Benchmark levels of ambition from country's INDC (Intended Nationally Determined Contributions)

REPORT

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CONTENT

1. Introduction

Under the Paris Climate Agreement, all countries engaged to act against climate change. All of them has submitted self-defined contributions called INDCs regarding climate change issues like mitigation, adaptation, finance and others. The Paris Climate Agreement which entered in force on November 2016 brought on the international climate governance a new era moving, from a top-down approach with Kyoto Protocol that engaged only few countries, to a bottom-up approach with all countries engaged by their Nationally Determined Contributions (NDCs) satisfying their national circumstances.

However, outside the fact that now all countries will act, it is difficult to understand and monitor the global efforts with the aim to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels.

The Swedish Energy Agency commissioned Enerdata to analyse ways to appreciate and benchmark levels of ambition from country's INDC (Intended Nationally Determined Contributions). The study should consider national baselines (Business as Usual), INDC pledges as well as theoretical contributions compatible with a below 2°C scenario for a set of countries for the period up to 2050. The countries should be a representative panel of emerging and middle income countries from different geographical zones. The purpose is to have a comparative framework on trajectories and needed efforts by sector and by country regarding to its potential climate actions. The intended focus of the study is on mitigation but issues related to energy system transformation and sustainable development should also be considered.

INDCs contain information on climate change key issues (mitigation, adaptation, finance, technology transfer, capacity building) but lack transparence and uniformity. It is also important to keep in mind that for a large number of countries (mainly developing countries), it is mostly their first submission of climate change contributions, some of them having in addition a relatively limited understanding about what impacts their contributions may have on their development to 2030 and further, and how they should implement their mitigation targets.

For this reasons, it is crucial to analyze and assess each of the INDCs considering their national circumstances. During this project, we focused on mitigation which is the key action to reduce speed and amplitude of climate change future variations. The following forecast analysis, based on scenarios, provide trends and key findings on emission pathways with their implications on energy sectors for a representative set of countries and regions.

Several recent studies[1] assessed the global contribution of INDCs regarding other current policy and 2°C trajectories. These studies provide an aggregated analysis of where INDCs bring us and what is the remaining gap. For most of them, focused is generally made on developed and developing G20 economies. In this report, we carry out a similar analysis for a representative panel of emerging and middle income countries from different geographical zones going through a detailed analysis on their energy systems and emissions pathways.

Section 1 introduces the three scenarios and global key findings. Section 2 analyses energy and climate trajectories for a representative set of developing and emerging economies benchmarking their INDC efforts.

[1] UNFCCC - Synthesis report on the aggregate effect of INDCs: http://unfccc.int/focus/indc_portal/items/9240.php
UNEP - The Emissions Gap Report 2016: http://web.unep.org/emissionsgap/resources

2. POLES energy and climate scenarios

2.1. Scenario descriptions

EnerFuture[2] is an energy forecasting exercise carried out every year by Enerdata to describe the possible trajectories of global energy systems from today to 2050. Three characteristic pathways are described through three different scenarios:

- **Ener-Brown** describes a world where **fossil fuel resources are abundant** and energy prices are durably low, with consequences for the entire long-term energy system.
- **Ener-Blue** examines the prospects of energy systems based on the **achievement of the 2030 targets set in the INDCs**.
- **Ener-Green** explores the implications of more ambitious climate and energy policies, to achieve a compatible path to limit the global temperature increase to about **+ 1.5-2°C by the end of the century.**

Scenarios have been simulated using Prospective Outlook on Long-term Energy Systems (POLES) model, global energy supply and demand model (see **Annex 1** for POLES description). Main assumptions (macroeconomic context, market price of fossil fuels) are detailed in **Annex 2**.

POLES is a global partial equilibrium model with 66 regions (latest model version), 22 energy demand sectors and around 40 energy technologies[3]. The model is rather technology rich in the supply side, with a large variety of technologies such as CCS, renewable energy of different kinds and nuclear energy.
The overall economy is exogenous, whereas equilibrium is obtained in energy markets. The model is a recursive myopic optimization model that simulates the global energy supply from 2000 to 2050.
In this project, base years (most recent historical data) are 2013 or 2014 depending to availability of country's energy data. POLES only considers the energy system and emission of CO2 and other GHGs.
Energy demand in POLES is derived from economic growth, autonomous technological trends as well as short- and long-term demand elasticities. Further end-use technologies are modeled to some extent such as more energy efficient buildings. Electricity supply is modeled in detail through load curves over the year as well as the day. Technological diffusion is dependent on the return of investment, and the speed of diffusion is directly related to the profitability of a technology. Also the profitability affects the potential market share, as distribution functions are used to allocate market shares between competing technologies.
For more information, Hedenus and al.[4] made an energy model comparative study in 2012.

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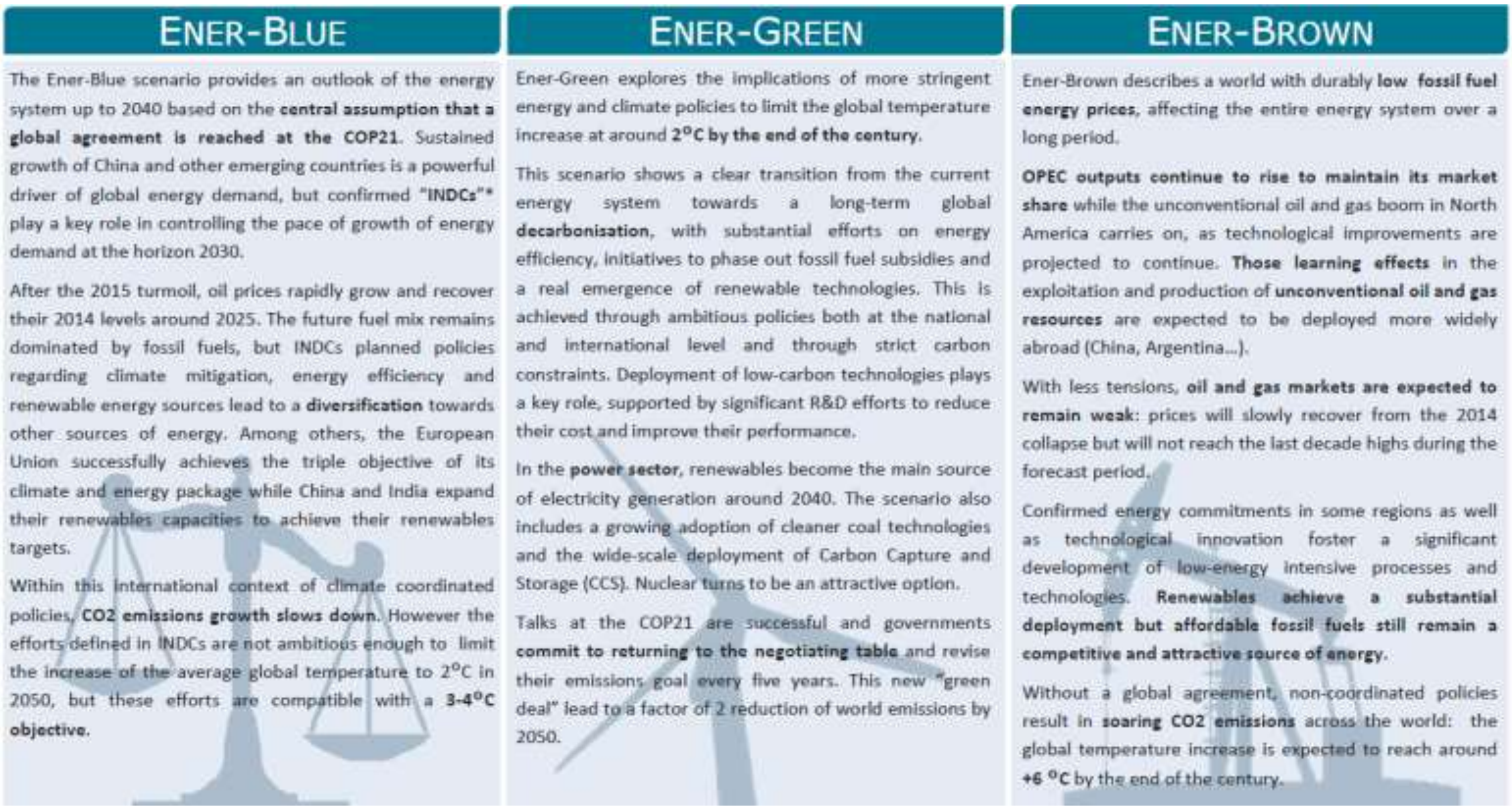
[2] http://www.enerdata.net/enerdatauk/knowledge/subscriptions/forecast/enerfuture.php

[3] Criqui P, Mima S, Menanteau P, Kitous A (2015) Mitigation strategies and energy technology learning: An assessment with the POLES model. Technological Forecasting and Social Change 90, Part A:119–136.

[4] Hedenus, Fredrik, Daniel JA Johansson, and Kristian Lindgren. A critical assessment of energy-economy-climate models. Chalmers University of Technology, 2012.

The following table describes the different scenario storylines.

Figure 1– Enerfuture 2015 scenario storylines



ENER-BLUE

The Ener-Blue scenario provides an outlook of the energy system up to 2040 based on the **central assumption that a global agreement is reached at the COP21**. Sustained growth of China and other emerging countries is a powerful driver of global energy demand, but confirmed **"INDCs"*** play a key role in controlling the pace of growth of energy demand at the horizon 2030.

After the 2015 turmoil, oil prices rapidly grow and recover their 2014 levels around 2025. The future fuel mix remains dominated by fossil fuels, but INDCs planned policies regarding climate mitigation, energy efficiency and renewable energy sources lead to a **diversification** towards other sources of energy. Among others, the European Union successfully achieves the triple objective of its climate and energy package while China and India expand their renewables capacities to achieve their renewables targets.

Within this international context of climate coordinated policies, **CO2 emissions growth slows down**. However the efforts defined in INDCs are not ambitious enough to limit the increase of the average global temperature to 2°C in 2050, but these efforts are compatible with a **3-4°C objective**.

ENER-GREEN

Ener-Green explores the implications of more stringent energy and climate policies to limit the global temperature increase at around **2°C by the end of the century**.

This scenario shows a clear transition from the current energy system towards a long-term global **decarbonisation**, with substantial efforts on energy efficiency, initiatives to phase out fossil fuel subsidies and a real emergence of renewable technologies. This is achieved through ambitious policies both at the national and international level and through strict carbon constraints. Deployment of low-carbon technologies plays a key role, supported by significant R&D efforts to reduce their cost and improve their performance.

In the **power sector**, renewables become the main source of electricity generation around 2040. The scenario also includes a growing adoption of cleaner coal technologies and the wide-scale deployment of Carbon Capture and Storage (CCS). Nuclear turns to be an attractive option.

Talks at the COP21 are successful and governments **commit to returning to the negotiating table** and revise their emissions goal every five years. This new "green deal" lead to a factor of 2 reduction of world emissions by 2050.

ENER-BROWN

Ener-Brown describes a world with durably **low fossil fuel energy prices**, affecting the entire energy system over a long period.

OPEC outputs continue to rise to maintain its market share while the unconventional oil and gas boom in North America carries on, as technological improvements are projected to continue. **Those learning effects** in the exploitation and production of **unconventional oil and gas resources** are expected to be deployed more widely abroad (China, Argentina...).

With less tensions, **oil and gas markets are expected to remain weak**: prices will slowly recover from the 2014 collapse but will not reach the last decade highs during the forecast period.

Confirmed energy commitments in some regions as well as technological innovation foster a significant development of low-energy intensive processes and technologies. **Renewables achieve a substantial deployment but affordable fossil fuels still remain a competitive and attractive source of energy.**

Without a global agreement, non-coordinated policies result in **soaring CO2 emissions** across the world: the global temperature increase is expected to reach around **+6 °C** by the end of the century.

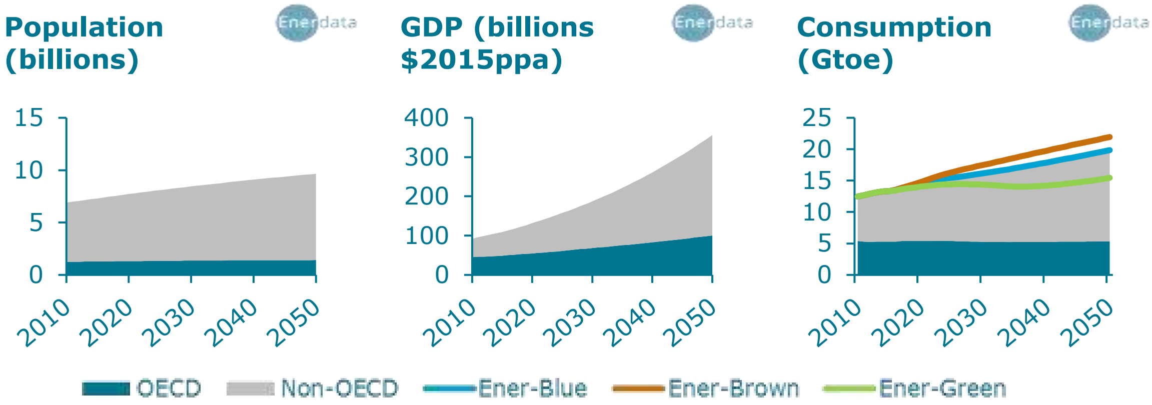
For this study, Enerfuture scenarios have been assimilated to:

- Baseline scenario – Ener-Brow
- INDC scenario – Ener-blue
- 2°C scenario – Ener-green

2.2. Key findings at world level

1. The global population will increase from 7 billion in 2015 to **about 9.6 billion in 2050** (+32%) while **global economy will more than triple** with a very strong economic growth in non-OECD countries (4.2%/year on average over the period). This context is identical in the 3 scenarios.
   To support this increase of activity, **global energy demand will keep growing**: from 13.7 Gtoe in 2015, it will reach up to 23 Gtoe in the baseline scenario (Ener-Brown). In both other scenarios, the strengthening of energy and climate policy will slow the growth (21 Gtoe in Ener-Blue et 16 Gtoe in Ener-Green in 2050).

Figure 2– Key factors in global energy demand for the 3 Enerfuture scenarios



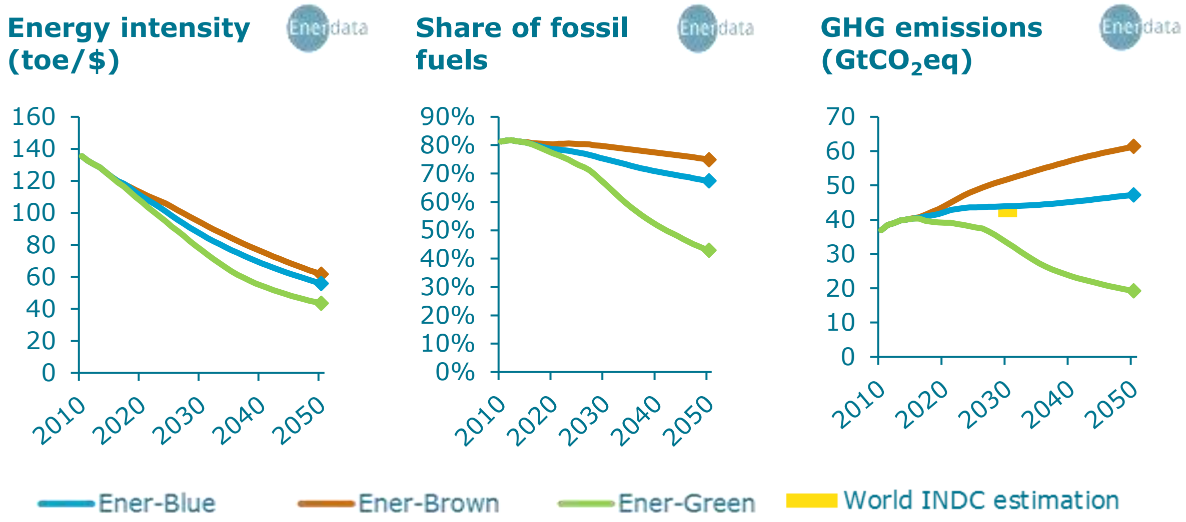
2. **Energy efficiency increases** in the three scenario cases, including in the baseline: while the primary energy intensity (measured as energy consumption per unit of GDP) has historically declined at a rate of -1.5%/year between 2000 and 2015, the decoupling increases by 2050, with -1.9%/year in Ener-Brown, -2.2%/year in Ener-Blue and up to -2.9%/year in Ener-Green

3. The share of fossil fuels decreases, but without an ambitious climate policy, **fossil fuels continue to be the main energy sources of global energy mix**: they still represent 75% of the mix in 2050 in Ener-Brown and 67% in Ener-Blue. The 1.5-2-degree goal in Ener-Green allows reducing this share to 43% against 80% currently.
   Production costs of green energies keep reducing, and **the renewable energy development** will increase its share from 14% in 2015 to 18% in 2050 in the least ambitious configuration (Ener-Brown), while its competitiveness increased with more active policies: 24% in Ener-Blue and 41% in Ener-Green.

4. According to Ener-Brown scenario, **a sharp increase in greenhouse gas[5] (GHG) emissions** is expected (+50% by 2050), in a context of weak climate policies combined with low fossil fuel prices. This could lead to an increase in temperature of +5-6°C by the end of the century.
   The establishment of INDCs, as submitted today, would help to contain the increase to +20% (+3-4°C by 2100), which is still far from the 1.5-2°C global goal that **requires regular revisions of national contributions**, reflected in Ener-Green scenario. The effort compared to the baseline scenario would require an additional cumulative emissions reduction of 40% between 2015 and 2050 (corresponding to nearly **800 GtCO2eq avoided**).

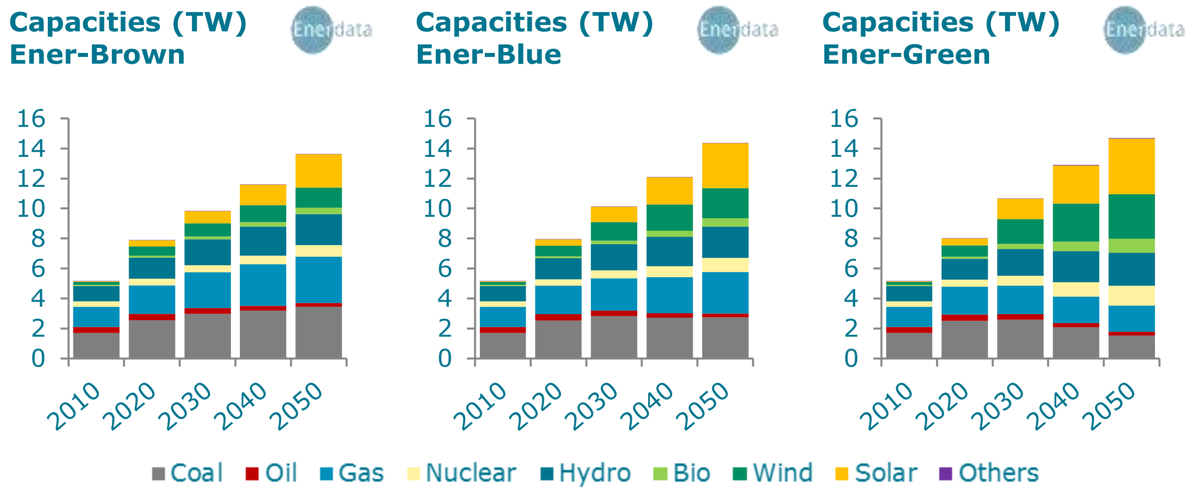
[5] Excluding Agriculture, forestry and other land uses (LULUCF) that are not covered

Figure 3– Global energy indicators for the 3 Enerfuture scenarios



5. The share of electricity demand is growing (20% in 2015 to 26%-35% in 2050 depending on the scenario), and **the production of electricity will double by 2050**, which will involve significant transformations in the sector. **Investments in production capacity**[6] to meet this demand will be huge, between 630 $bn/year (Ener-Brown) and 780 $bn/year (Ener-Green) compared to an average of 550 $bn/year over 2000-2015 period.
   The electricity mix will change substantially and the use of renewable energy rises in all scenarios, particularly **solar and wind power which benefit from increasingly competitive production costs**. A total of 4 TW of new solar and wind capacities will be put into service by 2050 in Ener-Brown and twofold (9 TW) in Ener-Green (60% from Non-OECD countries).

Figure 4 – Installed capacities for the 3 Enerfuture scenarios (world)



[6] These investments relate only to production capacity, investments related to networks, are not covered by this study

2.2.1. INDC contributions

To meet the global climate change challenge, policymakers around the world have agreed to commit on **emission reduction targets that shall be included in their Intended Nationally Determined Contributions** (162 INDCs submitted today covering more than 99% of global GHG emissions of the 169 countries represented[7]).

Often presented under a range format with unconditional and conditional criteria, **these commitments are characterized by a wide variety from one country to another**. They differ on the form of emission reductions (relative to BaU, absolute, intensity, policies and actions), type of emissions (CO2, total GHG), sectoral coverage (economy-wide or only certain sectors), reference year (1990, 2005 2010 or other or relative to a baseline), and even target year (2025, 2030 and beyond), which makes analysis difficult (see summary table of INDCs for selected countries in *Figure 5*).

Figure 5 – General information on the 162 submitted INDCs

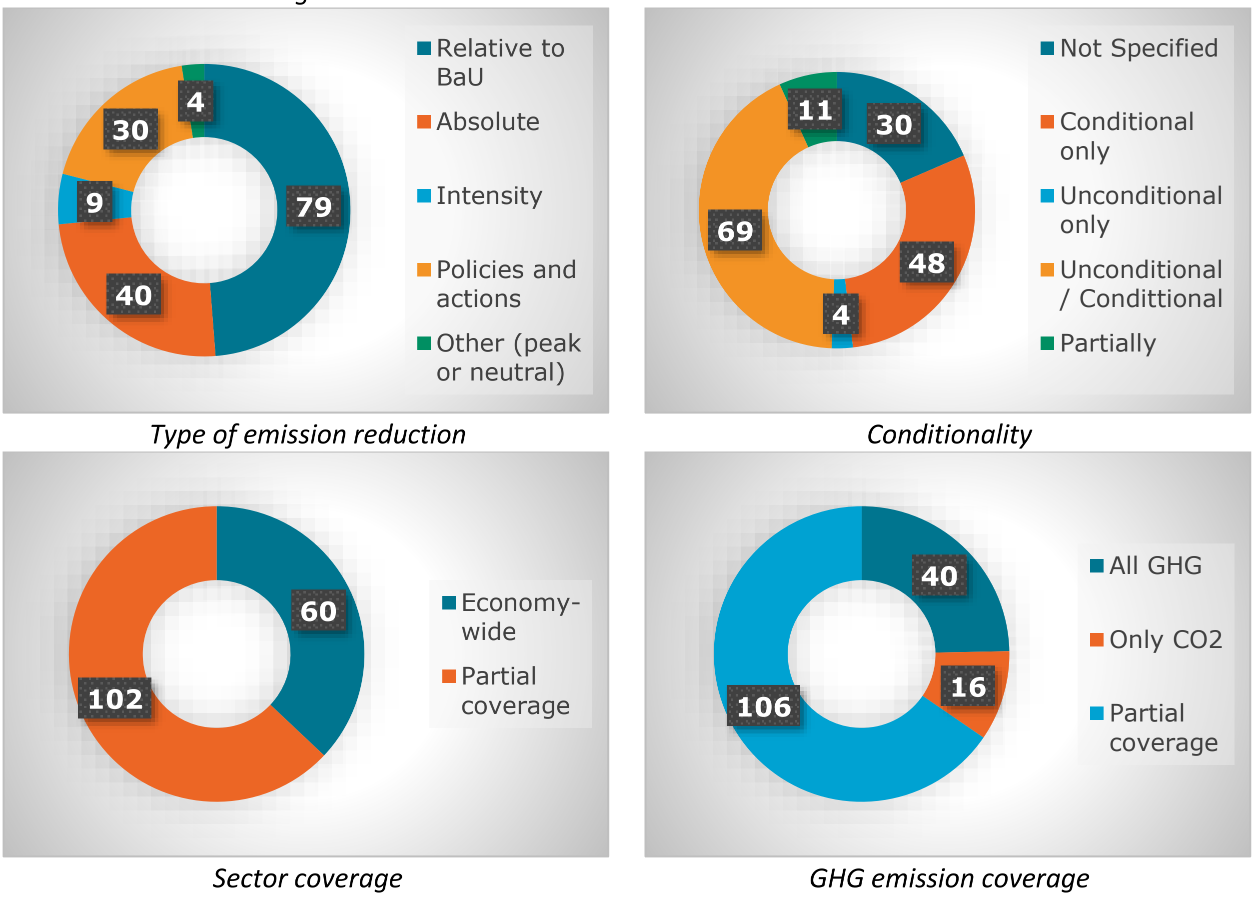


Figure 6 details the INDCs of selected countries for this study and provides INDC mitigation target ranges of absolute emissions by 2030 (orange color) with scope adjustment estimations to energy-related sectors covered by POLES (blue color).

[7] 162 submitted INDCs over 169 parties (EU is counted here as 1 which includes 28 Member States)

Figure 6- INDC detailed table for some countries

Countries	OECD	Type of target	Total mitigation effort		Reference Year	Reference Year		GHGs included	Sectors included	Target Year
			Unconditional (Low)	Conditional (High)		(intensity or emissions)	*Unit*			
China	Non-OECD	% Intensity/GDP	60%	65%	2005	0.78	*kgCO2eq./$15*	CO2 Only	All	2030
India	Non-OECD	% Intensity/GDP	33%	35%	2005	0.41	*kgCO2eq./$15*	All GHG	All	2030
Indonesia	Non-OECD	%	29%	41%	BaU	2 881	*MtCO2eq.*	CO2, CH4, N2O	All	2030
Thailand	Non-OECD	%	20%	25%	BaU	550	MtCO2eq.	All GHG	All	2 030
Vietnam	Non-OECD	%	13%	25%	BaU	787	*MtCO2eq.*	All GHG	All	2030
Brazil	Non-OECD	%	43%		2005	2 100	*MtCO2eq.*	All GHG	All	2030
Mexico	OECD	%	22%	36%	BaU	973	*MtCO2eq.*	All GHG	All	2030
Turkey	OECD	%	21%		BaU	1 175	*MtCO2eq.*	All GHG	All	2030
Egypt	Non-OECD							All GHG	All	2030
South Africa	Non-OECD	MtCO2eq.	398	614				All GHG	All	2030

Countries	Mitigation target (MtCO2eq.)		Estimated mitigation effort at POLES scope*		Other mitigation trends	Other sectoral mitigation targets
	Unconditional (Low)	Conditional (High)				
China	14 027	12 273	14 027	12 273	GHG emissions Peak around 2030 and making best efforts to peak early	Share of non-fossil fuels in primary energy consumption around 20% by 2030
India	4 855	4 710	4 337	4 208		40% power installed capacity from non-fossil fuel by 2030
Indonesia	2 046	1 700	1 253	994		Renewable (primary) energy target of 23% by 2025 (NEP14)
Thailand	440	413	347	325	30% emission intensity reduction per unit of GDP for 2036 compared to 2010	20% share of power generation from renewable sources in 2036 (PDP)
Vietnam	689	590	614	481	20% emission intensity reduction per unit of GDP for 2030 compared to 2010	
Brazil	1 197		863	602		45% of renewables in the energy mix by 2030
Mexico	759	623	690	563	Consistent with pathway to reduce 50% of emissions by 2050 compared to 2000	
Turkey	928		855		20% emission intensity reduction per unit of GDP for 2023 compared to 2011 (EE2023)	
Egypt					Emission reduction for 2030 at the lowest cost to the national economy	
South Africa	398	614	377	673	GHG emissions trajectory peak by 2020	

Benchmarking INDC ambitions

First step is to **harmonize different objectives** to be able to compare ambitions. One way of assessing mitigation effort is to look at GHG emissions and particularly at emission intensities per unit of GDP or per capita.

To estimate the drivers of INDC scenarios for the different countries, we often faced two types of issues:

- Lack of information in INDC documents
- Level of Business As Usual (BaU) emissions, on which mitigation targets refer, are generally not explicitly described (BaU can also be modified over the commitment period).
- Unclear scope under the mitigation target, especially on covered sectors (e.g. with or without LULUCF)
- Scope problem between emissions covered in INDC and in POLES. POLES does not cover emissions from LULUCF and non-CO2 agriculture (see Annex 1 for POLES GHG coverage details).

To solve these issues, we used different sources to collect information from the INDCs and to adapt them to POLES coverage like CAT, WRI, our Enerdata global energy and CO2 database, UNFCCC database and national forecasts (National Communication, Biennal Report or other energy plans) (see references). When mitigation targets are carbon intensities per unit of GDP (China and India), we used GDP forecasts from CEPII (baseline version: 2.3 (2014-10)) to estimate resulting emission by the target year.

Emission reductions for energy systems per unit of GDP (carbon intensity) allows **taking into account the overall level of the economy**. Results differ greatly depending on the chosen reference year: for example, China's commitments appear ambitious when compared to its performance in 1990 but must be relativized if we consider the current situation. Moreover, the indicator does not take into account the efforts of LULUCF sector (the focus here being energy systems). Then commitments from a number of countries, for which this sector will greatly contribute to the decarbonization of the economy, appear unambitious (e.g. Brazil's INDC shows ambitious economy-wide mitigation target with -37% GHG reduction by 2020 compared to 2005 level that still leaves space to an increase of GHG emissions for energy-related sectors by 2030). When looking at G20 members, 2 countries seem particularly non proactive: Turkey and Saudi Arabia expect an increase of their carbon intensity by 2030 (*Figure 7*).

We can also observe that some regions aspire to significantly reduce their emissions per capita in their INDC framework. Some major emitters such as China, India and Turkey plan to continue to increase their emissions per capita in the future (*Figure 8*).

Figure 7 – Carbon intensity development resulting from INDCs by 2030 (for energy related emissions only)

Compared to 1990 | *Compared to 2015*

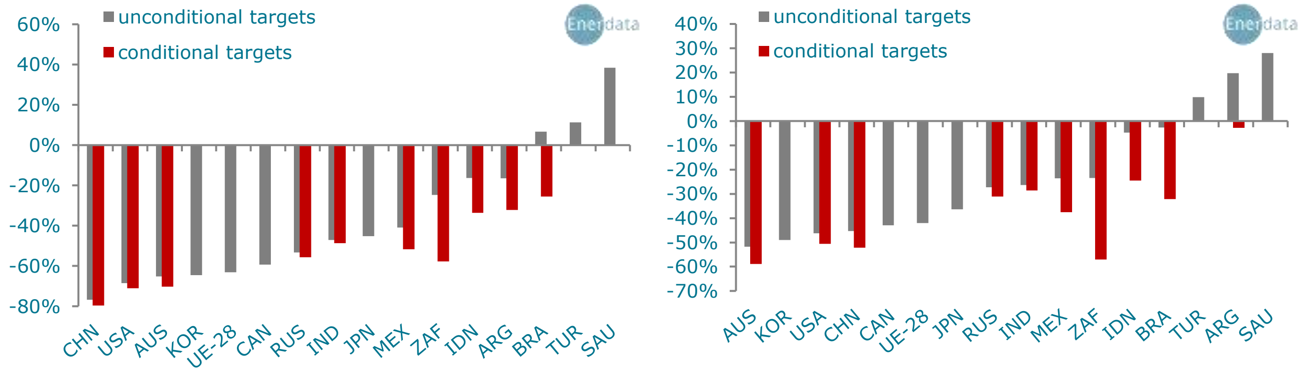


Figure 8 – INDC emission development per capita by 2030 (for energy related emissions only)

Compared to 1990 | Compared to 2015

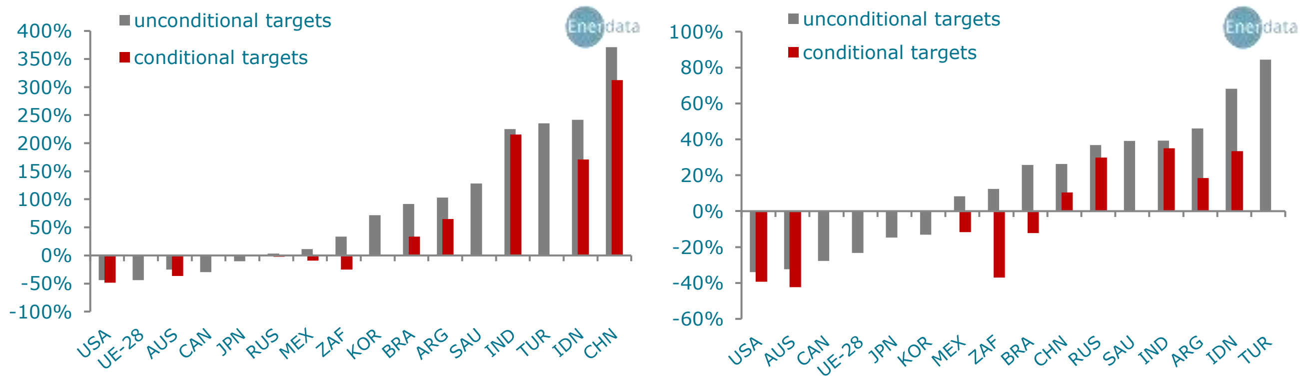
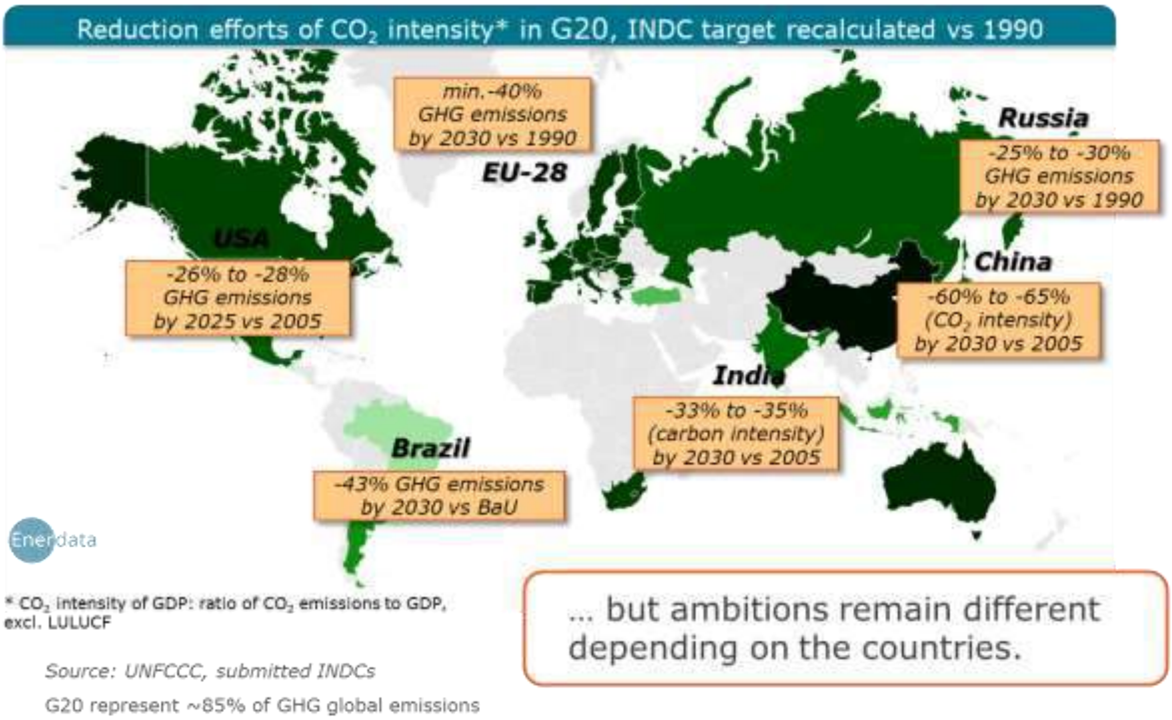


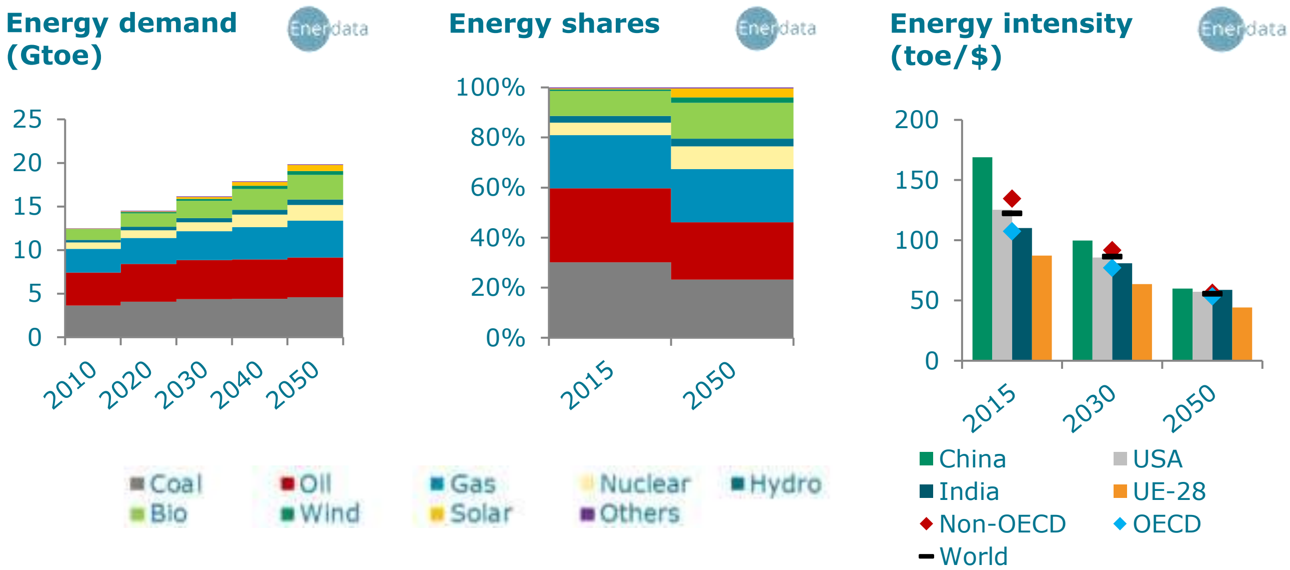
Figure 9 - Reduction efforts of CO2 intensity in G20, INDC target recalculated vs 1990



Implications on energy demand and on GHG emissions

Analysis of Ener-Blue scenario shows that mitgation goals, announced in INDCs, lead to a diversification of energy sources as well as a decoupling between energy consumption and economic activity.
Even if fossil energies still dominate the mix in 2050 (67%), wind and solar energies show the fastest growth (4.9%/year and 7.4%/year respectively) and the share of renewables reach 24% in 2050 against 14% only in 2015.
In parallel, energy efficiency and conservation are improving, and energy intensity per unit of GDP is reduced by more than half: for the same economic value creation (GDP), less than half the energy needed today will be consumed in 2050. Energy savings options are particularly important in China that reaches the level of United States, and generally efforts of non-OECD countries become similar to those of most developed countries.

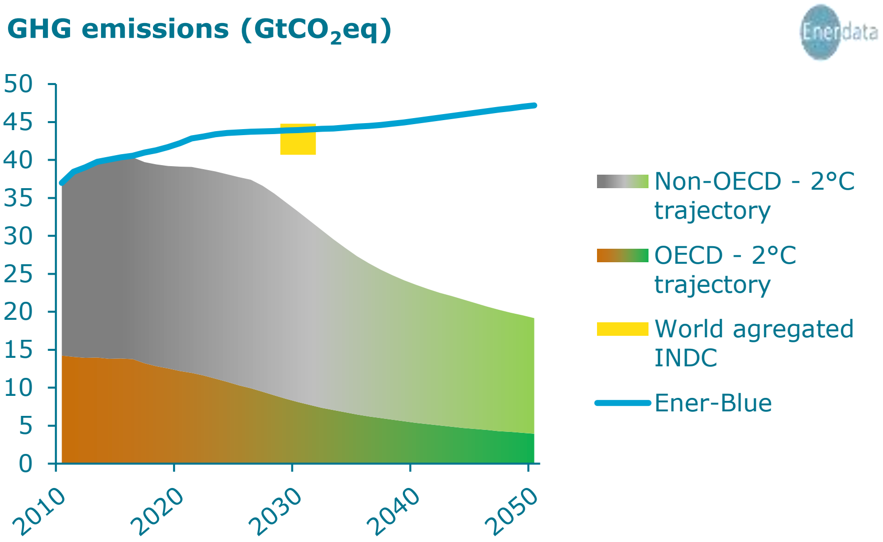
Figure 10 – World primary energy demand - Ener-Blue



In an international context of coordinated climate policies (Ener-Blue), increased GHG emissions slows. However, **efforts defined in INDCs are not sufficiently ambitious to limit the average global temperature**

increase well below 2°C by 2100. They might lead instead to an increase in temperature about 3-4°C by the end of the century.

Figure 11- INDCs versus 2°C trajectory. Global GHG emission forecasts for Ener-Blue and Ener-Green.

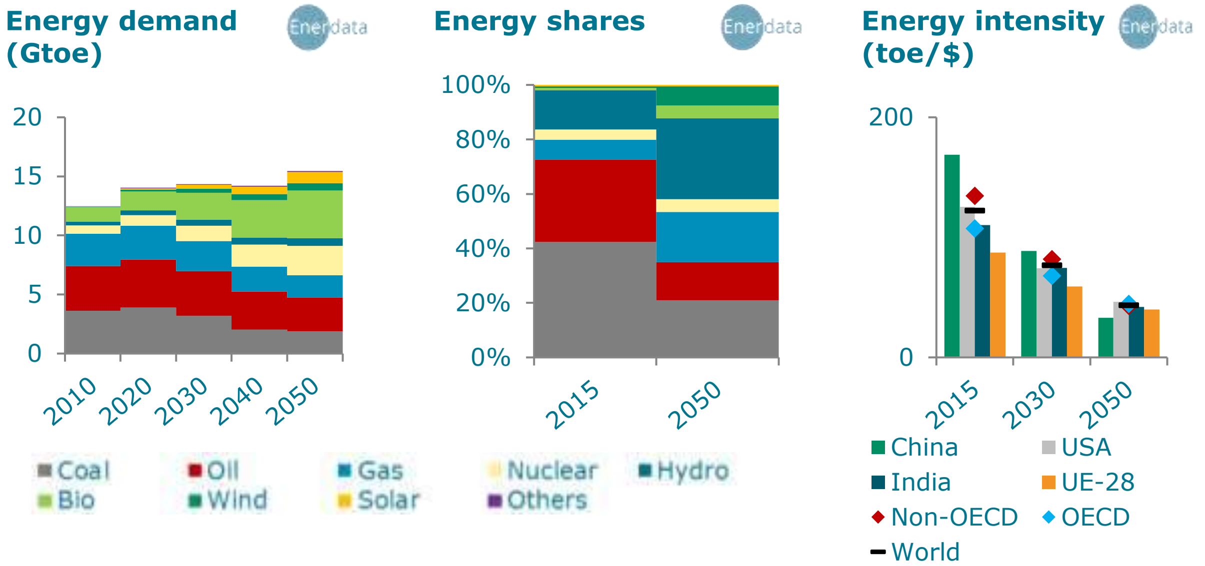


2.2.2. Ambitious climate trajectories compatible with Paris Agreement

Implications on energy demand and on GHG emissions

In Ener-Green scenario, a clear transition of current energy system is carried towards a long-term decarbonization, with considerable efforts on energy efficiency, decisions taken to remove fossil fuels subsidies and strong diffusion of renewable technologies.

Figure 12 – World primary energy demand - Ener-green



This transition is made possible by policies implemented both at national and international level and with strict constraints on carbon. The development of low-carbon technologies plays a major role, supported by significant efforts in research and development to reduce their costs and to improve their performances.

Although still significant in the global energy mix, fossil fuels are no longer predominant (43% in 2050) and, compared to the baseline scenario, about **80 Gtoe of coal consumption is avoided during 2015-2050 period**. In particular, production of electricity from coal, first electricity source in 2015 (41% of world electricity production), tends to disappear (only 13% in 2050) despite the development of nearly 650 GW of CCS coal capacities. Meanwhile, nearly **70% of investments in this sector go to renewable technologies.**

Energy efficiency and conservation play a critical role. **Energy intensity (per unit of GDP) is almost divided by three** in 2050 (-65%). International cooperation and convergence of best practices between developed and developing countries will generate about **130 billion toe of cumulated energy savings** over 2015-2050 period compared to the baseline scenario.

In terms of GHG emissions, Ener-Green considers that concrete and rapid actions are taken under Paris Climate Agreement and that governments commit to revise and enhance their mitigation targets every 5 years.
To be compatible with a 2°C trajectory pathway following the recommendations of the assessment report (AR4, Assessment Report) of the Intergovernmental Panel on Climate Change (IPCC), this "green commitment" would lead to a 50% reduction of global emissions by 2050 compared to 2010.

In our Enerfuture scenarios, as in most of IPCC's assessed mitigation scenarios, we assume that the large-scale rollout of CO2 capture and negative-emission technologies is technically, economically, and socially viable. This, in addition to an important shadow carbon price incentive that not only promote the development of negative-emission and CO2 capture technologies but also renewable energies and energy efficiency, will allow GHG emissions pathway to stay in line with IPCC recommendations.

Effort sharing

Based on the IPCC recommendation referred to above, the additional cumulative effort, from INDCs commitments (Ener-Blue) to a climate ambitious scenario (Ener-Green), thus amounts to about 500 GtCO2eq (*Figure 13*), which involves ambitious emission reduction contributions from all world regions, including the least developed countries. OECD countries should reduce about 75% of their GHG emissions compared to 2010 (factor 4). The rest of the effort is distributed between non-OECD countries according to various criteria (economic circumstances, INDC, historical responsibility).
Three quarters of this additional effort will then be made by non-OECD countries (similar effort sharing is also expected by IEA) and over 1/3 would be realized in China. Several indicators (efforts in carbon intensity per GDP or per capita) were used to arbitrate between the different regions.

Looking at the mitigation efforts from the baseline (Ener-Brown) to a climate ambitious scenario (Ener-Green), the cumulative effort amounts to about 800 GtCO2eq avoided (*Figure 14*).

Figure 13 – Additional cumulative GHG emission reduction (2015 – 2050) by major regions between INDC and 2°C scenarios

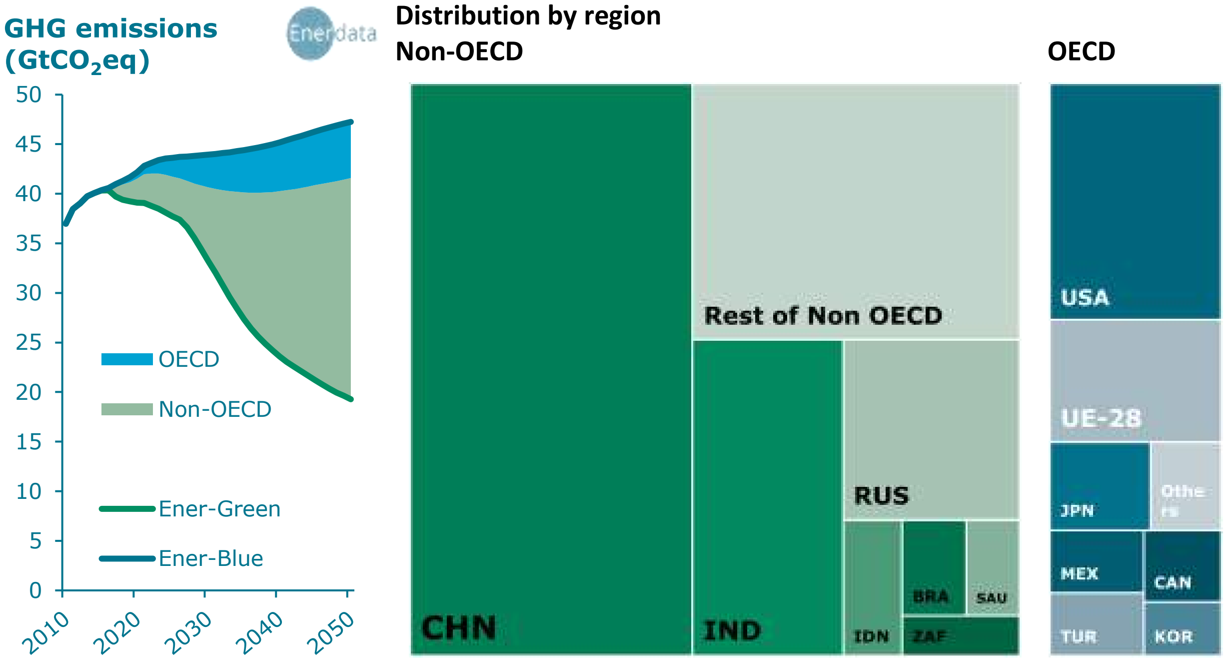
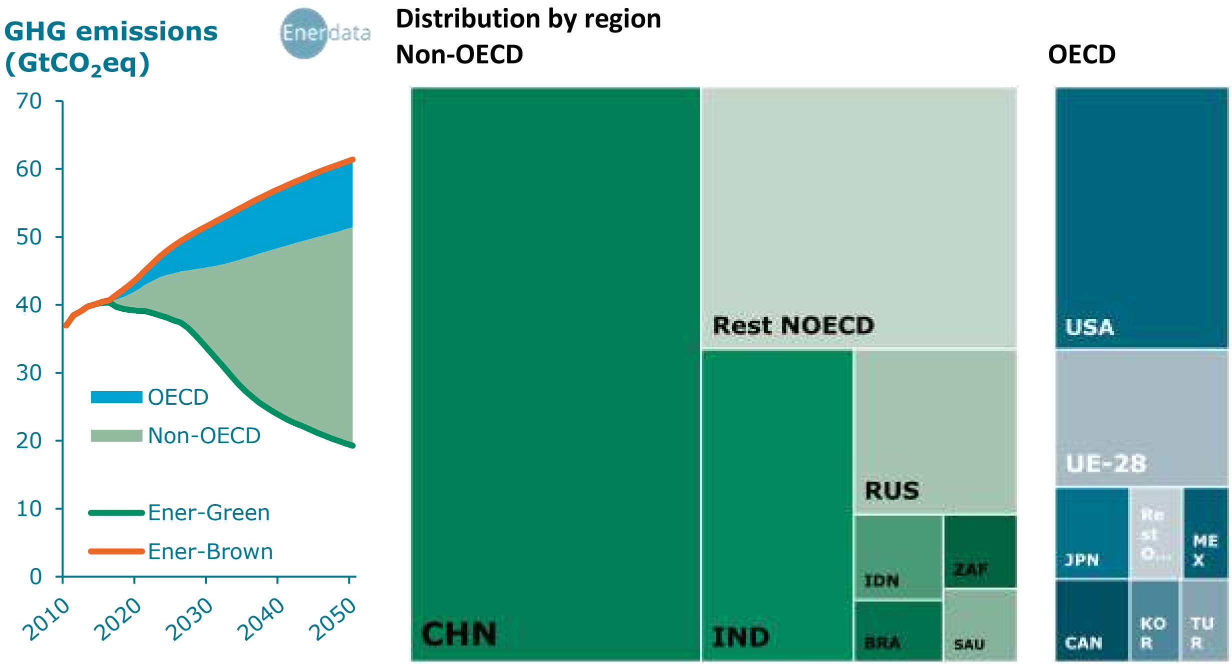


Figure 14 – Total cumulative GHG emission reduction (2015 – 2050) by major regions between Baseline and 2°C scenarios



Efforts by regions between baseline (Ener-Brown) and 2°C scenario (Ener-Green) show similar distribution and regions' contribution than efforts between INDCs (Ener-Blue) and 2°C scenario (Ener-Green). INDCs are engaging efforts in the direction to what would be necessary to satisfy Paris agreement but may account to only about 1/3 of needed accumulated GHG emission reductions by 2050. All regions must increase mitigation efforts over time. *Figure 15* represents the normalized cumulated GHG emissions reduction by key regions for both gaps between Ener-Brown/Ener-Green (normalized values) and Ener-Blue/Ener-Green. INDCs might represent almost 50% of OECD accumulated GHG emission reduction efforts to 2°C scenario and about 1/3 for Non-OECD.

Figure 15 – Normalized accumulated (2015-2050) GHG emission reduction efforts compared to Ener-Brown/Ener-Green effort

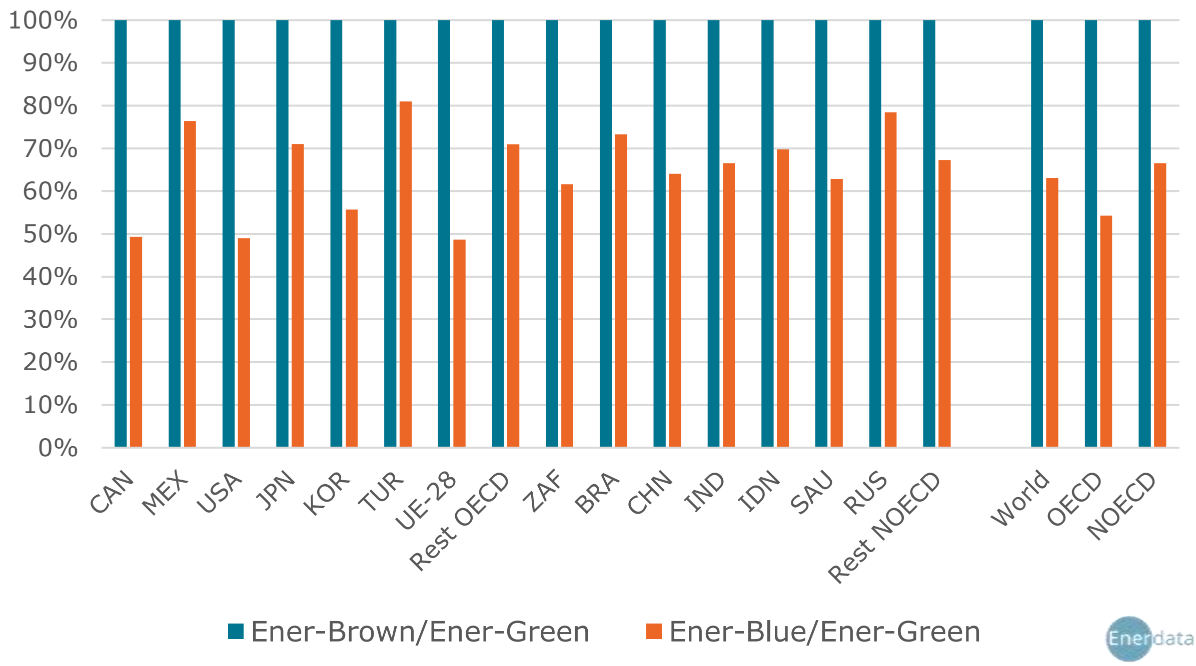


Figure 16 – Cumulated GHG emission reductions (2015-2050) by major regions – comparison with IEA

	Ener-Green vs Ener-Blue		IEA[8] (ETP 2016) scenarios 4°C scenario Vs 2°C scenario	
	Reduction effort	**Global share of effort**	**Reduction effort**	**Global share of effort**
World	**500.6 GtCO2eq**		**552.9 GtCO2eq**	
OECD	**119.3 GtCO2eq**	**24%**	**138.4 GtCO2eq**	**25%**
Canada	6.7 GtCO2eq	1%		
Mexico	7.2 GtCO2eq	1%	8.1 GtCO2eq	1%
United States	49.2 GtCO2eq	10%	62.6 GtCO2eq	11%
Japan	10.8 GtCO2eq	2%		
South Korea	5.1 GtCO2eq	1%		
Turkey	7.2 GtCO2eq	1%		
EU-28	25.5 GtCO2eq	5%	30.7 GtCO2eq	6%
OECD remains	7.5 GtCO2eq	2%		
Non-OECD	**381.4 GtCO2eq**	**76%**	**414.3 GtCO2eq**	**75%**
South Africa	5.3 GtCO2eq	1%	8.4 GtCO2eq	2%
Brazil	6.7 GtCO2eq	1%	8.4 GtCO2eq	2%
China	176.1 GtCO2eq	35%	148.8 GtCO2eq	27%
India	52 GtCO2eq	10%	84.4 GtCO2eq	15%
Indonesia	8.8 GtCO2eq	2%		
Saudi Arabia	5.6 GtCO2eq	1%		
Russia	34.7 GtCO2eq	7%	27.9 GtCO2eq	5%
rest Non OECD	92 GtCO2eq	18%		

Figure 17 – Carbon intensity (per GDP) reduction by 2050 for the 3 Enerfuture scenarios

Compared to 1990 / Compared to 2015

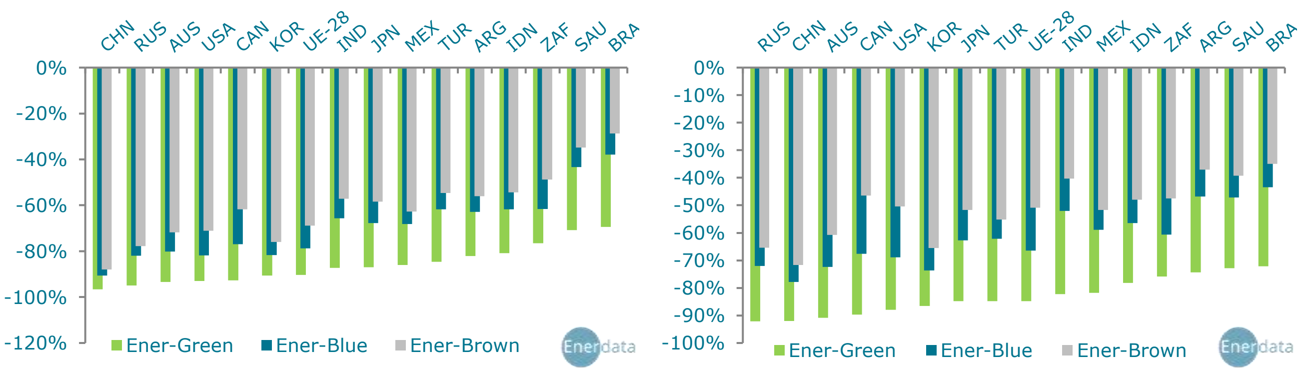
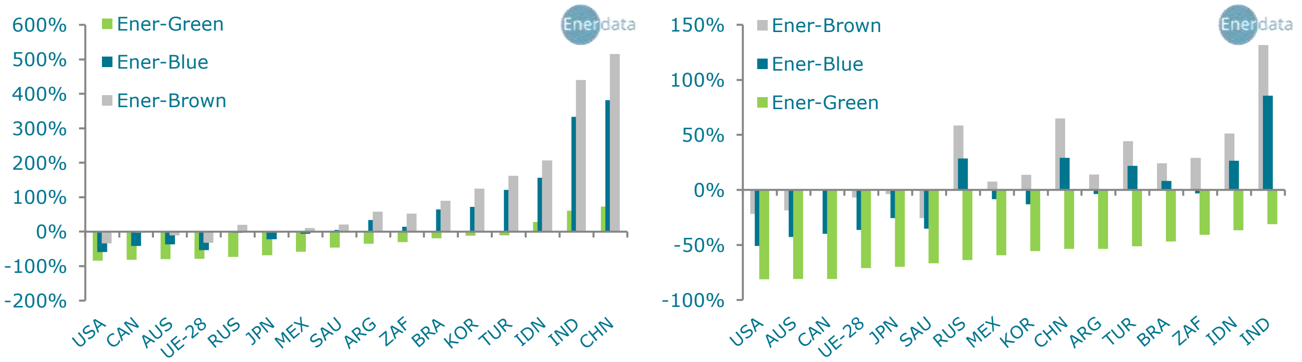


Figure 18 - Carbon intensity (per capita) reduction by 2050 for the 3 Enerfuture scenarios

Compared to 1990 / Compared to 2015



[8] IEA cumulative emission reductions are estimates based on CO_2 emissions from 2°C and 4°C scenarios (Energy Technology Perspectives 2016, http://www.iea.org/etp/) which are the closest to our scenarios. Non-provided years were interpolated to estimate the cumulative emission reductions and the same GHG/CO_2 ratio (by region) was applied

3. Analysis of energy and climate trajectories for developing and emerging economies

There is no unique global solution on climate change. Solutions would rise from the combination of a multitude of initiatives that reflect the diversity of national circumstances. Thus understanding development patterns and efforts in regard to GHG emission mitigation actions of each country are key in the fight against climate change. In this study, we provide detailed analysis of mitigation drivers for different countries and regions by looking at their energy trajectories from 2014 to 2050 for the 3 presented scenarios in above sections (baseline, INDC and 1.5-2°C scenarios).

To get a representative panel of emerging and developing countries, we selected countries from all continents (*Figure 19*). Considering the limitation that countries should be represented in POLES (see **Annex 1**), we chose to cover all BASIC countries (Brazil, South-Africa, India and China) as well as other emerging economies like Mexico, Indonesia and Turkey. Finally, we selected also 3 developing economies (Egypt, Vietnam and Thailand). In addition to countries, we studied also energy trajectories of regions that allows providing information about how countries are contributing to the region energy transformation but also providing aggregate information for non-covered countries within the region. 3 major regions are studied (Africa, Non-OECD Asia, and Latin and Central America). Africa is divided in 2 sub-regions (North Africa and Sub Saharan Africa) where Sub Saharan Africa include South Africa and Rest of Sub Saharan Africa sub-region.

Figure 19 – Selected countries and regions

Geographic zones	Countries
Africa	
North Africa	Egypt
Sub Saharan Africa	South Africa
	Rest of Sub Saharan Africa
Non-OECD Asia	China
	India
	Indonesia
	Vietnam
	Thailand
Latin and Central America	Brazil
	Mexico
Other *(not included)*	Turkey

Selected countries and regions also show a wide variety of macroeconomic assumptions[9] (population, GDP and income forecasts to 2050). The strongest activity growth is expected in the Asia (primarily India and China, and to a lesser extent Indonesia and Vietnam) and Africa, while more moderate growth is expected in countries like Brazil, Mexico, Thailand, South Africa and other OECD countries (*Figure 20*). The largest population growth will take place on the African continent, with 2.5%/year increase by 2020, before keeping on a lower growth rate until 2050 still well above the expected growth of the rest of the world (*Figure 21*). Income per capita for most of the countries and regions will still be lower than OECD levels by 2050 except for China and to a lesser extent for Turkey (*Figure 22*).

[9] Note that these assumptions are identical in the 3 scenarios (Ener-Brown, Ener-Blue and Ener-Green).

Figure 20 – Annual average GDP growth (%)
(High and low level highlighted in orange and blue respectively)

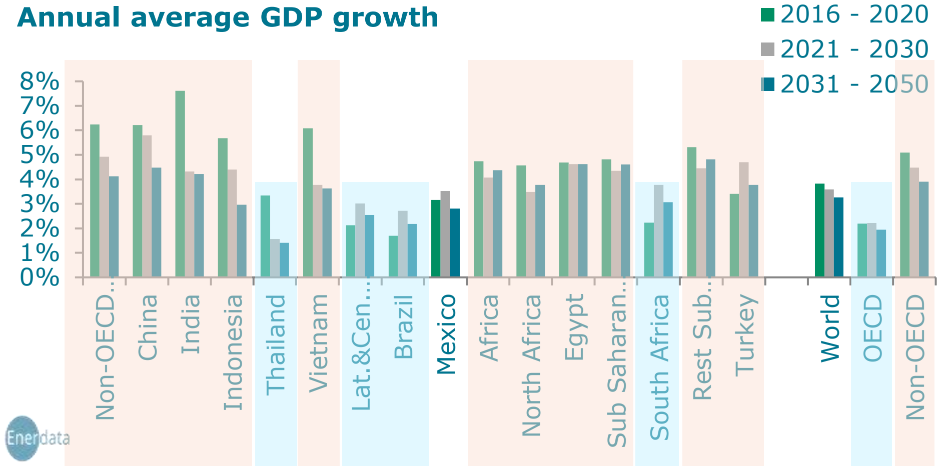


Figure 21 – Annual average population growth (%)
(High and low level highlighted in orange and blue respectively)

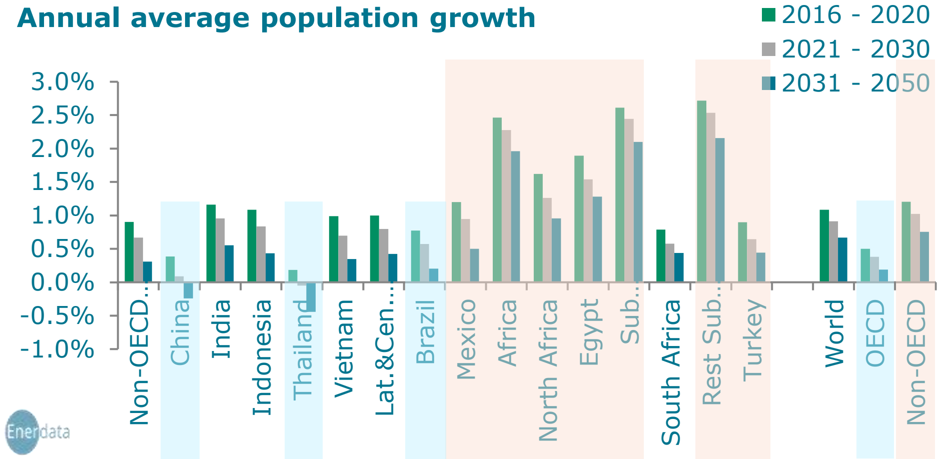
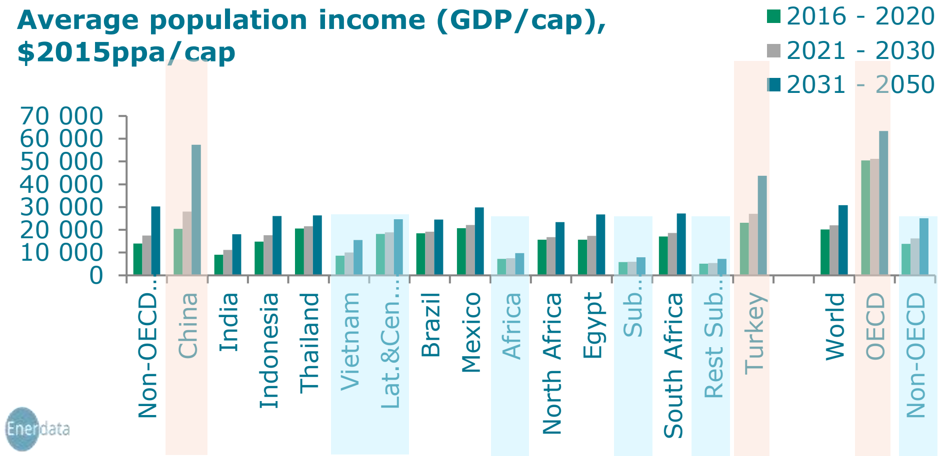


Figure 22 – Annual population income ($2015ppa/cap)
(High and low level highlighted in orange and blue respectively)

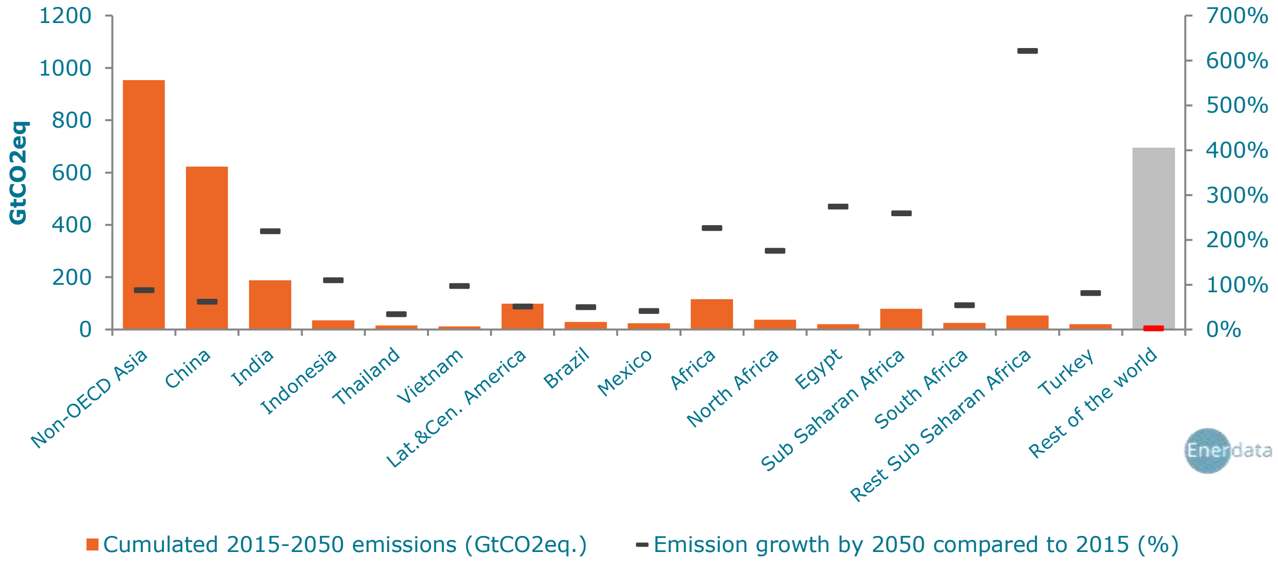


These demographic and economic trends by 2050 will lead in all these regions to a sharp increase in energy demand, and if no additional measures are taken (Business as Usual), this increase will be accompanied by a significant use of fossil fuels. Thus, in the Ener-Brown scenario, GHG emissions are increasing in all analyzed regions and countries; the diversity of macroeconomic contexts, however, will modulate this increase:

- GHG emissions in Africa triple between 2015 and 2050, largely because of highly dynamic demographic trends and improving population access to energy (reaching even more than 7 times 2015 levels by 2050 for rest of Sub Saharan Africa)
- Emissions double in Asia, linked to sustained economic growth; However, the decoupling of economic activity and GHG emissions is more pronounced which could be partly explained by the level of development (particularly in China, which becomes high-income countries) that induces a transformation of the economic structure.
- Increase of GHG emissions is less pronounced in Latin and Centrale America, but still reaches +50% even with weaker economic and demography growth conditions.

From 2015 to 2050, cumulated GHG emissions in the baseline scenario (Ener-brown) will come principally from Non-OECD Asia region (about 950 GtCO2eq) with China, the major contributor accounting for 620 GtCO2eq and emitting as much as the rest of the world (about 700 GtCO2eq) which includes all OECD countries. It would reach in total about 1900 GtCO2eq of global GHG emissions over 2015-2050 period far above the remaining carbon budget which is estimated between 600 and 1200 GtCO2eq[10] from 2015 onwards to keep chance to stay below 2°C temperature increase.

Figure 23 – Cumulated 2015-2050 GHG emissions and growth by 2050 compared to 2015 for Ener-Brown scenario



[10] Joeri Rogelj et al, Differences between carbon budget estimates unraveled, Nature Clim. Change, 2016 - "For a >66% chance of limiting warming below the internationally agreed temperature limit of 2 °C relative to pre-industrial levels, the most appropriate carbon budget estimate is 590–1,240 GtCO2 from 2015 onwards."

3.1. Different emission reduction trajectories between countries

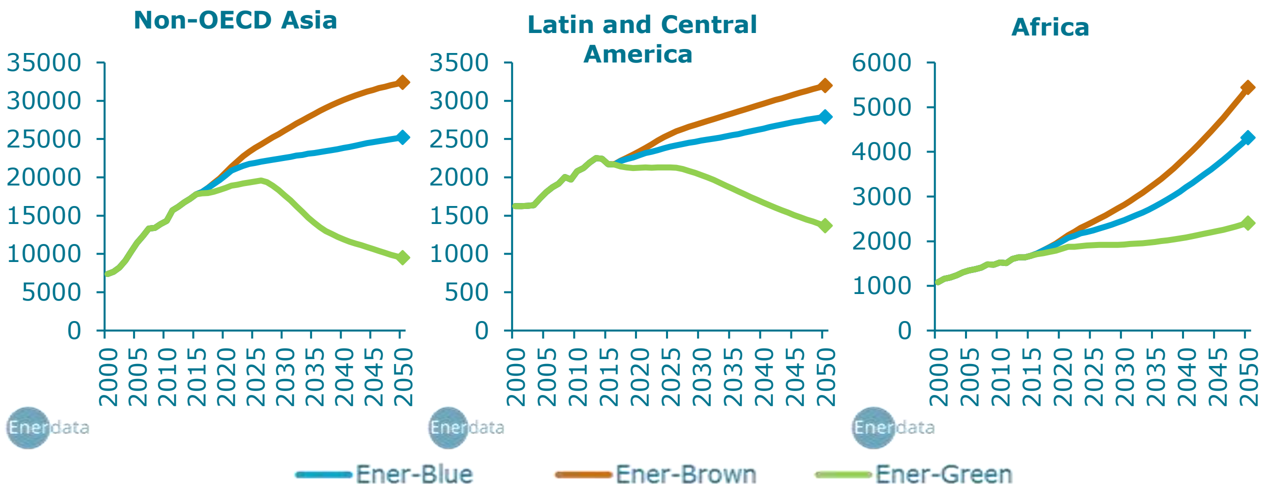
To limit the temperature rise to less than 5-6°C (Ener-Brown), this section presents the efforts to reach 2 alternative scenarios:

- INDCs scenario (Ener-Blue) where all countries achieved their pledges by 2030 and keeping then same effort trends to 2050.
- 1.5-2°C scenario (Ener-Green) where ambitious energy and climate policies are regularly enhanced and revised with the aim to keep the global average temperature increase below 2°C

The analysis shows both the trajectories of emissions reductions in various countries and regions, as well as the sectoral distribution of the requested efforts.

Starting by looking at the 3 main regions (Non-OECD Asia, Latin & Central America and Africa), we observe for all regions fast increase of GHG emissions from 2015 to 2050 for the baseline (Ener-Brown) (*Figure 24*). Increase is slowing down over the period for Non-OECD Asia and Latin & Central America, but not for Africa where emissions are rapidly increasing even in 2050.
Considering today's INDC mitigation targets (Ener-Blue), GHG emissions would be strongly reduced compared to the baseline. However, emissions would keep increasing and might now plateau before 2050.
Important additional effort would be needed to keep the global average temperature increase below 2°C. Only the climate ambitious scenario (Ener-Green) would allow GHG emission to peak between 2020 and 2030 in Non-OECD Asia and Latin & Central America. For Africa, even in a climate ambitious scenario, GHG would be tremendously decreased but might not peak by 2050.

Figure 24 – GHG emissions (excl. LULUCF) MtCO2eq



In Non-OECD Asia, GHG emissions per capita will reach OECD Ener-Blue levels by 2050 for the baseline scenario (Ener-Brown) and even for the INDC scenario (Ener-Blue), this indicator will become higher than the world average level by 2030. In Latin and Central America and in Africa, GHG emissions per capita will still stay lower than world average (Ener-Blue). As for absolute GHG emissions, emissions per capita would keep increasing even under INDC scenario. However, this indicator will decrease for all regions in Ener-Green scenario (*Figure 25*).

Figure 25 – Average GHG emissions per capita (tCO2/cap)

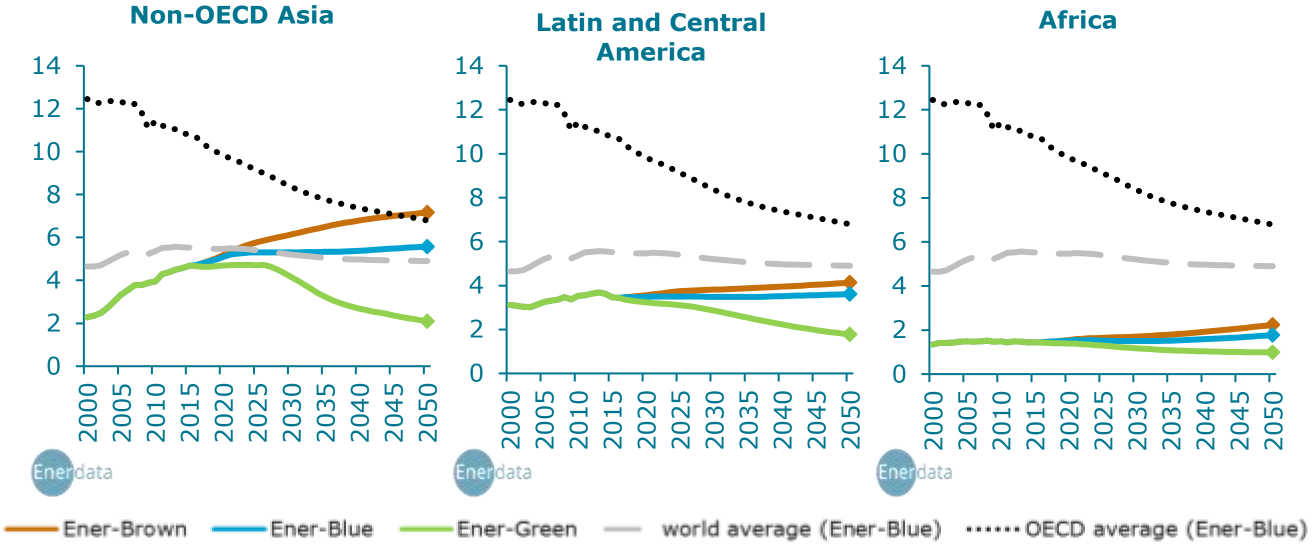
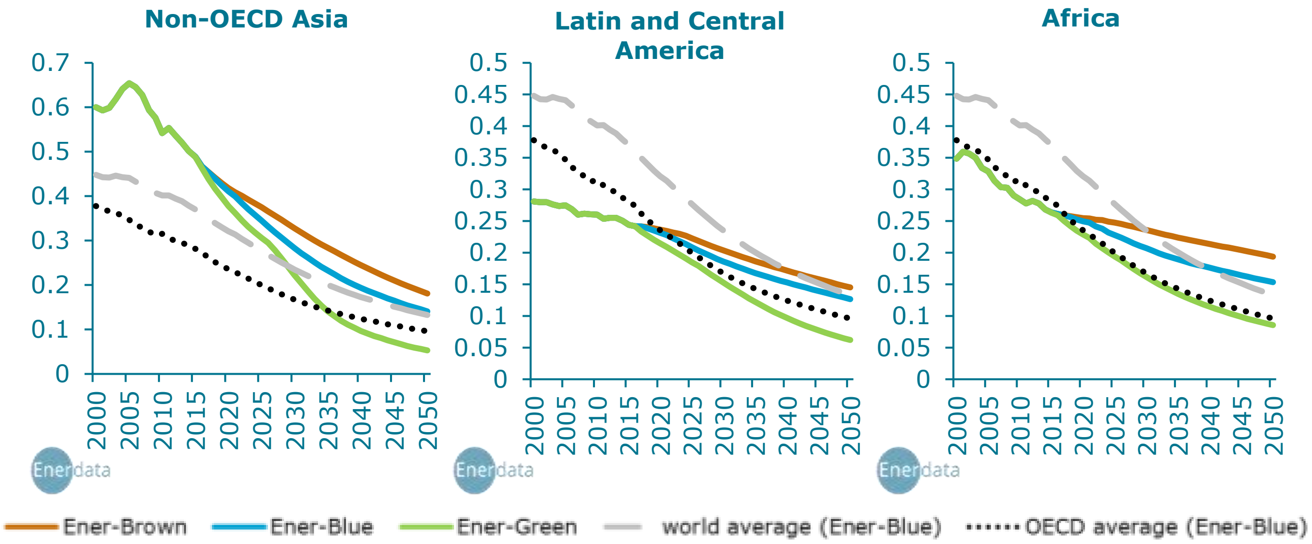


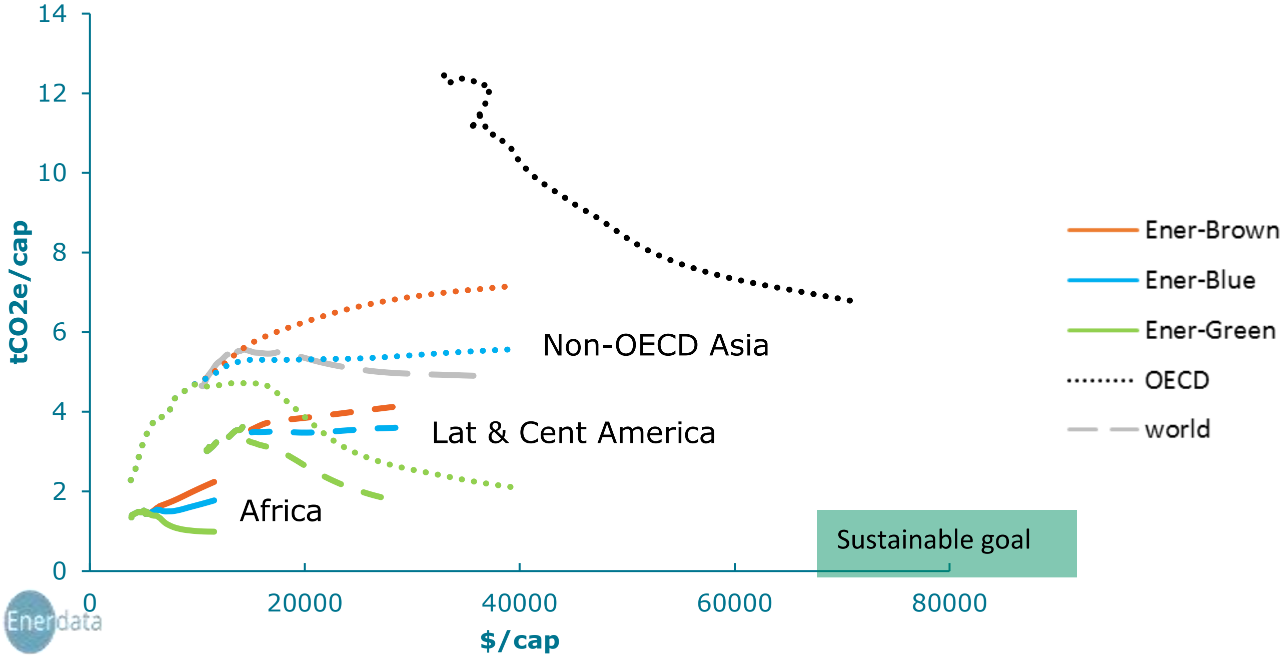
Figure 26 shows the average GHG emissions intensity per unit of GDP which is decreasing for all regions but at different rates. Starting for strongly different emission intensities, all regions are converging to similar range by 2050 between 0.1 and 0.2 kgCO2/US$15. Non-OECD Asia, with high emission intensity, will show the fastest decrease of its indicator over time. Latin and Central America which enjoyed today a low emission intensity (lower than OECD levels), would slowly reduce its intensity overpassing OECD and even reaching world average levels by 2050. For Africa, only Ener-Green scenario will pursue the historical decreasing trend to 2050. Its emission intensity for Ener-Brown and Ener-Blue would however show slower decrease and even might overpass world average levels.

Figure 26 – Average GHG emissions per GDP (kgCO2/US$15)



Comparing wealth (income per capita) and emissions per capita (*Figure 27*) **gives us information on the society structure**. Wealth has generally been supported by increase of energy consumption firstly provided by fossil fuel which generates the increase of GHG emissions per capita. Thus, in the figure, OECD countries show the highest emissions per capita which have been increasing over the last century before peaking. For the world and the 3 regions which include also emerging and developing countries, we could clearly see the direct correlation between wealth and emission. Regarding climate change, it is then important to stabilize and even peak as fast as possible and at the lowest emissions per capita. For the 3 regions, **in the baseline scenario all regions are pursuing an increasing trend over the period aiming to unsustainable development path**. INDC scenario allows reducing emission per capita compared to the baseline but does not change its trend. **Only Ener-Green scenario would guide the 3 regions to climate ambitious goal and sustainable development.**

Figure 27 – Average GHG emissions per capita (tCO2/cap) Vs incomes per capita ($/cap)



The emissions avoided between Ener-Brown and Ener-Blue scenarios allow **assessing the required effort to achieve the INDCs** for the different regions and countries, while comparison with Ener-Green provides information on the needed additional reduction efforts to be consistent with 1.5-2°C trajectories (*Figure 28*). To benchmark the effort, these reductions between scenarios are shown in terms of effort per capita (*Figure 29*). At the global scale, **the world would have to realize about -2.5 tCO_{2eq} per capita** to pass from the baseline scenario (Ener-Brown) to climate ambitious 1.5-2°C scenario (Ener-Green).

The three countries providing the biggest efforts compared to the baseline scenario (China -5.5 tCO_{2eq}/cap, South Africa -4.2 tCO_{2eq}/cap and Turkey -2.8 tCO_{2eq}/ cap in average over the period 2015-2050) are historically the major emitters where emission trends are even accentuated in the Ener-Brown scenario. The potentials of energy savings and of fossil fuel substitution are high in these countries with strong economic growth. Despite these substantial reductions**, China and South Africa stay among the largest emitters per capita**, while Turkey converges to the global average, which would be around 3.6 tCO_{2eq}/cap for Ener-Green scenario by 2050.

Apart from these three countries, other countries provide **an effort well below the world average one.**

Mitigation efforts (between -1 and -1.8 tCO_{2eq}/cap on average) of Latin American countries are more difficult to assess because of the large potential but also uncertain contribution of LULUCF sectors in this region (not covered this study). Excluding LULUCF, the region shows very low emissions per capita due in major part to a clean energy mix. Emissions per capita are below the world average and will remain in all scenarios.

In Africa, apart from the case of South Africa, we must distinguish between the North African countries, which would provide an effort -1.7 tCO_{2eq}/cap, to those in Sub-Saharan Africa with only -0.5tCO_{2eq}/cap compared to the baseline scenario.

Figure 28 –Cumulated 2015-2050 GHG emission mitigations (GtCO$_{2eq}$)

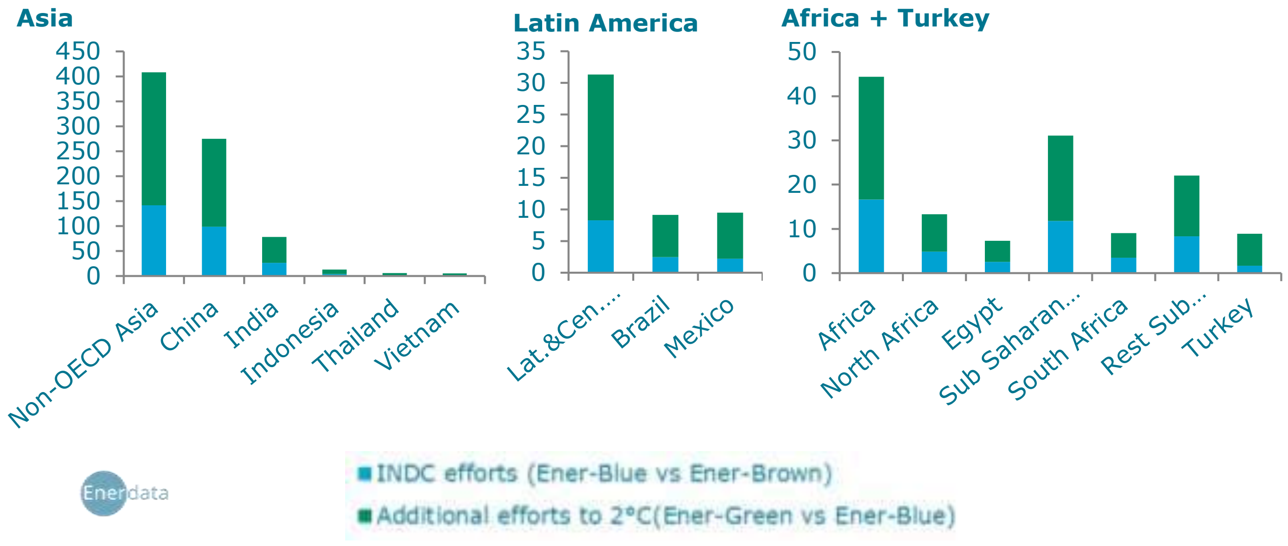
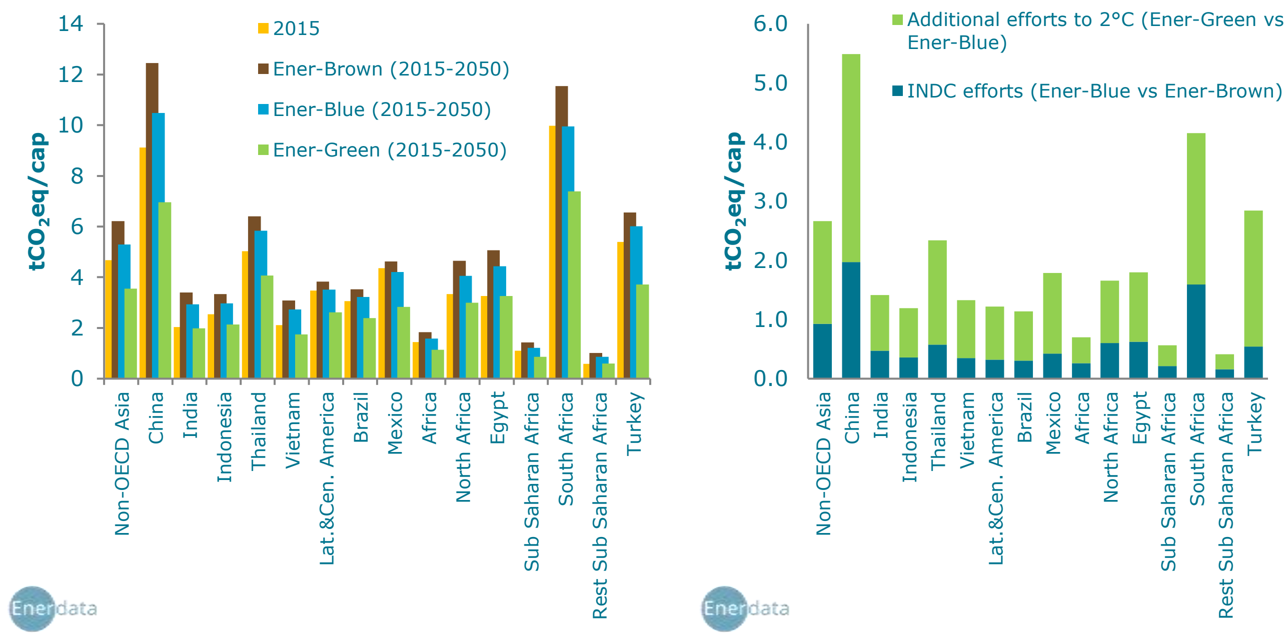


Figure 29 –Average 2015-2050 emissions per capita for the 3 scenarios compared to 2015 levels



These efforts vary by region, not only because of their ambitions but also as regards to the level of contribution of each sector to the reduction, measured in terms of avoided emissions between Ener-Brown and other scenarios. It is interesting to notice that sectoral contribution of avoided emission efforts would not be the same from Ener-Brown to Ener-Blue (*Figure 30*) than from Ener-Brown to Ener-Green (*Figure 31*). Power and industry sector would have to contribute more to needed additional efforts for closing the gap between the INDC and 2°C pathways.

Figure 30 –Sectoral contribution from Baseline to INDC pathways in studied regions (Gtoe)

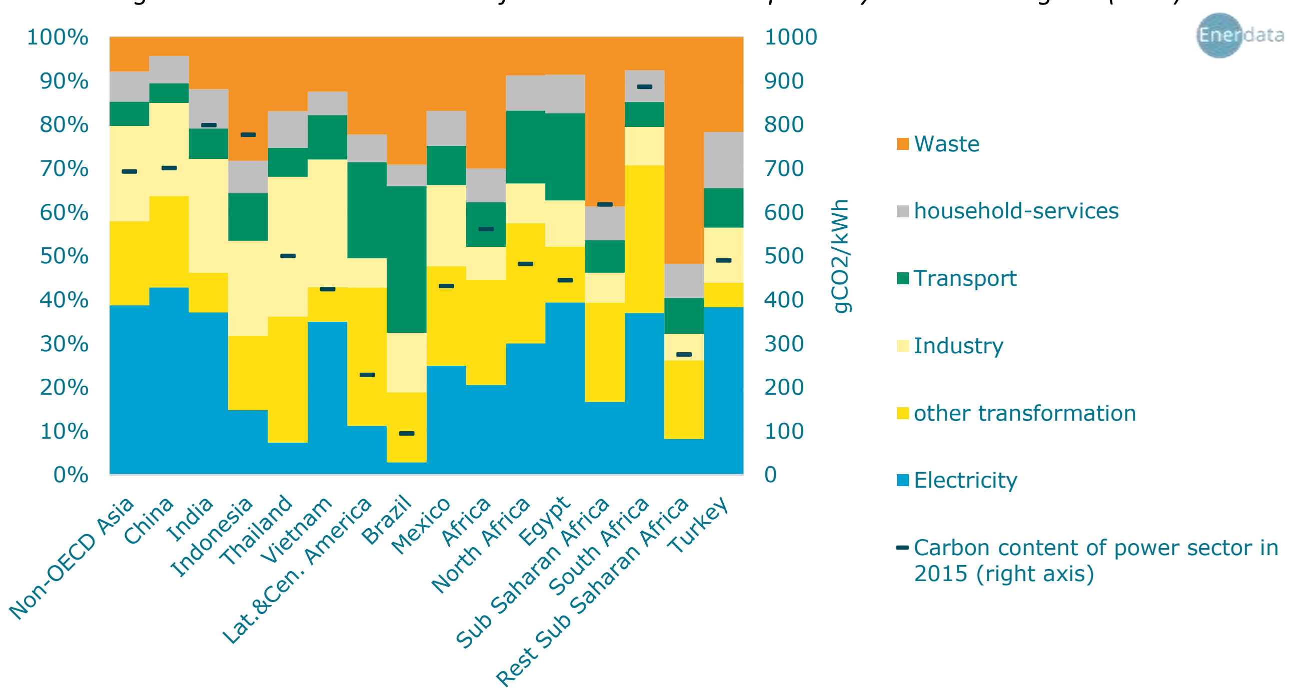
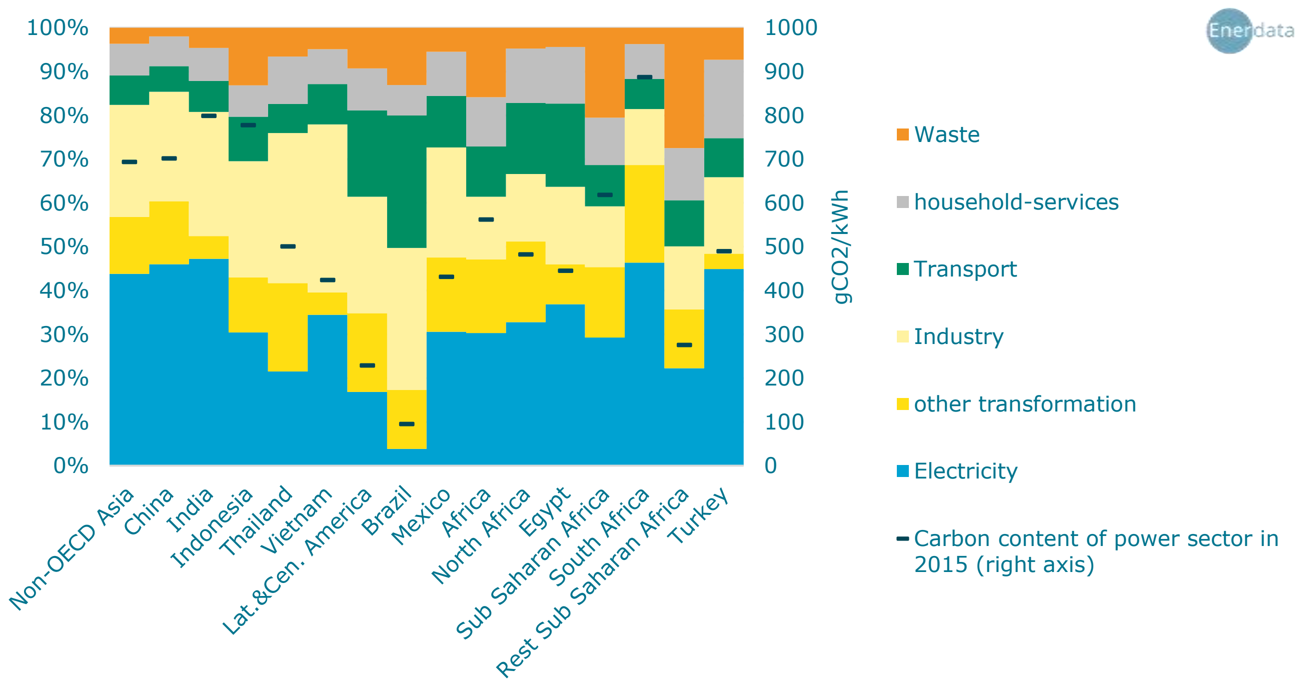


Figure 31 –Sectoral contribution from Baseline to 2° pathway in studied regions (Gtoe)



The role of the electricity production sector is crucial in most countries included in this study. This is particularly the case in Asia and South Africa where historical carbon contents are high due to the coal dominance in their mix (66% of electricity generation in Asia and 90% in South Africa in 2015). The replacement potential of these plants, by less emitting or carbon neutral technologies, is significant. In Latin America, and particularly in Brazil, the important use of hydro resources (53% of electricity production) is leaving few room for improvement.

3.2. Decarbonization of the energy sector based on 3 pillars:

3.2.1. Energy Efficiency

The **first essential pillar for a decarbonization of the energy sector is energy efficiency** with policies and instruments aiming to save energy. More precisely, energy efficiency requires action on energy intensity to **consume less energy per unit of wealth produced**, and on energy consumption per capita (household consumption and expenditure relating to economic activities). From a global perspective, the decarbonization pathways for achieving the 1.5-2°C goal (Ener-Green scenario) combine these two factors which are the result of an integrated effort covering both the consumption per capita and energy intensity.

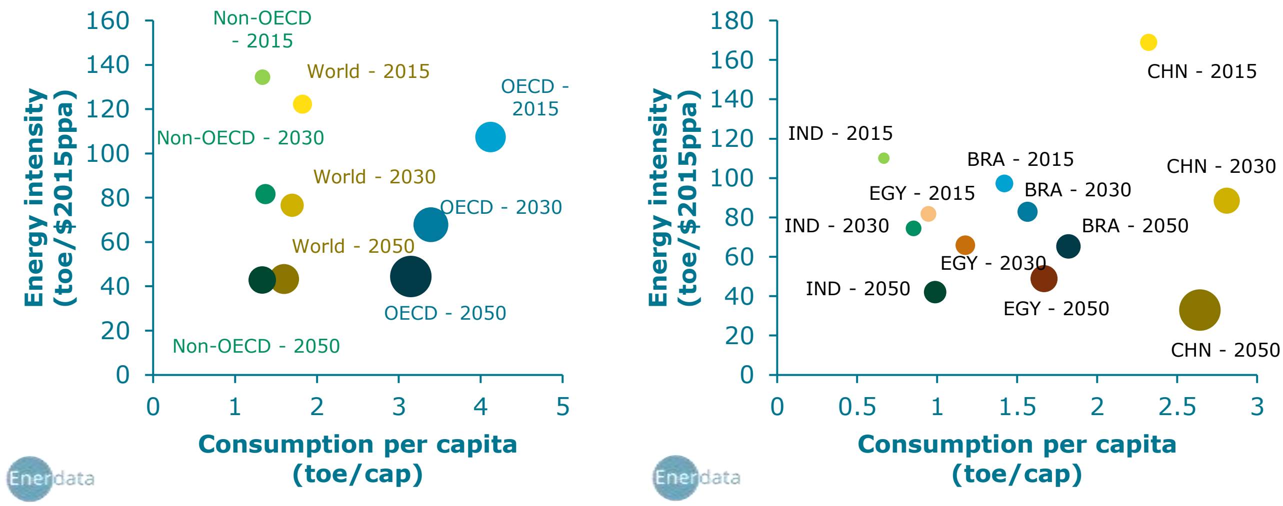
However, in a regional or national perspective, significant differences could be observed regarding the levers to improve energy efficiency. These are largely related to **national characteristics of studied countries**, and could be explained by analyzing separately developed and emerging countries.

Figure 32 compares the trend over time (2015, 2030, 2050) of these two indicators for some of individual countries or groups of countries, while noting also their level of wealth (the circle size is proportional the average income of the population).

In the OECD countries, although some efforts on energy intensity have already been made in the past (107 toe/$2015ppa in 2015 against 122 toe/$2015ppa worldwide), these **countries pursue energy efficiency efforts** on both levers, including a decline in consumption per capita over the period (4.1 toe/cap in 2015 to 3.1 toe/capita in 2050).

In Non-OECD countries, progress in energy efficiency are more linked to **energy intensity improvements**. For example, Chinese energy intensity decreases on average about 4.6%/year between 2015 and 2050, which is consistent with efforts already made over the last 10 years (4.2%/year on average over 2005-2015). Globally for these countries, **consumption per capita remains constant and relatively low** at 1.3 toe/cap, which would still represent less than a third of OECD level in 2015, and less than half in 2050. However, consumption per capita tends to naturally increase, but in a rational way, in emerging countries (India, Egypt, Brazil) and even peak for China. Finally, thanks to cooperation and uniformization, OECD and Non-OECD will converge to similar energy intensity around 40 toe/$2015ppa by 2050.

Figure 32 – Global/regional trends improvement of energy efficiency in Ener-Green



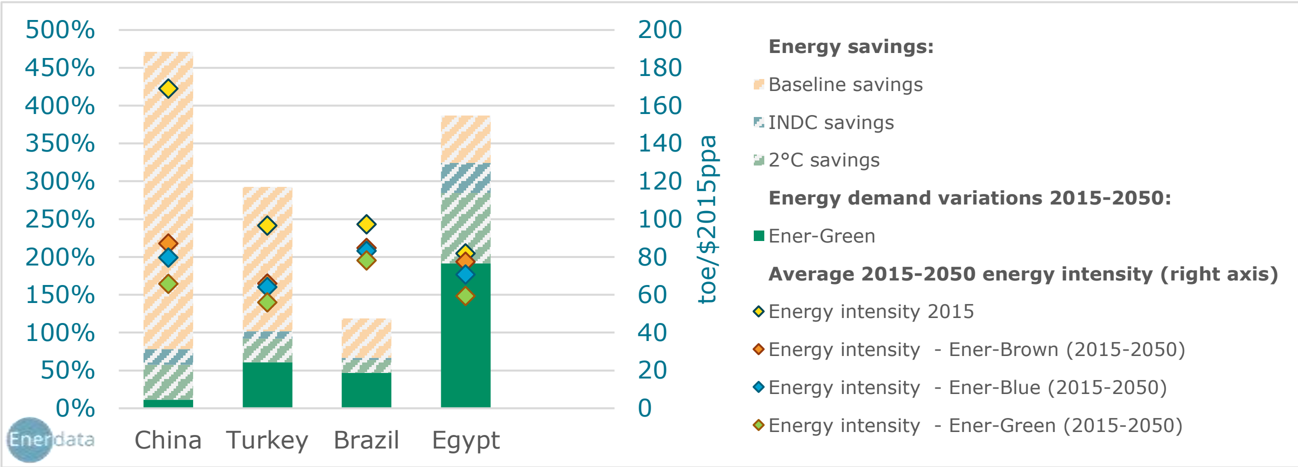
Without reduction of energy intensity, the demand growth would be much higher. These savings can be disaggregated into different components, considering of the evolution of different sectors in our scenarios.

Baseline savings are estimated through the difference between demand levels of Ener-Brown scenario and those that would be observed without energy efficiency improvement (2015 level). This counterfactual trajectory, which cannot be considered as a scenario, does the assumption of "frozen" behaviors in terms of consumption: the amount of energy consumed per unit of GDP remains constant from 2015 to 2050. For example, if China maintains its intensity of 170 toe/$2015ppa in 2015 to 2050, its energy demand would grow at the same pace as its GDP (5.7 times). But over the period 2005-2015, China has improved its energy intensity about 4.2%/year, and the baseline scenario (Ener-Brown) shows the continuation of these efforts to 3.3%/year by 2050 (and therefore an average intensity of 90 toe/$2015ppa over 2015-2050 period), which will limit the demand growth at +80% between 2015 and 2050. This difference between +470% and +80% represents the baseline savings (orange in *Figure 33* left axis).

Similarly, **savings from INDCs implementation** are deducted from the Ener-Blue comparison with Ener-Brown and **savings to achieve the 1.5-2°C objective** by the difference between Ener-Green and Ener-Blue.

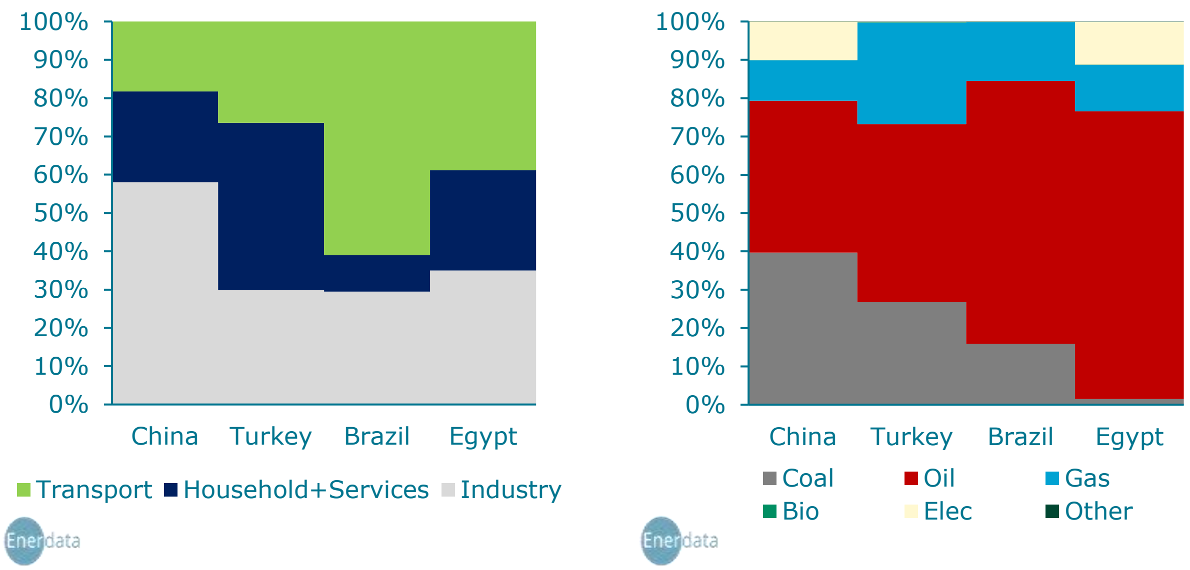
For better comparison between selected regions where consumption levels are difficult to compare, savings are shown in *Figure 33* (right axis) in terms of avoided demand growth, i.e. 2015-2050 cumulative savings in absolute level over the period.

Figure 33 – Primary energy demand changes in Ener-Green and savings due to energy intensity improvements



To understand in more detail the changes to operate in different countries, *Figure 34* shows the **share by sector of the energy saving efforts** cumulated from 2015 to 2050 in four countries. These results give a coherent vision of **sectoral efforts compatible with the specificities of national energy systems**. For example, industrial sector accounts in China about 60% of energy savings to achieve a 1.5-2°C trajectory. Brazil and Egypt efforts would come in major part from oil consumption and transport sector.

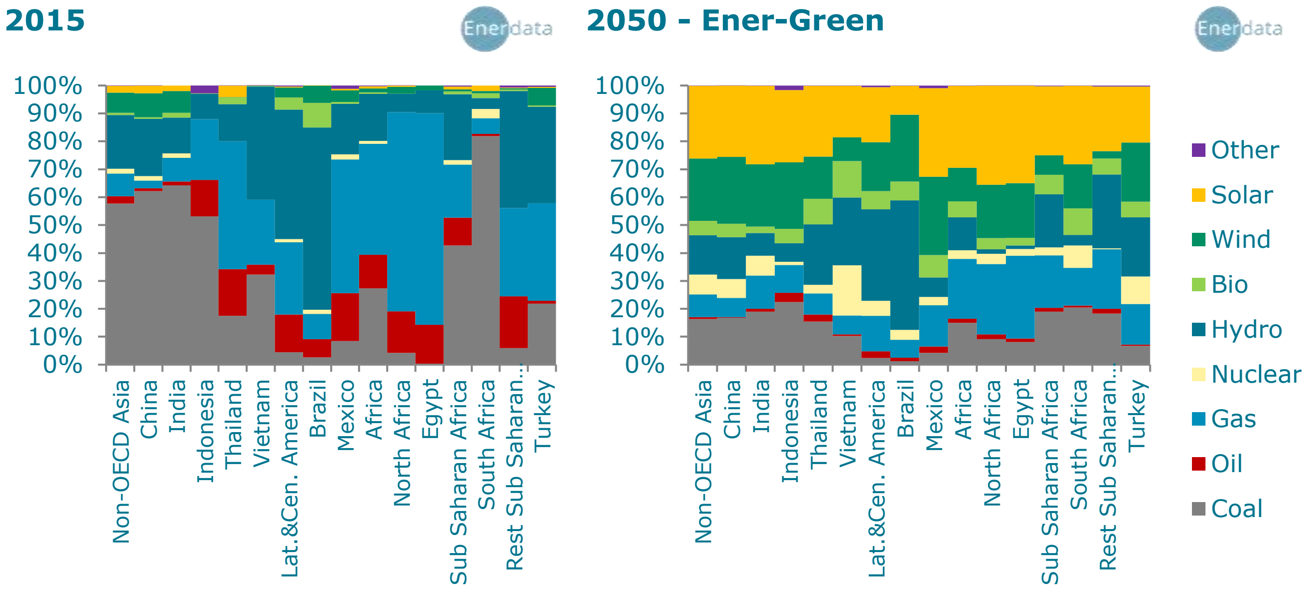
Figure 34 – Energy savings by sector and by energy (2015-2050, Ener-Brown vs Ener-Green)



3.2.2. Penetration of Renewable Energies in power mix

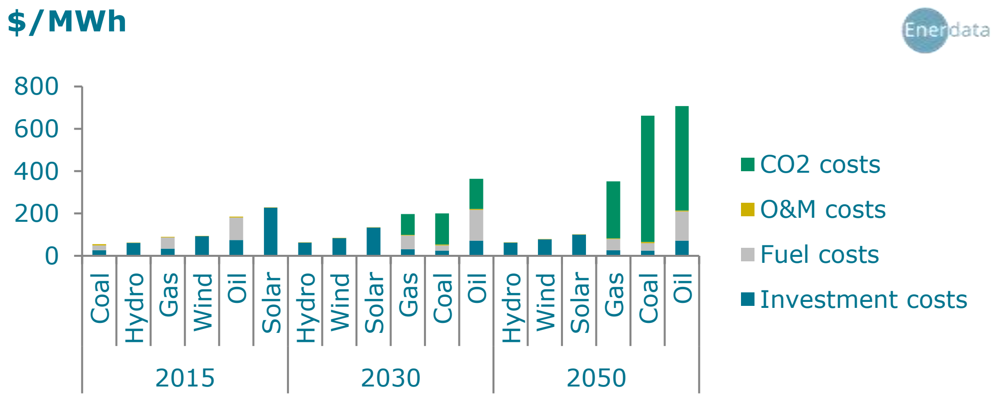
The **global electricity generation will double by 2050** in Ener-Green. In this scenario, a clear transition of the power production system is realized; production from renewable energies is quickly growing, and by 2050 horizon, renewables become **dominant in terms of installed capacity in all regions,** representing up to nearly 80% in Latin America (including hydropower plants).

Figure 35 – Power capacity mix by regions/countries and by technology, Ener-Green 2015 and 2050 comparison



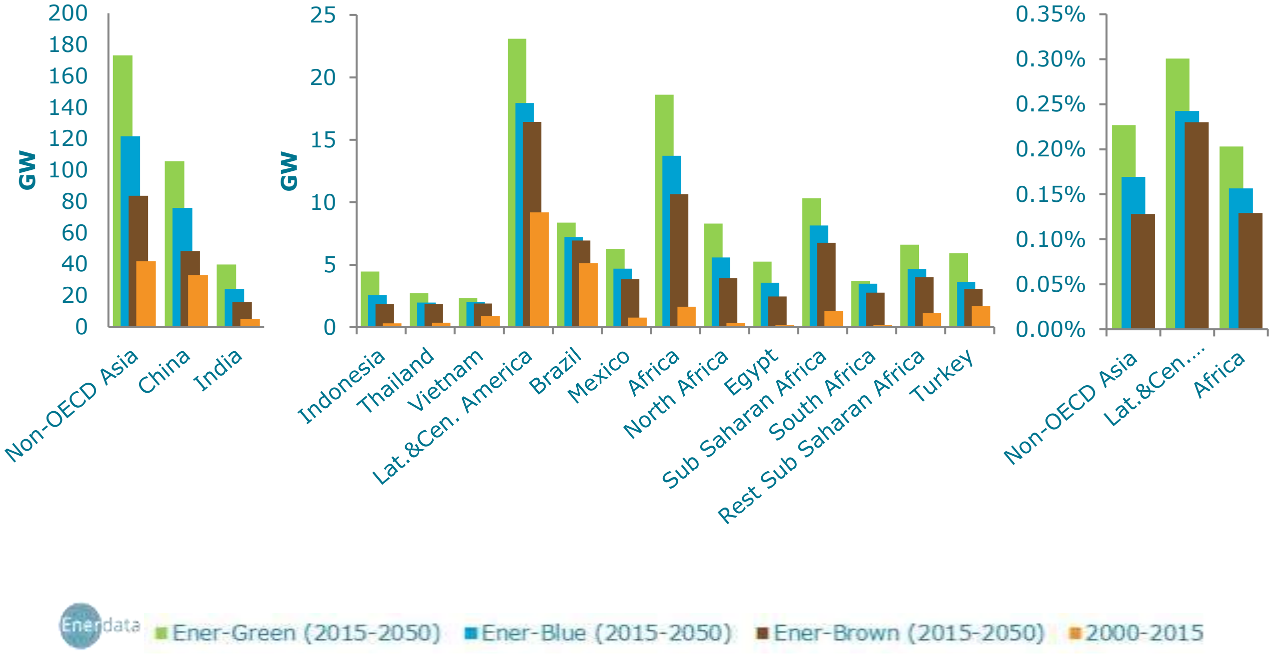
The development of solar and wind technologies (onshore and offshore) between 2015 and 2050 is supported by an **increasingly competitive production costs** (investment costs respectively decrease about 55% and 17% over the period at global level). Moreover, climate policies implemented in the context of this energy transition **penalize fossil fuels according to their carbon content** ("CO2 costs") which increase competitiveness of low and zero carbon energy sources, especially renewable energy.

Figure 36 – Levelized costs of electricity production (LCOEs) in Ener-Green (global average)



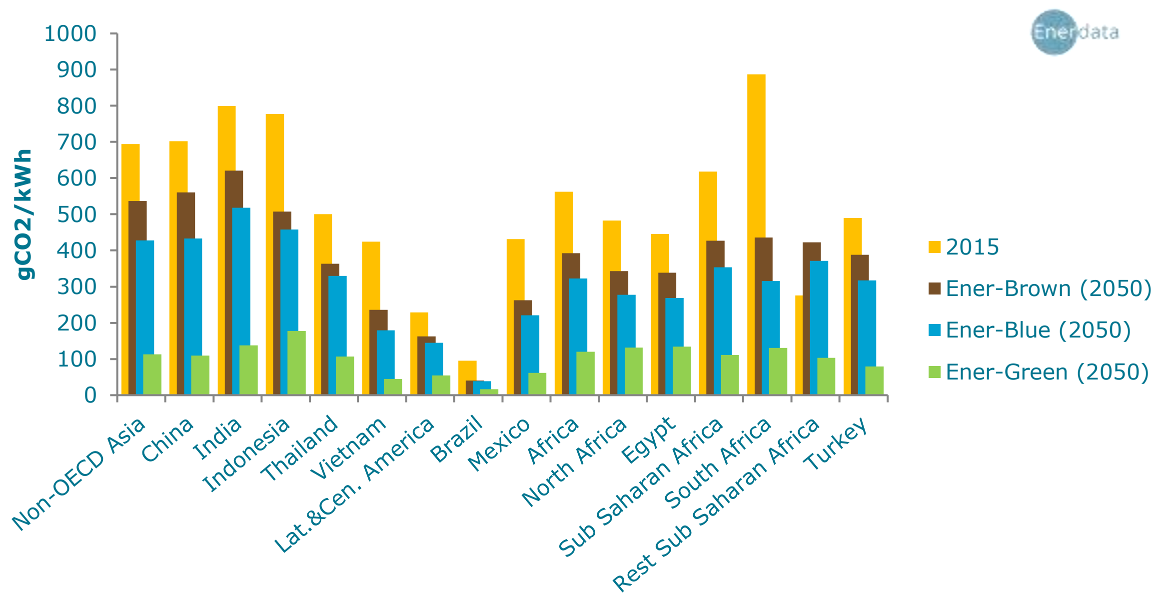
In Ener-Green scenario, **70% of new power plants commissioned between 2015 and 2050 are powered by renewable energy sources (30% solar and 20% wind).** Asian countries are by far the most dynamic markets and pace of installation in this region reaches approximately 170 GW/year of new renewable capacity (including 60% in China) which is more than double compared to the baseline scenario (Ener-Brown). In this ambitious scenario, investments associated with these renewable electricity installations will represent on average between 0.2% and 0.3% of GDP over the period depending to the region (*Figure 37* right graph).

Figure 37 – Average new renewable installed capacities (MW) by year and cost by unit of GDP for the 3 scenarios (left figure)



These massive investments in renewables and other technologies such as nuclear and carbon capture and storage, will allow a **significant decarbonization of electricity generation**. The sector's emission factor (carbon content), measured by the amount of CO2 emitted per unit of electricity generated, drastically decreases in all regions: it is **divided by 5 in Asia and 3 in Africa and Latin America** compared to the baseline scenario.

Figure 38 – Carbon content of power sector by region/country for the 3 scenarios



3.2.3. Substitution of fossil fuels with low-carbon energy sources

With the strengthening of climate and energy policies required to achieve a consistent trajectory with Paris Agreement goal, efforts on efficiency and on rational use of energy are also supported by a **decline in the share of fossil fuels in the primary energy mix for all countries and regions**.

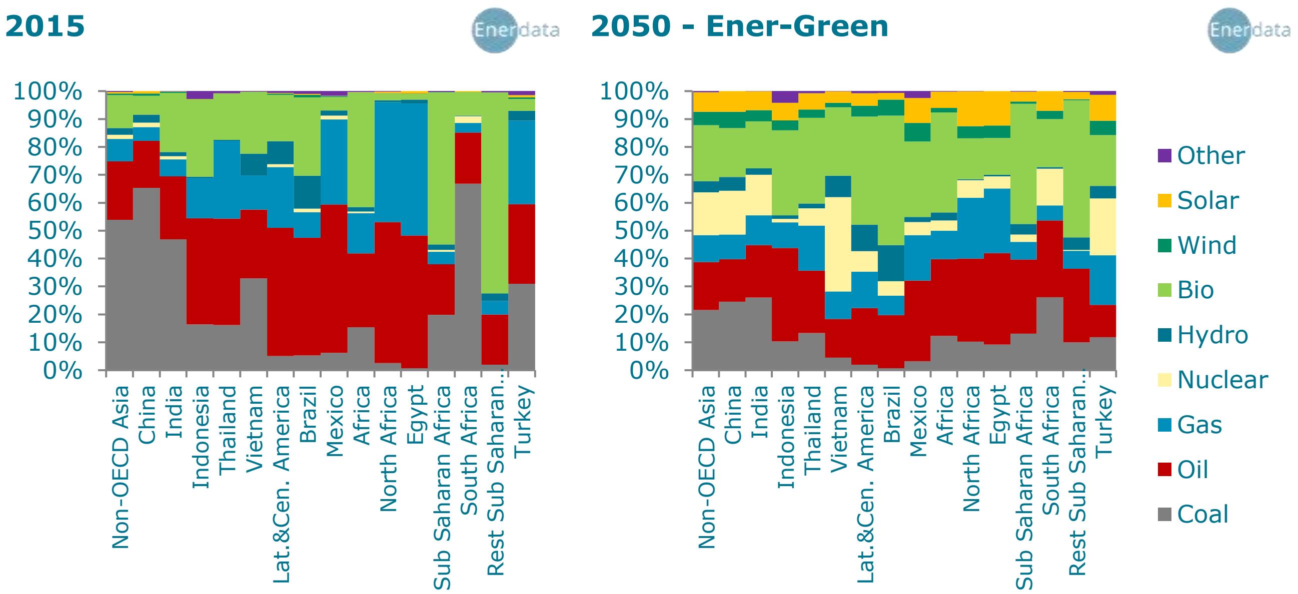
In **Asia**, while fossil fuels represent 83% of the primary energy mix (54% for coal) in 2015, the proactive policies of Ener-Green scenario lead to reduce the fossil fuel share to 48% in 2050. In this energy system transformation, **coal is the most penalized**, while the share of oil, because of its captive use inherent in the transport sector, is maintained during the period. Primary energy consumption of renewables, which represents 16% of the mix in 2015, **triple in volume** over the period to reach 36% in 2050, including a breakthrough of wind (12%) and solar. Vietnam, due to high nuclear expectation in their plans to 2030, shows in Ener-Green scenario a strong nuclear development to 2050 reaching 40% of primary energy mix. This forecast should then be carefully considered regarding today's situation.

In **Latin America**, similar trend is observed: fossil fuels share in primary energy decreases in Ener-Green scenario from 73% in 2015 to 48% in 2050. But oil consumption (46% of the mix in 2015) shows the greatest transformations which is **divided by 2 from 2015 to 2050**. Renewable energy share goes from 26% in 2015 (mainly biomass, 17%) to 60% in 2050, carried out by continuous development of biomass consumption (40% of the mix in 2050), solar (+10%/year over the period) and wind.

In **Africa**, North Africa which strongly rely on fossil fuels in 2015 (mainly oil and gas representing more than 90% of the mix) will diversify its energy mix by 2050. However, fossil fuels will still be dominant in the mix. Sub-Saharan Africa, excluding South Africa, will see the share of biomass reducing and of fossil fuel (mainly coal and oil) increasing while renewables will also penetrate in the mix at a rate of +13%/year for solar and 11%/year for wind over 2015-2050 period.

On a global point of view, countries, which show different energy mix patterns today characterizing by their recent development and energy resources, will all tends to similar patterns by 2050. Energy diversification seems to be one of the possible solution to sustainable development and energy security.

Figure 39 – Primary energy demand by region/country and by fuel, Ener-Green 2015 and 2050 comparison



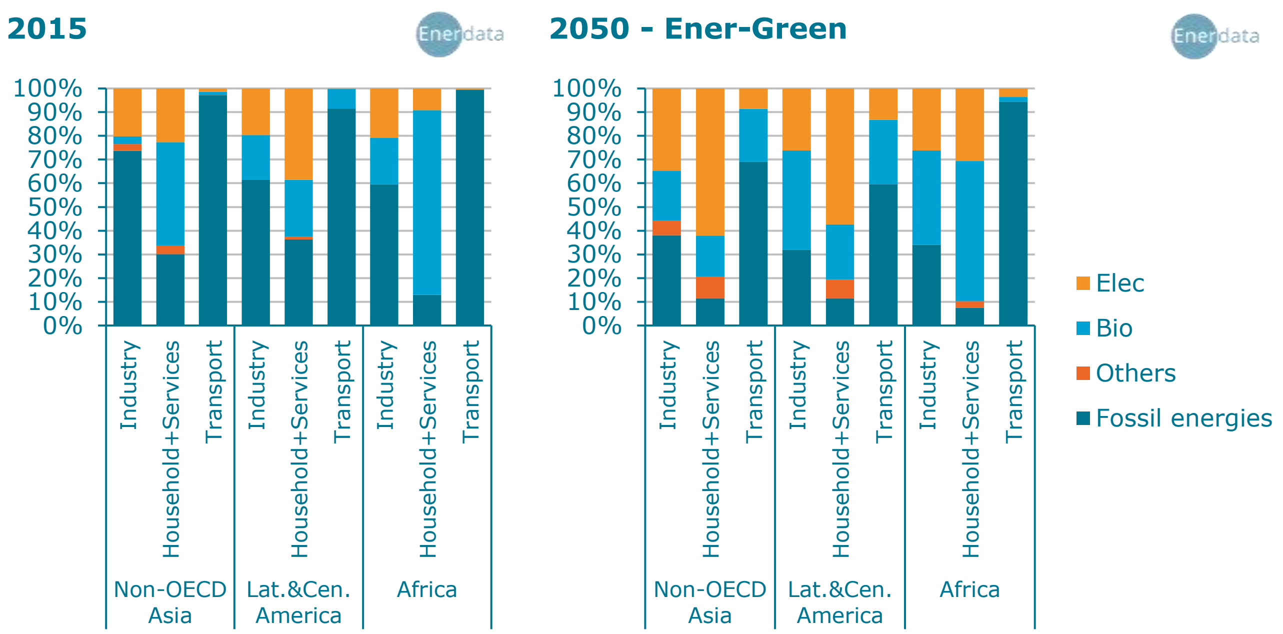
At the same time, **electricity use is increasing in all regions and all sectors** (*Figure 40*), driven mainly by economic growth coupled with strong urbanization, increased access to electricity in developing countries but also through policy measures and instruments promoting energy efficiency and **substitution between fuels**.

In **Asia**, final consumption of electricity is rising sharply over the period 2015-2050 in Ener-Green scenario from 18% in 2015 to 38% in 2050. If electricity demand keep increasing in industry, it increases even more in households and services. This is particularly the case in China. With a structural change in its economy, the creation of Chinese wealth will ultimately rely more on services sector than on industrial production.

This growth of electricity demand in final consumption is also happening in other regions of the world. In **Latin America**, electricity will account for 30% of final demand in 2050 compared to 17% in 2015. In **Africa**, while the role of traditional biomass remains important, the share of electricity will increase from 10% to 31% over 2015-2050 period, i.e. a quadrupling in absolute value which obviously raise the question of electricity accessibility.

More generally, the breakthrough in electrical uses could be explained not only by **development of new uses in households and services** (heat pumps, electronic equipment, etc.), but also by a **significant increase in electric vehicles**, particularly in America Latin. Electric vehicles would account for about 30% of the global private vehicle fleet in Ener-Green scenario by 2050.

Figure 40 – Final energy demand by region and by fuel, Ener-Green 2015-2050 comparison



3.3. Impacts of low-carbon scenarios on country's energy security

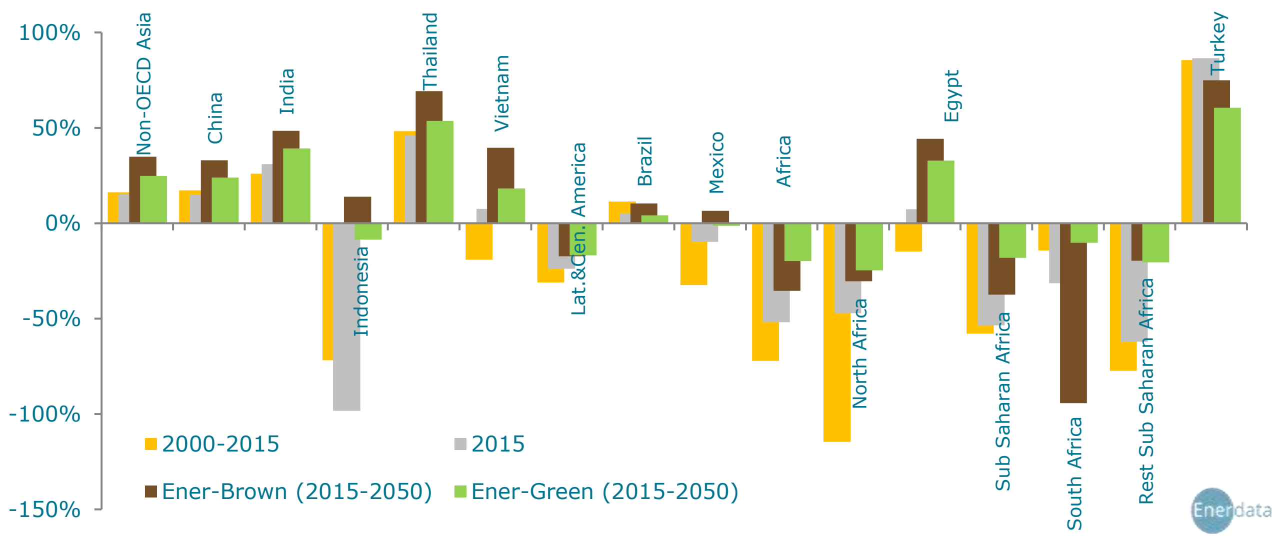
The expected **increase in energy consumption** in the baseline scenario by 2050 raises challenges that relate both to **climate change issue** but also to **energy security** considerations, due to changes in the availability of energy resources to meet the demand.

The rate of energy dependence proposed in this study covers only some components of the concept of **energy security, which can be assessed through four main dimensions**: availability, physical accessibility and geopolitics, economic accessibility, and social and environmental acceptability.

This indicator provides information on the share of energy consumption for which it is necessary to rely on imports. Thus, **this energy security indicator reflects the dynamics linked to the changes of demand over time but also to the domestic energy production and to the associated resource constraints**.

A net importing country will see this indicator move from 0% (in equilibrium) to 100% (when no domestic resources are available to meet demand). While a negative rate characterizes net exporting countries. For a region, the indicator allows to determine the importance of imports from other regions but the internal flows within the region are not considered.

Figure 41 – Energy dependence rate by region/country (annual averages)



A deterioration of this indicator over time reflects that the **change of domestic production over the period is lower than the increase of demand**. Comparing the baseline scenario (Ener-Brown) with historical trends, this is the case for a large majority of the countries studied:

Asia's dependence on external supplies rises from 15% on average over the period 2000-2015 to 35% over the period 2015-2050. Indonesia is shifting from net energy exporter to net importer in baseline scenario but slightly remains net exporter in Ener-Green scenario.

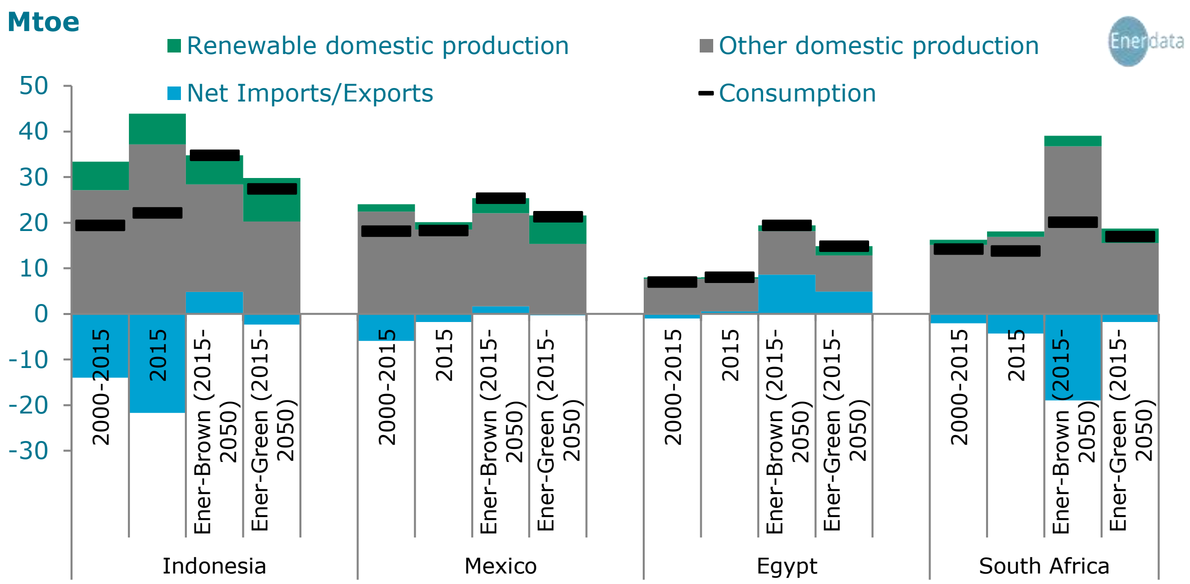
Latin and Central America countries are exporting less and less. In Mexico, production continues to grow by 2050 in the baseline scenario, but the increase in energy consumption exceeds the domestic supply around 2020, requiring the use of energy imports.

The same situation occurs in **Africa**. **South Africa and Sub-Saharan Africa are the only country and region that remain net exporter over 2015-2050 period in the baseline scenario.** In Egypt, while production increases by 30% over 2015-2050, consumption doubles over the same period. The country, a net energy exporter until 2013, sees its energy dependency changing sharply and becomes net importer reaching about 40% on average of its energy needs by 2015-2050.

On the contrary, **two countries (Turkey and South Africa) see their energy security improved in the baseline scenario**. Turkey's energy dependence has risen from 85% on average over the last fifteen years to 60% for 2015-2050 period. This is due, in part, to the development of domestic renewable energy sources which balances more and more the consumption increase. South Africa confirms its position as a net exporter. Its coal and gas resources, which, in the baseline scenario (less climate ambitious), are not only covering domestic needs, but also can be massively exported.

The impact on energy dependency of the ambitious climate policies represented in the Ener-Green scenario is **globally positive, but several contradictory effects** should be analyzed more finely. On the one hand, because of slower energy demand growth, use of energy imports is more modest and at the same time development of renewable energies cover a larger part of the needs with local resources. On the other hand, at global level, the rationalization of consumption particularly affects carbon intensive energy sources, discouraging the production of oil, gas and especially coal.

Figure 42 – energy supply (annual averages)



These combined effects allow in some countries, whose domestic production is insufficient to cover their needs in the baseline scenario, **to reverse their trade balance**. This is the case for Indonesia and, to a lesser extent, for Mexico. The energy dependence of Egypt is reducing but remains important.

However, the decline in global coal consumption in a 1.5-2°C scenario **severely penalizes South Africa's coal exports** and **this effect is not offset by the domestic demand reduction neither by the renewables expansion**.

4. Conclusion

In this report, we analyse and benchmark levels of ambition of countries INDCs and the resulting gap to compatible 1.5-2°C pathway. Comparing three scenarios (baseline, INDC and 2°C), the report provides a comparative framework on trajectories and needed efforts by sector and by country regarding to its potential climate actions. Key findings are summarized below.

In the baseline scenario:

- GHG emissions in Africa triple between 2015 (1.7 $GtCO_{2eq}$) and 2050 (5.4 $GtCO_{2eq}$), largely because of highly dynamic demographic trends and improving population access to energy (reaching even more than 6 times 2015 levels by 2050 for rest of Sub Saharan Africa from 0.5 $GtCO_{2eq}$ to 3 $GtCO_{2eq}$)
- Emissions double in Asia from about 18 $GtCO_{2eq}$ in 2015 to 33 $GtCO_{2eq}$ in 2050, linked to sustained economic growth; However, the decoupling of economic activity and GHG emissions is more pronounced, with a carbon intensity moving from 0.5 $kgCO_{2eq}$/\$p in 2015 to 0.2 $kgCO_{2eq}$/\$p by 2050, which could be partly explained by the level of development (particularly in China, which becomes high-income countries) that induces a transformation of the economic structure.
- Increase of GHG emissions is less pronounced in Latin and Centrale America from about 1.8 $GtCO_{2eq}$ in 2015 to 2.7 $GtCO_{2eq}$ in 2050, but still reaches +50% even with weaker economic and demography growth conditions.

INDCs (Ener-Blue) allow to reduce emissions compared to the Ener-Brown scenario from 61 $GtCO_{2eq}$ by 2050 to 47 $GtCO_{2eq}$ avoiding about 300 $GtCO_{2eq}$ cumulated over the period 2015-2050 (from 51.8 $GtCO_{2eq}$ to 44 $GtCO_{2eq}$ in 2030). But emission increase remains significant, especially in Asia reaching 22.6 GtCO2eq in 2030 and 25.2 GtCO2eq in 2050 and on the African continent reaches almost 2.5 $GtCO_{2eq}$ in 2030 and 4.3 $GtCO_{2eq}$ by 2050. **Only ambitious policies implemented in Ener-Green lead to a peak in Asia at about 19.5 $GtCO_{2eq}$ and Latin America at about 2.1 $GtCO_{2eq}$ between 2020 and 2030.**

China, South Africa and Turkey, which are the main emitters per capita, make the most effort compared to the baseline scenario both for the INDC and 2°C scenarios. In average over the period 2015-2050, China will save 5.5 tCO_{2eq}/cap, South Africa 4.2 tCO_{2eq}/cap and Turkey 2.8 tCO_{2eq}/cap from the baseline to 2°C scenario. The potentials of energy savings and of fossil fuel substitution are high in these countries with strong economic growth. Despite these substantial reductions, **China and South Africa stay among the largest emitters per capita** for INDC scenario with 11.1 tCO_{2eq}/cap and 9.8 tCO_{2eq}/cap compared to world average 4.9 tCO_{2eq}/cap. Other countries provide **an effort but stay well below the world average one.** Regarding avoided GHG emissions over the period 2015-2050, China, India and Indonesia are the main contributors with about 176 $GtCO_{2eq}$, 52 $GtCO_{2eq}$, and 9 $GtCO_{2eq}$ avoided respectively between the baseline and INDC scenario representing almost 50% of world avoided emissions, and about 275 $GtCO_{2eq}$, 78 $GtCO_{2eq}$, and 12 $GtCO_{2eq}$ avoided respectively between the baseline and 2°C scenario.

The **role of the electricity production sector is crucial** in most countries included in this study. This is particularly the case in Asia and South Africa where historical carbon contents are high due to the coal dominance in their mix. The replacement potential of these plants, by less emitting or carbon neutral technologies, is significant. In Latin America, the important use of clean energy resources is leaving few room for improvement. Other sectors will also contribute to the decarbonisation effort. Transport sector has a significant reduction potential, based on the penetration of alternative technologies to oil and on the improvement of engine efficiency.

<u>The decarbonization of the energy sector is based on 3 pillars</u>:

- **Energy efficiency**
- **Fossil fuel substitution in primary energy mix**
- **Renewable development in power mix**

Energy efficiency requires action on energy intensity to **consume less energy per unit of wealth produced**, and on energy consumption per capita. In Non-OECD countries, progress in energy efficiency are more linked to **energy intensity improvements**. Globally for these countries, **consumption per capita remains constant and relatively low**, which would still represent less than a third of OECD level in 2015, and less than half in 2050. However, consumption per capita tends to naturally increase, but in a rational way, in emerging countries (India, Egypt, Brazil) and even peak for China. Finally, OECD and Non-OECD will converge to similar energy intensities around 40 toe/$2015ppa by 2050. Sectoral contribution to energy savings is closely related to country's energy system. For example, industrial sector accounts in China about 60% of energy savings to achieve a 1.5-2°C trajectory. Brazil and Egypt efforts would come in major part from oil consumption and transport sector.

The **global electricity generation will double by 2050** in Ener-Green. In this scenario, a clear transition of the power production system is realized; renewables become **dominant in terms of installed capacity in all regions**. Development of solar and wind technologies (onshore and offshore) is supported by an **increasingly competitive production costs**. In addition to stringent climate policies that also **penalize fossil fuels**. **70% of new power plants commissioned between 2015 and 2050 are powered by renewable energy sources (30% solar and 20% wind).** Asian countries are by far the most dynamic markets reaching approximately 170 GW/year of new renewable capacity (including 60% in China) which is more than double compared to the baseline scenario. Investments will represent on average between 0.2% and 0.3% of GDP over the period depending to the region. The carbon content of power sector is **divided by 5 in Asia and 3 in Africa and Latin America** compared to the baseline scenario.

Today's heterogeneity of country primary energy mixes is characterized by their development and their domestic energy resources, but future sustainable development might lead to energy diversification with similar energy mix pattern. In **Asia**, fossil fuels share is reduced by almost 2 by 2050 where **coal is the most penalized**, while oil share is maintained during the period. Primary energy consumption of **renewables triple in volume** to reach 36% in 2050. In **Latin America**, similar trend is observed: fossil fuels share in primary energy decreases. But **oil consumption is divided by 2 from 2015 to 2050** while **renewable energy share double**. In **Africa**, North Africa which strongly relies on fossil fuels will diversify its energy mix by 2050. However, fossil fuels will still be dominant in the mix**. Only Rest of Sub-Saharan Africa** will see shares **of biomass reducing and of fossil fuel (mainly coal and oil) increasing** while renewables will also penetrate in the mix.

At the same time, **electricity use is increasing in all regions and all sectors**. In **Asia** and **Latin America**, final consumption of electricity will see its share double between 2015 and 2050. In **Africa**, electricity share in final energy consumption will triple and quadrupling in absolute value which obviously raise the question of electricity accessibility. The breakthrough in electrical uses could be explained not only by **development of new uses in households and services**, but also by a **significant increase in electric vehicles**, particularly in America Latin.

Finally, **impact on energy dependency** of the ambitious climate policies (Ener-Green) is **globally positive**. On the one hand, because of slower energy demand growth, use of energy imports is more modest and at the same time development of renewable energies cover a larger part of the needs with local resources. On the other hand, at global level, the rationalization of consumption particularly affects carbon intensive energy sources, discouraging the production of oil, gas and especially coal. These combined effects allow in some countries, whose domestic production is insufficient to cover their needs in the baseline scenario, **to reverse their trade balance**. This is the case for Indonesia and, to a lesser extent, for Mexico. The energy dependence of Egypt is reducing but remains important.

References

POLES

- Toon Vandycka, Kimon Keramidas, Bert Saveyn, Alban Kitous, Zoi Vrontisi (2016), A global stocktake of the Paris pledges: Implications for energy systems and economy, Global Environmental Change, Volume 41, November 2016, Pages 46–63
- European Commission – Joint Research Centre (2015), Analysis of scenarios integrating the INDCs, JRC Policy Brief. European Commission, Joint Research Centre. October 2015. JRC97845
- Andrews-Speed, P., van der Linde, C., Keramidas, K. (2014) Conflict and cooperation over access to energy: Implications for a low-carbon future. Futures 58, pp.103-114
- Kranzl, L. et al. (2014) Medium and Long-Term Perspectives of International Bioenergy Trade. Chapter in Junginger M. et al. (eds.), International Bioenergy Trade: History, status & outlook on securing sustainable bioenergy supply, demand and markets, Lecture Notes in Energy 17, pp.173-189
- Griffin, B., Buisson, P., Criqui, P. and S. Mima (2013) White Knights: will wind and solar come to the rescue of a looming capacity gap from nuclear phase-out or slow CCS start-up?. Climatic Change. Special Issue on "The EMF27 Study on Global Technology and Climate Policy Strategies". Climatic Change 123 #3-4, pp.623-635
- Duscha, V., Schumacher, K., Schleich, J., Buisson, P. (2013) Costs of meeting international climate targets without nuclear power. Climate Policy. 2013:1-26.
- Flachsland, C. et al. (2011) Climate policies for road transport revisited (II): Closing the policy gap with cap-and-trade. Energy Policy 39, pp. 2100-2110
- Kitous, A., Criqui, P., Bellevrat, E., Chateau, B. (2010) Transformation Patterns of the Worldwide Energy System – Scenarios for the Century with the POLES Model. The Energy Journal, Volume 31 (Special Issue 1: The Economics of Low Stabilization). International Association for Energy Economics (IAEE), Cleveland, Ohio, USA
- Criqui, P. Mima, S. et al. (1999) Marginal abatement costs of CO2 emission reductions, geographical flexibility and concrete ceilings: an assessment using the POLES model. Energy Policy 27, pp 585-601

Citations

EDF & IETA 2016 – *Doubling Down on Carbon Pricing, Laying the Foundation for Greater Ambition*
Use of POLES-Enerdata model and EnerFuture 2016 scenarios and MACCs
https://www.edf.org/sites/default/files/doubling_down_carbon_pricing_edf-ieta.pdf

IDDRI 2015 – *Beyond the Numbers: Understanding the Transformation Induced by INDCs*, A report of the MILES project consortium, IDDRI study n°05/15, Climate, October 2015
http://www.iddri.org/Publications/Collections/Analyses/MILES%20report.pdf

London School of Economics and Political Science, 2015 – *Tracking intended nationally determined contributions: what are the implications for greenhouse gas emissions in 2030?* Policy paper, August 2015
http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/08/Boyd-et-al-policy-paper-August-2015.pdf

UN Emissions Gap Report 2015 – *The Emissions Gap Report 2015: A UNEP Synthesis Report*
POLES-Enerdata and Carbon Market Tool used in scenario calculations underlying the Report on estimating the global greenhouse gas emissions as implied by submitted by INDCs (Chapter 3).
http://uneplive.unep.org/media/docs/theme/13/EGR_2015_301115_lores.pdf
http://uneplive.unep.org/media/docs/theme/13/EGR_2015_Annex_B_Additional_INDC_assessment_information.pdf

Danish Energy Agency, Centre for Climate and Energy Economics, *Analyzing the 2030 emissions gap (draft version),* Ref: Steffen Dockweiler, November 2015 (COMPARE model developed by Enedata for DEA using POLES MACCs)
https://ens.dk/sites/ens.dk/files/Analyser/dea_analyzing_the_2030_emissions_gap_1_1.pdf

Historical data

- Climate Action Tracker : http://climateactiontracker.org
- Enerdata: http://www.enerdata.net/enerdatauk/knowledge/subscriptions/database/
- UNFCC: http://unfccc.int/di/DetailedByParty/Event.do?event=go
- World Resources Institute: http://www.wri.org/resources/charts-graphs/ghg-emissions-targets-base-years

Forecasts

- Enerdata (Enerfuture): http://www.enerdata.net/enerdatauk/knowledge/subscriptions/forecast/
- Agence Internationale de l'Energie
    - WEO 2015 : http://www.iea.org/bookshop/720-World_Energy_Outlook_2016
    - ETP 2015 : http://www.iea.org/bookshop/710-Energy_Technology_Perspectives_2015
    - INDC scenario: http://www.worldenergyoutlook.org/energyclimate/energyandco2trendsintheindcscenario/
- Climate Action Tracker: http://climateactiontracker.org
- CEPII : "The Great Shift: Macroeconomic projections for the world economy at the 2050 horizon", CEPII Working Paper 2012-03, by Jean Fouré, Agnès Bénassy-Quéré & Lionel Fontagné, February 2012.

UNFCCC

- INDC portal: http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx
- Biennal Report: http://unfccc.int/national_reports/non-annex_i_natcom/reporting_on_climate_change/items/8722.php
- National Communications: http://unfccc.int/national_reports/non-annex_i_natcom/submitted_natcom/items/653.php

Annex 1 – The POLES energy-economy model

Context

The POLES model provides a complete system for the simulation and economic analysis of the sectoral impacts of climate change mitigation strategies. The POLES model is not a General Equilibrium Model, but a dynamic Partial Equilibrium Model, essentially designed for the energy sector but also including other GHG emitting activities, with the 6 GHG of the "Kyoto basket". The simulation process is dynamic, in a year by year recursive approach that allows describing full development pathways from 2000 to 2050.

The use of the POLES model combines a high degree of detail on the key components of the energy systems and a strong economic consistency, as all changes in these key components are at least partly determined by relative price changes at sectoral level. Thus each mitigation scenario can be described as the set of consistent transformations of the initial Reference case that are induced by the introduction of a carbon constraint or carbon value/penalty.

As the model identifies 66 regions of the world, with 22 energy demand sectors and more than 40 energy technologies – now including generic Very Low Energy end-use technologies – the description of climate policy induced changes can be quite extensive (see below for a brief presentation of key features, technologies and modelling principles).

As far as induced technological change is concerned, the model provides dynamic cumulative processes through the incorporation of Two Factor Learning Curves, which combine the impacts of "learning by doing" and "learning by searching" on the technologies' improvement dynamics. As price induced diffusion mechanism (such as feed-in tariffs) can also be included in the simulations, the model allows for a taking into account of the key drivers to the 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 in all cases on a framework of permanent inter-technology competition, with dynamically changing attributes for each technology. In parallel, the expected cost and performance data for each key technology are gathered and examined in the *TECHPOL* database that is developed at EDDEN for any modelling and policy-making purpose.

Finally, one can emphasise the fact that, although the model does not provide the total indirect macro-economic costs of mitigation scenarios, it however allows to produce reliable economic assessments that are principally based on the costs of developing low or zero carbon technologies, thus benefiting of a strong engineering background.

POLES general information

The POLES model is a world simulation model for the energy sector. It works in a year-by-year recursive simulation and partial equilibrium framework, with endogenous international energy prices and lagged adjustments of supply and demand by world region. Developed under different EU research programmes (JOULE, FP5, FP6, FP7), the model is fully operational since 1997. It has been used for policy analyses by EU-DG Research, DG Environment and DG TREN, as well as by the French Ministry of Ecology and Ministry of Industry. The model enables to produce:

- Detailed long term (2050) world energy outlooks with demand, supply and price projections by main region;
- CO_2 emission Marginal Abatement Cost curves by region and/or sector, and emission trading systems analyses, under different market configurations and trading rules;
- Technology improvement scenarios – with exogenous or endogenous technological change – and analyses of the value of technological progress in the context of CO_2 abatement policies.

Beyond the research community, the target users of the model are international organisations and policy makers and energy analysts in the field of global energy markets and environmental issues.

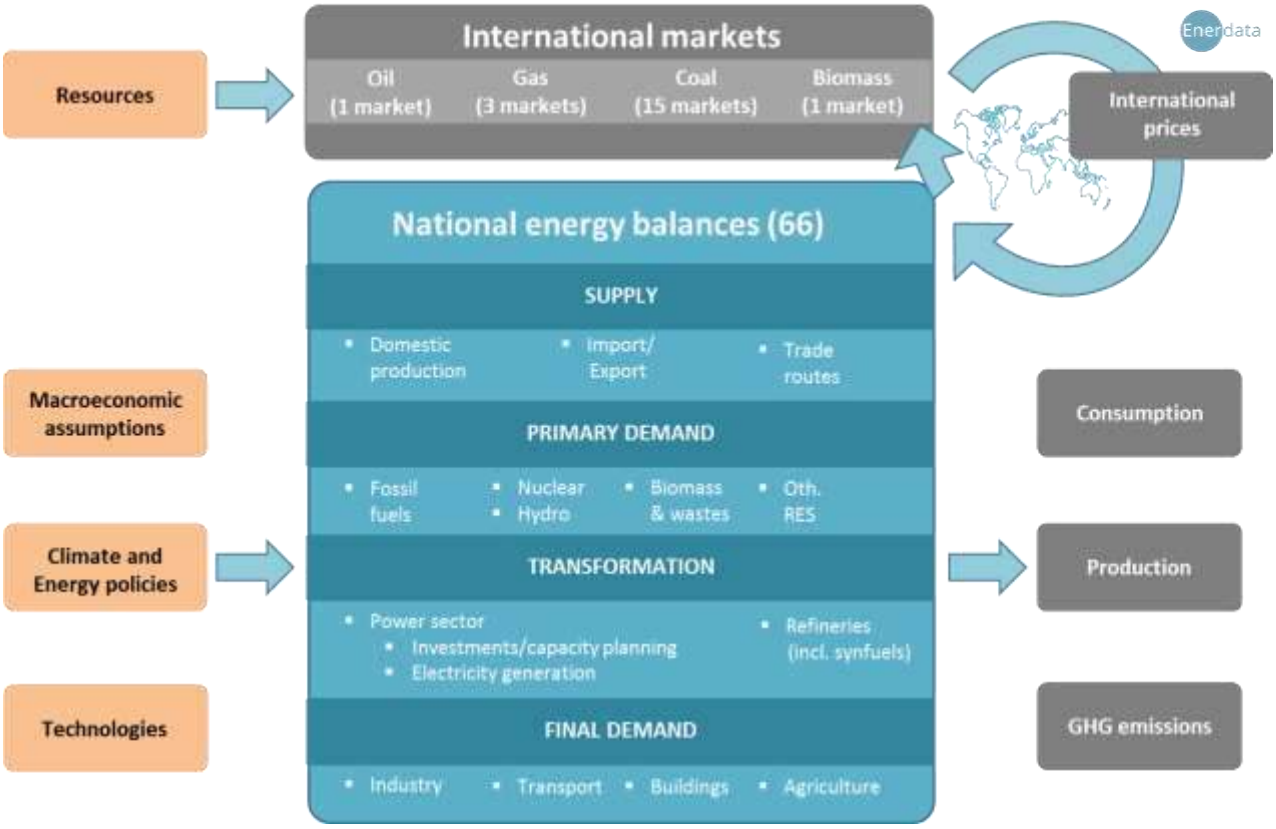
Key-issues addressed

- 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.
- Outlook for energy prices at international, national and sectoral level (10 products)
- National / regional energy balances, integrating final energy demand, new and renewable energy technologies diffusion, electricity, Hydrogen and Carbon Capture and Sequestration systems, fossil fuel supply.
- Impacts of energy prices and tax policies on regional energy systems. National Greenhouse Gas emissions and abatement strategies.
- Costs of international GHG abatement scenarios with different regional targets / endowments and flexibility systems. Emission Quotas Trading Systems analysis at world or regional level.
- Technology diffusion under conditions of sectoral demand and inter-technology competition based on relative costs and merit orders
- Endogenous developments in energy technology, with impacts of public and private investment in R&D and cumulative experience with "learning by doing". Induced technological change of climate policies

Model characteristics

The POLES model is a global sectoral model for the world energy system. It has been developed in the framework of a hierarchical structure of interconnected sub-models at the international, regional, national level. The dynamics of the model is based on a recursive (year by year) simulation process of energy demand and supply, with lagged adjustments to prices and a feedback loop through international energy prices.

Figure 43: The POLES model – global energy system



Model structure

In the current geographic disaggregation of the model, the world is divided into 57 countries or regions, with a detailed national model for each Member State of the European Union (27), four industrialised countries (USA, Canada, Japan and Russia) and five major emerging economies (Mexico, Brazil, India, South Korea and China). The other countries/regions of the world are dealt with a simplified but consistent demand model.

Table 1: POLES regional disaggregation

Regions	Sub-regions	Countries	Country aggregates
North America		USA, Canada	
Europe	EU15	France, United Kingdom, Italy, Germany, Austria, Belgium, Luxembourg, Denmark, Finland, Ireland, Netherlands, Sweden, Spain, Greece, Portugal	
	EU25	Hungary, Poland, Czech Republic, Slovak Republic, Estonia, Latvia, Lithuania, Slovenia, Malta, Cyprus, Croatia	
	EU28	Bulgaria, Romania	Rest of Europe
		Iceland, Norway, Switzerland, Turkey	
Japan – South Pacific		Japan, Australia, New Zealand	Rest of South Pacific
CIS		Russia, Ukraine	Rest of CIS
Latin America	Central America	Mexico	Rest of Central America
	South America	Brazil, Argentina, Chile	Rest of South America
Asia	South Asia	India	Rest of South Asia
	South East Asia	China, South Korea , Indonesia, Malaysia, Thailand, Viet Nam	Rest South East Asia
Africa / Middle East	North Africa	Egypt,	Rest of North Africa x2;
	Sub-Saharan Africa	South Africa	Rest of Sub-Saharan Africa;
	Middle-East	Saudi Arabia, Iran	Gulf countries; Rest of Middle East

This allows identifying the key world regions of most energy studies: North America; South America; Former Soviet Union; North Africa and Middle-East; Africa South of Sahara; South Asia; South East Asia; Continental Asia; Pacific OECD.

For each region, the model articulates five main modules dealing with:

- final energy demand by main sector
- new and renewable energy technologies
- the Hydrogen and Carbon Capture and Sequestration technologies and infrastructures
- the conventional energy and electricity transformation system
- fossil fuel supply

While the simulation of the different energy balances allows for the calculation of import demand / export capacities by region, the horizontal integration is ensured in the energy markets module, the main inputs of which are import demand and export capacities of the different regions.

Only one world market is considered for the oil market (the "one great pool" concept), while three regional markets (America, Europe, Asia) are identified for coal, in order to take into account for different cost, market and technical structures. Natural gas production and trade flows are modelled on a bilateral trade basis, thus allowing for the identification of a large number of geographical specificities and the nature of different export routes.

The comparison of import and export capacities and the changes in the Reserves/Production ratio for each market determines of the variation of the prices for the subsequent periods.

Final energy demand module and very low energy technologies

In the detailed demand model for the main countries or regions, the energy consumption is disaggregated into homogeneous sectors which allow to identify the key energy intensive industries, the main transport modes and the residential and tertiary activities: Steel industry ; Chemical industry ; Non metallic mineral industries ; Other industries ; Road passenger transport ; Road freight transport ; Rail passenger transport ; Rail freight transport ; Air transport ; Residential sector ; Tertiary sector ; Agriculture.

Table 2: POLES energy demand – final sectors

INDUSTRY	Steel Industry Chemical industry (+chemical feedstock) Non metallic mineral industry Other industries (+non energy use)
TRANSPORT	Road transport Rail transport Air transport Other transports
OTHER	Residential sector Service sector Agriculture
BUNKERS	International air International marine

Energy consumption is calculated in each sector on the one hand for substitutable fuels and on the other hand for electricity, while taking into account specific energy consumption (electricity in electrical processes and coke for the other processes in steel-making, feedstock in the chemical sector, electricity for heat and for specific uses in the Residential and Tertiary sectors). Each demand equation combines a revenue or activity variable elasticity, price elasticity, technological trends and, when appropriate, saturation effects. Particular attention has been paid to the dynamic impacts of price of price effects.

The POLES model represents the development of Very Low Energy/Emission end-use technologies (VLE). While going beyond the concept of energy efficiency through new concepts and product designs, these technologies may allow to considerably improve the energy performance in the two strategic sectors of buildings and road vehicles. In the building sector two generic VLE buildings are considered with energy consumption being cut by a Factor of 2 (Low Energy Building, new and retrofitting) or 3-4 (Very Low Energy Building, new). In the transport sector, the competition between six types of vehicles is described, allowing for the potential introduction of Hydrogen and/or electricity in road transport (while biofuels are mixed, according to relative costs, to conventional petroleum products).

Vehicle types:

- Conventional ICE
- Hybrid (plug-in)
- Electric (battery)
- Gas Fuel Cell
- Hydrogen Fuel Cell
- Hydrogen in a conventional ICE

Power production module

The electricity system is dealt with in POLES in a fairly detailed manner, mostly due to the fact that the electricity system is in any country not only one of the main energy consuming sector but also probably the major sector for inter-fuel substitution. It must be added that because of the particularly long lifetime of equipment, this sector presents a higher price-elasticity in the long-term than in the short-term.

Production needs are derived from the total power demand appearing on the national grid, including net exports:

Total production needs = final demand + self-consumption + losses + net exports

The production means are split into different categories, based on their distance to the final consumer:

- Distributed and decentralised means: described in POLES as competing with electricity from grid to satisfy electricity final demand. They gather PV, CHP, fuel cells, small hydro;
- Centralised means: gather all the other technologies, for which there is a full modelling of capacity development and production based on merit order functions.

In order account for capacity constraints, the model simulates the evolution of existing capacities at each period as a function of equipment development decisions taken in the preceding periods, and thus of the anticipated demand and costs at the corresponding time.
To simplify, the existing capacities of each type of power plant at time t are equal to the target capacities calculated in t-10 for t, after the taking into account of decommissioning constraints.

Most power production technologies are considered as "centralised", including some key renewables. They obey the same general principles in terms of capacity planning.

The modelling of power production is differentiated for:

- "must-run" technologies: technologies with a with small (or null) variable cost,
- "merit order" technologies: technologies with an important variable production cost.

A number of them are associated to resource and technical potentials possibly limiting their development.

Table 3: Large scale non-renewables technologies

Large Scale Power Generation	
Large Hydro** Nuclear LWR** New Nuclear Design** Geothermal**	*Must run*
Super Critical Pulverized Coal* Integrated Coal Gasification Comb. Cycle* Coal Conventional Thermal Lignite Conventional Thermal Gas Conventional Thermal Gas Fired Gas Turbines Gas Turbines Combined Cycle* Oil Conventional Thermal Oil Fired Gas Turbines	*Merit order*

**These technologies are considered without and with CCS.*
*** These technologies are associated to a potential.*

Table 4: Large scale renewables technologies

Large scale Renewable technologies	
Onshore Wind** Offshore Wind** Solar Thermal Power plants**	*Must run*
Biomass Power plants** Biomass Gasification*, **	*Merit order*

**These technologies are considered without and with CCS.*
*** These technologies are associated to a potential.*

Hydrogen module

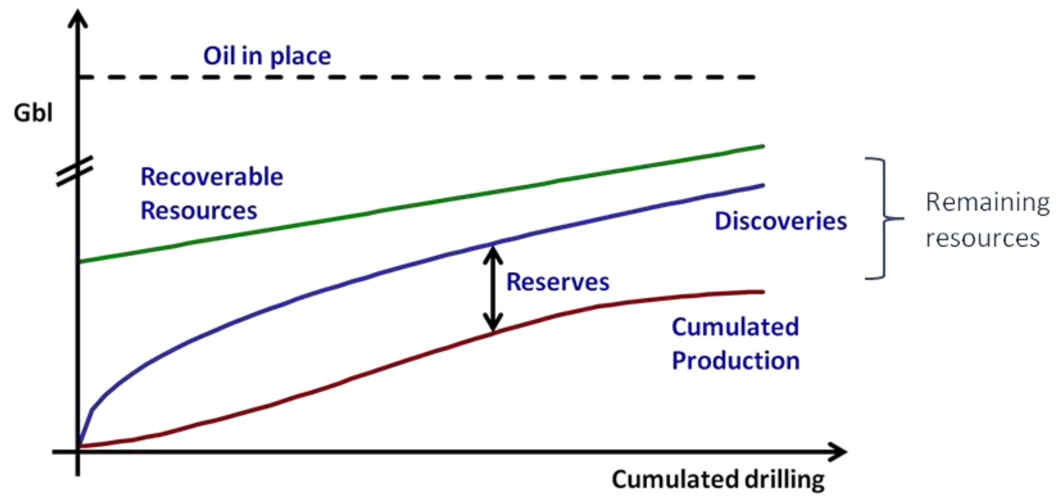
POLES uses a full description of future Hydrogen production, transport and consumption technologies. While Hydrogen is only an energy carrier, great attention is paid to the description of the many technological solutions to produce H2, to transport costs in new infrastructures and to the interfaces of the H2 system with the conventional electricity system.

Ten competing options are identified for the mass production of Hydrogen, relying on fossil fuels (coal or gas, with or without Carbon Capture and Sequestration) or electrolysis, from network electricity or dedicated nuclear or renewable electricity. Two end-use markets are considered for Hydrogen: distributed electricity with cogeneration and Very Low Emission vehicles in road transport with fuel cells (direct injection in a conventional ICE is also considered).

Oil and gas production module

Oil and gas production is simulated for each region using a full discovery-process model for the main producing countries and simplified relations for minor producing countries.

Figure 44: Oil discovery process



For each main producing country, the available data cover the estimate of Ultimate Recoverable Resources for oil and for gas, the cumulative drilling and cumulative production since the beginning of fields' development and the evolution of reserves. Cumulative discoveries are then calculated as the sum of cumulative production and remaining reserves. For base producers, oil or gas production then depends on a depletion ratio, applied to the remaining reserves (discoveries - cumulative production) in each period.

International energy prices module

In the current version of the model, the basis for international oil price modelling combines a Target Capacity Utilisation Rate model for the Gulf countries and the global oil R/P ratio as a long-term explanatory variable. This reflects the fact that most applied analyses of the oil market points to the fact that, as experienced in the seventies and eighties, the shorter term variations or shocks in the price of oil can be explained by the development of under- or over- capacity situations in the Gulf region.

Coal and natural gas prices are computed for each one of the three main regional markets with regional coal and gas trade matrixes and price variations linked respectively to coal production capacities and to the gas R/P ratio of the key residual producers for each region.

GHG emissions

GREENHOUSE GAS SOURCE	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6
SINK CATEGORIES	CO_2 equivalent (Gg)					
Total (Net Emissions)						
1. Energy						
A. Fuel Combustion (Sectoral Approach)						
1. Energy Industries						
2. Manufacturing Industries and Construction						
3. Transport						
4. Other Sectors						
5. Other						
B. Fugitive Emissions from Fuels						
1. Solid Fuels						
2. Oil and Natural Gas						
2. Industrial Processes						
A. Mineral Products						
B. Chemical Industry						
C. Metal Production						
D. Other Production						
E. Production of Halocarbons and SF6						
F. Consumption of Halocarbons and SF6						
G. Other						
3. Solvent and Other Product Use						
4. Agriculture						
A. Enteric Fermentation						
B. Manure Management						
C. Rice Cultivation						
D. Agricultural Soils						
E. Prescribed Burning of Savannas						
F. Field Burning of Agricultural Residues						
G. Other						
5. Land Use, Land-Use Change and Forestry						
A. Forest Land						
B. Cropland						
C. Grassland						
D. Wetlands						
E. Settlements						
F. Other Land						
G. Other						
6. Waste						
A. Solid Waste Disposal on Land						
B. Waste-water Handling						
C. Waste Incineration						
D. Other						
7. Other (as specified in Summary 1.A)						
Memo Items:						
International Bunkers						
Aviation						
Marine						
Multilateral Operations						
CO2 Emissions from Biomass						

POLES coverage
Full coverage
Partial coverage
Non covered
Not relevant

Inputs

The energy balance data for the POLES model are extracted from an international energy database, which also includes international macro-economic data concerning GDP, the structure of economic activity, deflators and exchange rates.

Technico-economic data (energy prices, equipment rates, costs of energy technologies, etc.) are gathered from both international and national statistics.

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

Outputs

The core output of the model is the production of regularly updated **Energy Outlooks**. POLES provides endogenous international energy prices and all information on energy flows for each country / region, in a structure similar to that of a standard IEA-type energy balance. A summary balance provides a synthesis of information on energy consumption and transformation, new energy technologies and electricity production capacities.

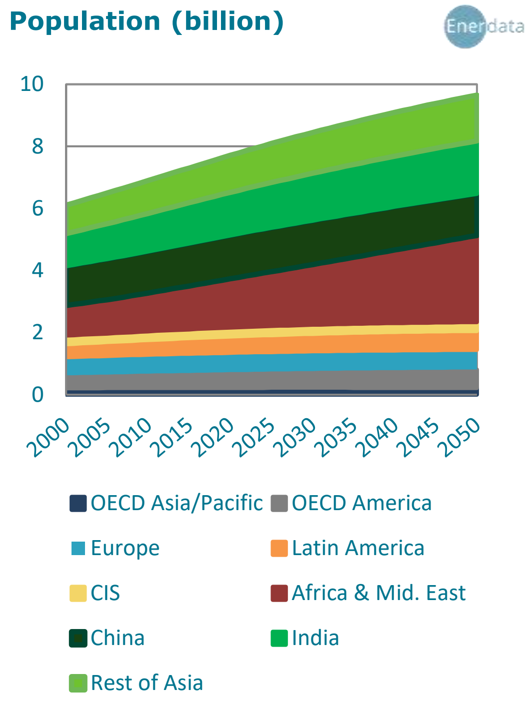
Studies on CO_2 abatement policies are currently performed using the model by the systematic introduction of a "shadow-carbon tax" wherever it is relevant. Multiple simulations of the model then allow analysing the impacts on emissions by sector and regions, to build the Marginal Abatement Cost curves and to analyse emission trading issues. Dedicated softwares, **Carbon Market Tool** and **EVALUATE**, allow to calculate – on robust micro-economic bases – the MAC, permit price, total cost and quantities exchanged under different market configurations.

The **impact of technological change in the Baseline and in Emission Control Scenarios** can be addressed either with a set of exogenous "Technology Story" alternatives or with a module of R&D driven endogenous technology improvement, which also includes "learning by doing" or experience effects.

Annex 2: Context information on POLES scenarios

Macroeconomic assumptions by major region

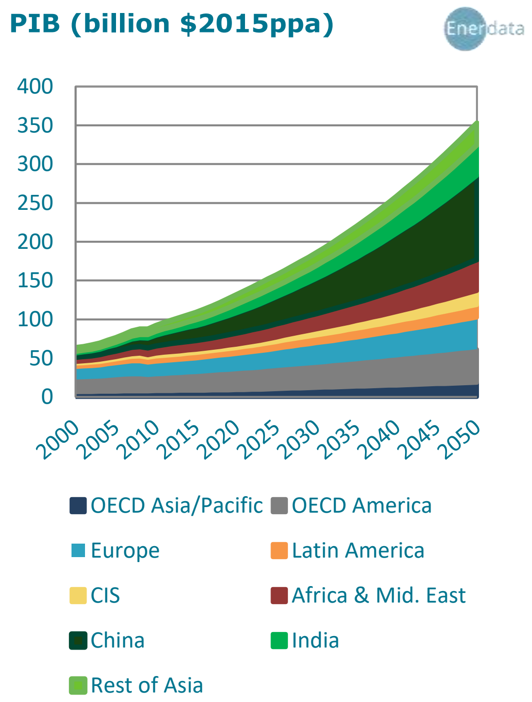
Figure 45 - Demographic assumptions for the 3 EnerFuture scenarios



CAGR (%)

	2000 - 2015	2015 - 2030	2030 - 2050
Non OECD	**1.3**	**1.1**	**0.8**
E Europe / Eurasia	0.0	-0.1	-0.2
Russia	-0.1	-0.2	-0.4
Asia	1.1	0.7	0.3
China	0.5	0.2	-0.2
India	1.5	1	0.6
Africa & Mid. East	2.5	2.2	1.8
Latin America	1.2	0.8	0.4
Brazil	1	0.6	0.2
OECD	**0.7**	**0.4**	**0.2**
North America	1	0.8	0.5
US	0.8	0.7	0.4
Europe	0.5	0.2	0
Pacific	0.4	0.1	-0.1
Japan	0	-0.3	-0.6
World	**1.2**	**1**	**0.7**

Figure 46 - Economic growth assumptions for the 3 EnerFuture scenarios



CAGR (%)

	2000 - 2015	2015 - 2030	2030 - 2050
Non OECD	**5.9**	**4.6**	**3.9**
E Europe / Eurasia	4.1	4.4	4.3
Russia	3.6	4.1	4.2
Asia	7.5	5.3	4.1
China	9.6	5.9	4.5
India	7.2	5.4	4.2
Africa & Mid. East	4.6	3.6	3.5
Latin America	3.2	2.5	2.5
Brazil	2.6	2.4	2.2
OECD	**1.7**	**2.2**	**1.9**
North America	1.9	2.2	1.9
US	1.8	2.1	1.7
Europe	1.4	2.1	1.9
Pacific	1.7	2.5	2.3
Japan	0.7	1.6	1.4
World	**3.7**	**3.6**	**3.3**

Fossil fuel market prices

Figure 47- International oil prices for the 3 EnerFuture scenarios

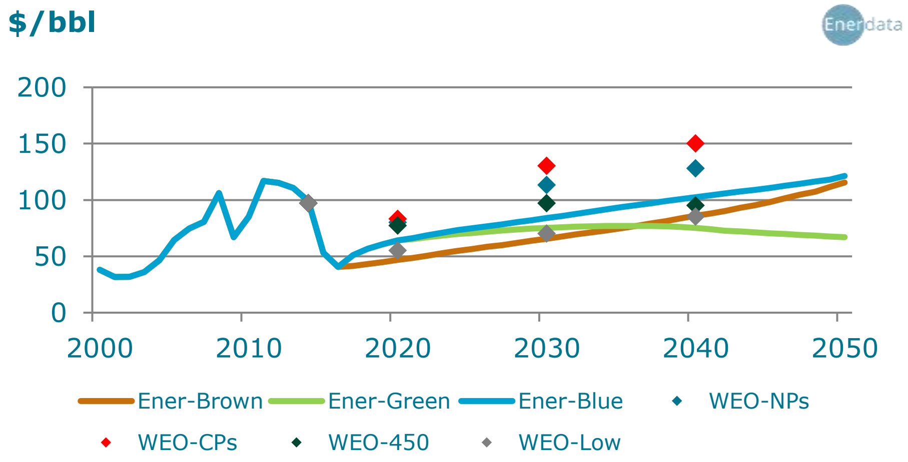


Figure 48 - International coal prices for the 3 EnerFuture scenarios[11]

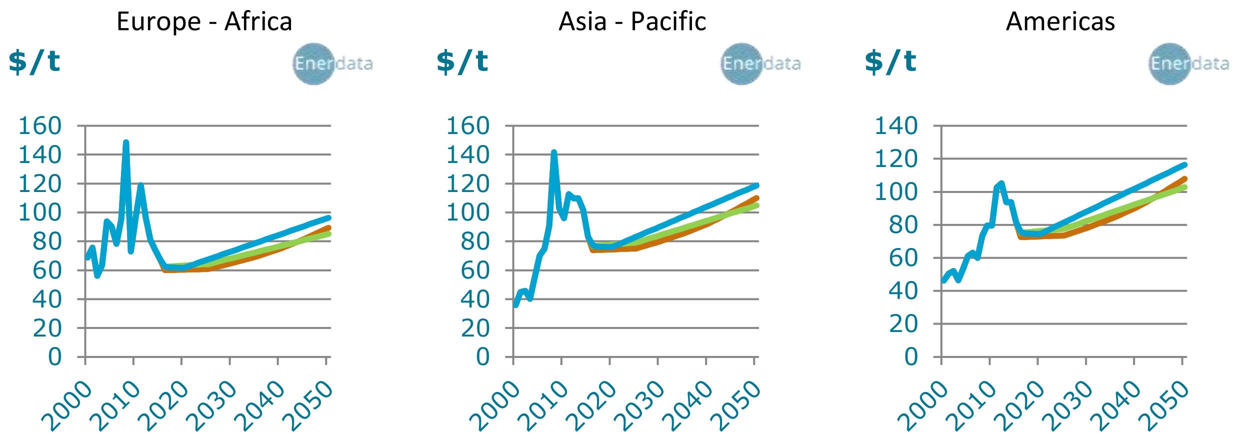
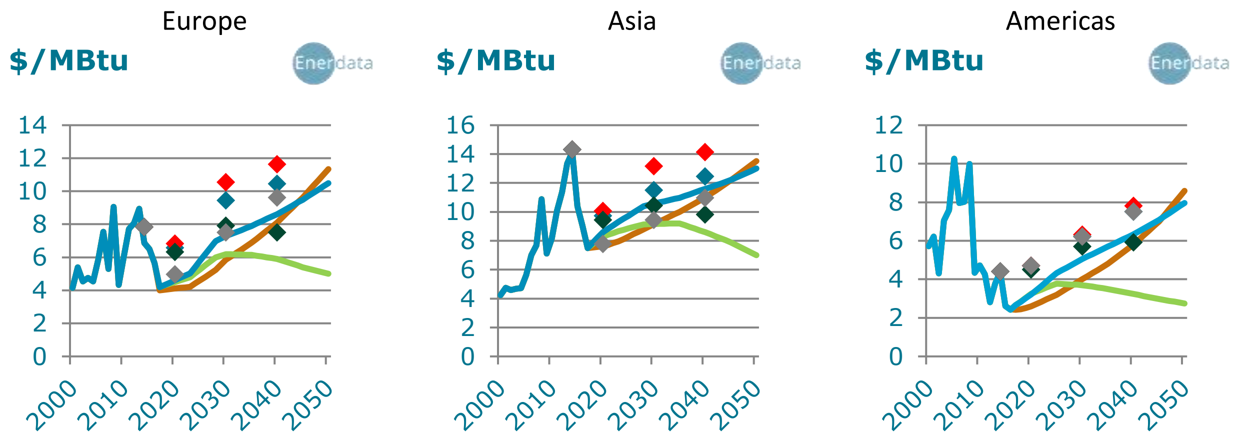


Figure 49 - International gas prices for the 3 EnerFuture scenarios



[11] IEA coal prices are given only for the OECD area, which makes comparison difficult