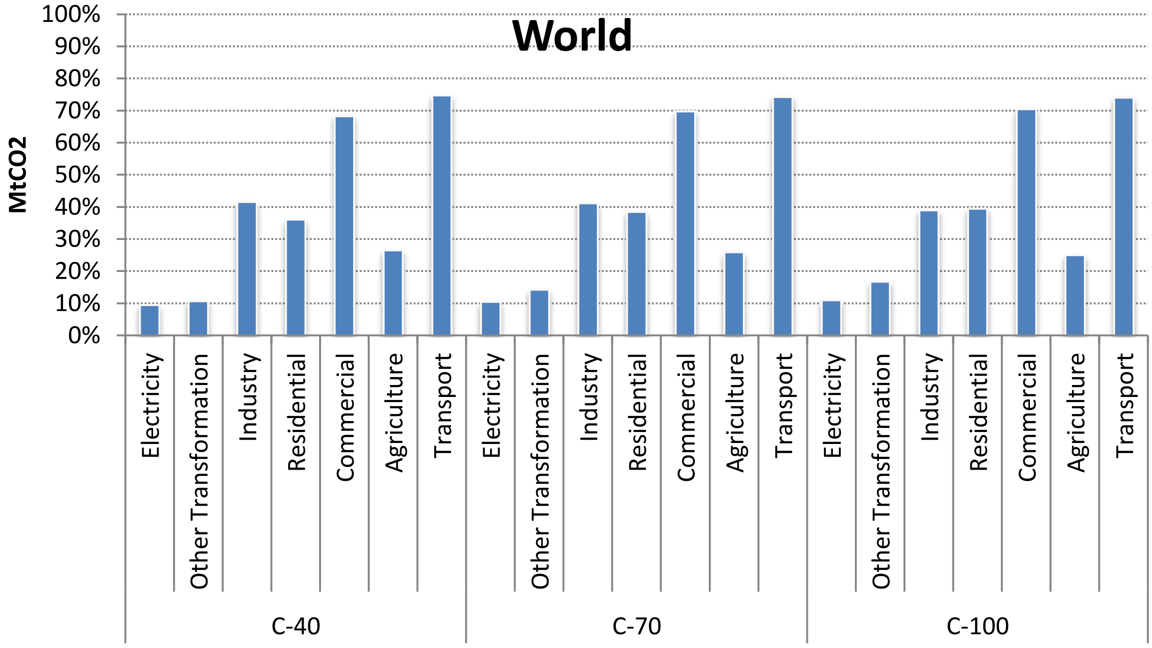
Two thirds of both total reductions and reductions due to energy efficiency are concentrated in a few countries: China (over 40%), USA (over 10%), India (about 10%) and Russia (about 6%).

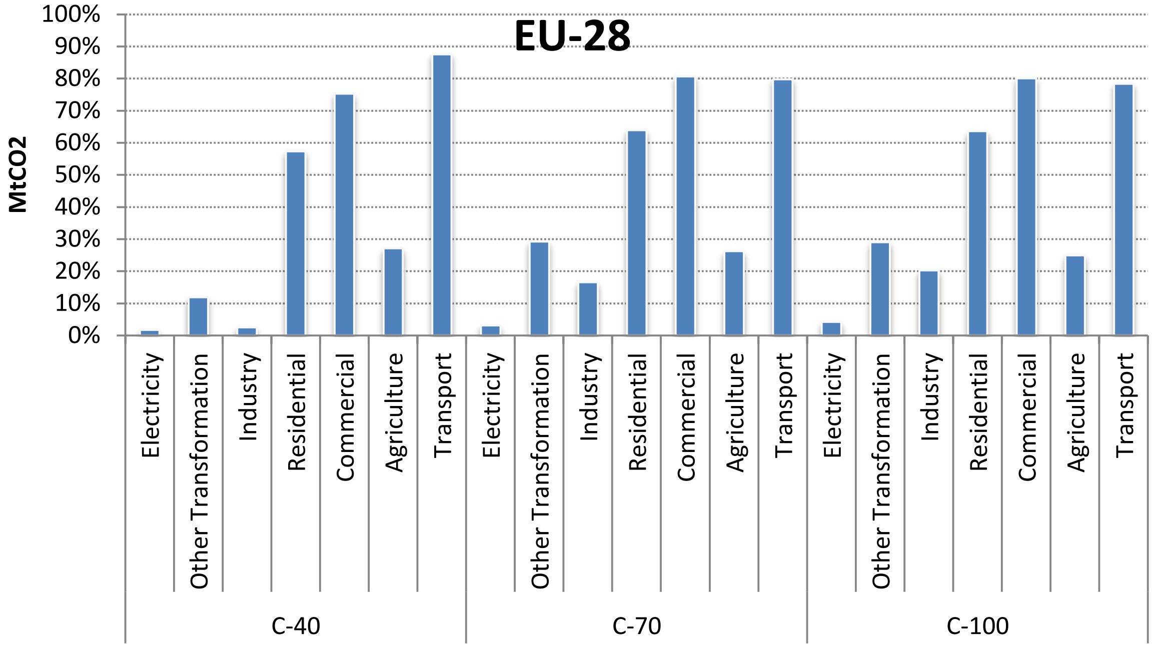
Cumulated reductions to 2030 due to energy efficiency worldwide with a $40 carbon tax are of 15.3 GtCO2e (2.2 GtCO2e in the year 2030). In terms of sectors most contributing:

- industry is the main sector (6.4 GtCO2e, or 42%; more specifically, non-metallic minerals, i.e. cement and glass, 16%, steel 6% and chemicals 5%);
- it is followed by the upstream sector (37%, with the power generation sector accounting for 2.5 GtCO2e, 16%, and other transformation activities 21%);
- buildings (1.6 GtCO2e, 10%, equally shared between residential buildings and commercial buildings);
- and transport (1.3 GtCO2e, 9%, most of which in road transport, 6%)

The distribution remains largely similar with a higher tax, with the power sector increasing its contribution at the expense of the industry sector as the tax increases, and cumulated reductions reaching 24.1 GtCO2e for a $70 tax and 31.1 GtCO2e for a $100 tax.

Figure 5: Share of reductions in each sector due to energy efficiency, cumulated 2010-2030, World and EU-28





As compared to the reductions achieved in each sector, the importance of energy efficiency (its share over the total reductions in a given sector) varies greatly. This is due to a large extent to the technological description of the POLES model (see also the section *Caveats and limitations* and *Table 4: Example of sectoral abatement options and methodology*):

- the sectors with a high level of technological description (e.g. power sector) have a lower share for EE, as a large part of reductions is explained by the penetration of specific technologies (e.g. nuclear, renewables) as compared to the BAU and not necessarily by an enhancement of EE of said technologies;
- the sectors with a more aggregate representation (e.g. other transformation) have a higher share for EE, as reductions assigned to EE are in part a result of an econometric description (i.e. price-induced reduction, once other options have been accounted for).

5. Annexes

Detailed results for World and G-20 countries (containing region provided in the case of Australia, Saudi Arabia, Argentina; see Table 1 above).