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Road from Paris

Impact of climate policies on global energy markets in the context of the UNFCCC Paris Agreement

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Abstract
This report examines the effects on greenhouse gases emissions and international energy markets of a Reference scenario where current trends continue beyond 2020, of two scenarios where the UNFCCC Intended Nationally Determined Contributions have been included, and of a scenario in line with keeping global warming below a temperature increase of 2°C above pre-industrial levels. The report presents an updated version of the modelling work that supported DG CLIMA in the UNFCCC negotiations that resulted in the Paris Agreement of the COP21 in December 2015. In the Reference scenario, emissions trigger global warming above 3°C. In the INDC scenarios, regions adopt domestic policies that result in global changes in emissions and energy use, and would result, if pursued beyond 2030, in the long term in a global warming around 3°C; the INDCs cover 28-44% of the cumulated emissions reductions necessary to remain below a 2°C warming. In the 2°C scenario, all regions realise domestic emission cuts to stay below 2°C, with various profiles in 2020-2050 depending on their national characteristics. Reduction of non-CO_2 emissions (34%), energy efficiency (20%) and the deployment of renewable energies (20%) are the main options contributing in the mitigation effort by 2030. A significant number of regions draw economic benefits from shifting their expenditures on fossil energy imports to investments in low-carbon and energy-efficient options. Global efforts to reduce emissions appears compatible with robust GDP growth is in most regions – in particular, high growth rates are maintained in fast-growing low-income regions. The analysis uses the JRC-POLES and JRC-GEM-E3 models in a framework where economic welfare is maximised while tackling climate change.

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Executive summary

Context of the report

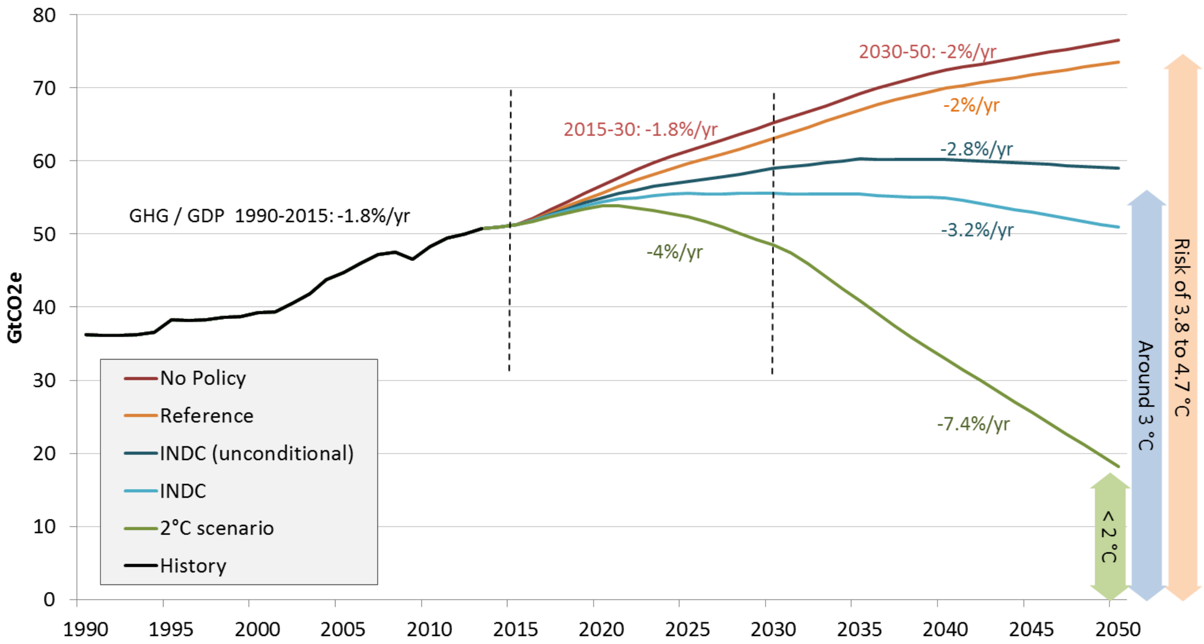
- The UNFCCC COP21 in December 2015 resulted in the Paris Agreement (UNFCCC 2015), the first multilateral, universally applicable, agreement on climate change covering almost all of the world's emissions, and making the pursuit of domestic climate mitigation measures legally binding. Following the science put forward by the IPCC, Parties agreed to take action to limit anthropogenic climate change to "well below" 2°C above pre-industrial era temperatures (and pursue efforts to limit it to 1.5°C).
- The new international climate regime was welcomed by the European Commission in its communication "The Road from Paris" in March 2016 (COM(2016) 110, see EC 2016), which mentioned that the EU aims to "maintain and exploit its first mover advantage when fostering renewable energy, energy efficiency and competing on the development of other low carbon technology market globally."
- This report aims at contributing to the international discussions and to the preparations for the future global stock-taking exercises, on the levels of emission reductions that the new climate agreement implies in order to stay below 2°C whilst maximising benefits for development. It presents an analysis of several low-emission development pathways and achievable through the aggregate effect of national policies, or through globally coordinated action, illustrating some of the economic challenges and opportunities for specific energy markets, sectors and technologies. The analysis is model-based, using the models JRC-POLES and JRC-GEM-E3.
- This report is complemented by detailed energy and GHG balances for key regions and countries (see Kitous and Keramidas, 2016a).

Key conclusions

1. The implementation by 2025-2030 of the Intended Nationally Determined Contributions (INDCs put forward by countries throughout 2015) ushers a significant transformation of the energy system and accelerate the reduction of emissions intensity compared to the Reference case. The **INDCs** collectively bring about **54% of the mitigation effort in 2030** necessary to reach an emission trajectory compatible with remaining below 2°C over the long run. The extension of the INDCs with a similar effort in intensity beyond 2030 would bring, in 2050, about 42% of the mitigation effort necessary to remain below 2°C.

2. A total decoupling of growth from emissions does not happen under the continuation of the current policies; only pro-active mitigation policies by all countries can unlock the necessary changes in investment patterns and decoupling of growth from emissions. The implementation of **INDCs** brings about the global **peak in emissions** sooner than with current policies, **as early as 2025** at 55.6 $GtCO_2e$ (excluding sinks; 15% above 2010), achieved with an average carbon value applied on GHG emissions of 23 $\$/tCO_2$ in 2030. A 2°C case would need to realize the peak soon after 2020 at 53.9 $GtCO_2e$, with an average carbon value of 48 $\$/tCO_2$ in 2030.

Figure 1: World GHG emissions in the GECO2016 scenarios and average annual growth rates for GHG emissions intensity of the economy



Note: the average yearly evolution of emission intensity of GDP is given for each scenario.
Note: total GHG emissions excluding LULUCF sinks.

3. The **2°C** scenario requires significant large-scale changes in the global energy sector compared to trends expected in the Reference scenario. In particular, up-scaling of low-carbon energy supply, improvements in energy efficiency and adopting low-emission technologies in all sectors are essential. Over 2010-2050, for the world to **cut emissions by 62%**, **low-carbon sources** in primary energy supply should rise from 18% to **66%**, energy intensity of GDP should shrink by 67%, while income per capita is expected to be multiplied by 2.4.

4. Emissions **mitigation options** adopted by each country are adapted to national circumstances, potentials and opportunities. At the global scale, easy and quickly reachable reductions are to be found in **non-CO_2 emissions** in energy supply and transformation. By 2030, the **power sector** would play a large role in reductions (40%); overall, **energy demand reduction** and **renewables** would contribute to around 20% of reductions each.

5. The implementation of the INDCs would result in decelerating energy demand growth at the global level; the oil and coal markets would stabilize, while the gas, nuclear and renewables market would continue growing. Moving towards a **below 2°C world would see global energy demand peak in 2030**; all fossil fuel markets would contract significantly, while the growth of the nuclear and renewables markets would be further accelerated. The **role of electricity is expected to increase** and would be significantly enhanced by climate policies, with its share rising to 30%-40% of final energy demand (vs. less than 20% today).

6. Total investments in energy supply would need to rise over time; however the composition differs between scenarios. A 2°C scenario would involve switching to a more capital-intensive energy system with slightly higher investment up to 2030, but then significantly lower investment subsequently, compared to other scenarios. Overall, **remaining below 2°C would require cumulative energy supply investments over 2010-2050 that are 10% lower compared to the Reference** (i.e. 72 tn$); in the 2°C scenario **the importance of the power sector in investments rises**, compared to investment on fossil fuel supply, up to half of total investments (compared to less than 40% in the Reference).

7. For each country, engaging in a 2°C-compatible action is a long-term structural challenge involving shifts in investments, trade flows, and key sectors of the economy. These changes would be manageable compared to the pace of economic growth at global level and in each region. Integrating climate action in the framework of the national economic policy, and especially using the revenues of emission pricing to reduce other distortionary taxes, an approach that would benefit each and all regions. Overall, the global **GDP impact** of the INDCs and 2°C scenarios in 2030 ranges from 0.4% to 0.7% compared to GDP levels without these policies. In terms of annual growth rates, this would mean an **impact of less than 0.1% of annual growth** as a global average (from nearly 3% per year in the Reference to 2.9% per year in the 2°C scenario over the 2020-2030 period). Thus, the INDC and 2°C objectives are still **consistent and compatible with robust economic growth**. These GDP impact estimates are also typically lower than the cost of inaction. Furthermore, carbon pricing revenue recycling can limit losses or in some countries even foster additional growth.

8. The efforts that countries are taking to engage in global climate action in line with 2°C are also delivering benefits in terms of **improving energy security for key net importers** (imports expenditure in importing countries would be limited to a 30-40% growth, compared to as much as a doubling with less ambitious climate policies) and in improving productivity and diversifying the economy. Reducing GHG emissions can be **close to neutral in terms of employment** (less than 0.02% lower employment compared to the Reference in 2030) and a number of important sectors for employment (services, agriculture) are not the sectors among those most affected. Considering climate and fiscal policies simultaneously provides an opportunity to shift taxes away from labour and consumption towards emission-intensive activities, leading to a transition of jobs towards low-carbon, service-oriented sectors.

Caveats and changes since GECO2015

Major benefits from global climate action have not been considered in this report: reduced air pollution reduction and improved health, food and water security, spurred innovation, etc., as focus has been put on mitigation policy.

In addition, the modelling framework that was used in the report concentrates on GHG emissions from energy, for which it gives technological and sectoral detail. While agriculture and land use are also included, specific analysis of related mitigation opportunities and options rely on other tools dedicated to these sectors. Hence the findings in this report related to the role of agriculture and land-use in the transition to a low-emission economy by 2050 must be seen together with these other analyses (see in particular IIASA (2016) and Grassi (2015)).

The major change since the 2015 GECO report (Labat et al. 2015) has been the adoption of the Paris Agreement and communication of INDCs from 189 countries. This was partially captured in the October 2015 policy brief *Analysis of scenarios integrating the INDCs* (EC-JRC 2015a). However a greater number of INDCs, covering over 97% of emissions, is now available and covered in this report.

In addition, modelling elements have been updated and upgraded in the quantitative analysis presented here, including historical energy balances and non-CO_2 abatement potentials. In particular, two important revisions lead to differences in the future emission projections:

- the (upwards) revision of historical coal consumption in China (see Olivier JGJ et al. (2015) and IEA (2016)), which influences the country's 2020 and 2030 emission objectives (defined compared to 2005);

- the assumption on fossil fuels subsidy policies: while a phase out by 2050 was assumed in the 2015 exercises, the 2016 report considers, by default, constant subsidy ratios throughout the whole period. An analysis of a phase out by 2030 is discussed in section 5.2 below.

1 Introduction

In the 21st Conference of the Parties (COP21) of the UN Framework Convention on Climate Change in Paris held in December 2015, governments of 195 countries[1] reached a common agreement on reducing future greenhouse gases emissions and set the world on a path to limit global temperature rise to *well below* 2°C compared to pre-industrial levels by the end of the century. However, doing so will require strong, immediate and collective global effort. This effort should go beyond the aggregate of what has been put forward in 2015 in the course of COP21 as national contributions to 2025-2030. The agreement includes mechanisms to strengthen the ambition of national contributions every five years.

This report contributes to the international discussions and to the preparations for the future global stock-taking exercises (the first one being scheduled for 2018) and national commitment updates (by 2020), on the levels of emission reductions that the new climate agreement implies in order to stay below 2°C whilst maximising benefits for economic development.

This report presents a model-based analysis of several low-emission development pathways, achievable through the aggregate effect of national policies or through globally coordinated action, illustrating some of the economic challenges and opportunities for specific energy markets, sectors and technologies. The report also presents the assumptions underpinning each scenario and the results of the analysis conducted.

Policy context

Under the UN Framework Convention on Climate Change (UNFCCC), 195 countries[1] reached an agreement at the 21st Conference of the Parties (COP21) in Paris in December 2015 on the road to take to combat anthropogenic climate change. The Paris Agreement was a landmark event as the first multilateral, universally applicable, agreement on climate change covering almost all of the world's emissions, and making the pursuit of domestic climate mitigation measures legally binding.

Parties agreed to take action to limit anthropogenic climate change to "well below" 2°C above pre-industrial era temperatures (and pursue efforts to limit to 1.5°C).

The Agreement notably set out a clear framework for future UNFCCC activities, with a mechanism for stock-taking and strengthening ambition every five years from 2018, as well as setting up a framework for submitting greenhouse gas emissions inventories and for monitoring progress towards announced goals. It successfully established a new framework for international climate action beyond 2020, i.e. beyond the horizon of the second commitment period of the previous significant international climate protocol that covered the period up to 2020, the Kyoto Protocol (established in 1997 in the COP3).

This agreement comes as the culmination of a series of conferences in 2009-2012 in Copenhagen, Cancun, Durban and Doha that clarified the objectives of the UNFCCC, and in Warsaw and Lima in 2013-2014, in which countries agreed to submit their Intended Nationally Determined Contributions (INDC) for reducing their emissions by 2025-2030.

[1] There were 196 parties to UNFCCC at time of adoption; the EU acted as a separate UN party and negotiated on behalf of all 28 EU Member States. Palestine became the 197th Party to UNFCCC after the Paris Conference.

In the run-up to COP21, 189 countries submitted their INDC plans[2], aggregately making up for 98% of global emissions.

The EU's negotiation strategy was decisive in reaching the Paris Agreement. The EU pushed for ambition, bringing its experience of effective climate policy and tradition of negotiations and rules-based international co-operation. The EU became the first major economy to present its INDC on 6 March 2015. Throughout the Paris COP, the EU maintained a high level of political coherence; the EU acted as one, negotiating as a single UN party on behalf of all its 28 Member States. The EU and its partners built a broad coalition of developed and developing countries in favour of the highest level of ambition, which was instrumental in creating a positive dynamic during the negotiations and getting all big emitters on board the Paris Agreement.

The EU's continued spearheading effort in climate policy come as a result of the will of the EU and its Member States to pursue broader sustainable development goals. The establishment of the EU's 2030 climate and energy policy was another step in the close interaction between the European Council and the EU Member States, with the EU providing assistance for establishing the Member States' national energy and climate plans. The EU's INDC reflected the EU's 2030 climate and energy policy framework, with an ambitious economy-wide domestic target of at least 40% greenhouse gas emission reduction compared to 1990 for 2030. This commitment is in line with EU policies to achieve a transition to a low emissions economy, allowing for a likely chance to meet the below 2°C objective, on a cost effective pathway towards long term domestic emission reductions of 80% by 2050.

This GECO 2016 report provides a detailed study of the implications of implementing the INDCs in full around the world. It is consistent with the findings of several studies[3] that the implementation of the INDCs will lead to global emissions in 2030 of [52;64] $GtCO_2e$ ([53-59] $GtCO_2e$ in GECO 2016 depending on the conditionality of INDC implementation and whether LULUCF sinks are included or not) and would cover only a part of the gap that will get world emissions on the desired below-2°C trajectory. This result reinforces the need for the mechanism of strengthening ambition set up by the Paris Agreement in order to close that gap iteratively as we move towards 2030.

Indeed, the scientific field has been getting more and more confident in its affirmation that strong emissions cuts are quickly needed to limit temperature rise. The Intergovernmental Panel for Climate Change (IPCC) confirmed in its fifth Assessment Report (AR5) that without further climate action global temperatures will increase by 3.7-4.8°C compared to pre-industrial levels (WGIII, IPCC 2014). The IPCC also showed that significant, immediate and collective action to reduce global emissions of greenhouse gases (GHGs) would help to avoid the most severe impacts of climate change and decrease the likelihood of persistent and irreversible impacts. Such action is vital to protect sustainable development and economic growth worldwide, and not the least to protect the most vulnerable populations. These scientific developments became even more relevant in recent months as 2015 was measured to be the first year with an average global temperature increase of a 1°C compared to pre-industrial levels (WMO 2016).

Related and future JRC work

This report is a follow-up of the GECO2015 report that has been used in the preparation of the 2015 COP21 in Paris. The present version, along with future issues, aims at providing a quantitative base for upcoming negotiations in the framework of the

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[2] 162 submissions, including a single EU submission for all 28 EU Member States.
[3] For more detail see: https://eos.org/meeting-reports/nations-pledges-to-reduce-emissions-and-the-2c-objective

UNFCCC, including the COP22 in December 2016. It will be followed by regular updates so as to be able to incorporate recent developments in the energy sectors and GHG emissions and to address policy questions emerging in the international climate policy process up to the 2018 global stocktaking exercise and the 2020 updated National Determined Contributions (NDCs).

Structure of the report

This report is organised as follows:

Part 2 describes the economy-energy scenarios to 2050 developed for this report: key macro assumptions on population and GDP growth considered in the projections, which are shared across scenarios, and the scenario-specific policies considered. Four scenarios are considered in this report: a Reference scenario, which mostly takes into account all adopted policies for the 2020 time horizon; a 2°C scenario that aims at respecting the long-term 2°C target with a high probability, implying very rapid action in line with the recommendations of the IPCC AR5 report; and two INDC scenarios that assume the full implementation of the 2025-2030 country objectives submitted throughout 2015.

Part 3 provides an outlook of greenhouse gases emissions, how they evolve across scenarios and what mitigation options are undertaken in each scenario.

Part 4 provides an outlook of the energy markets in the context of climate mitigation policies, including the evolution of primary energy supply, energy supply by fuel, the power sector and final energy demand. It also looks at the future evolution of energy prices and investment needs in broad terms for energy supply and more specifically for the power sector.

Part 5 focuses on specific case studies that were developed as thematic variants to the central scenarios. It describes in particular a sustained low oil price and a phase-out of fossil fuel subsidies.

Part 6 presents the macro-economic implications of climate mitigation strategies.

Additional assumptions and descriptions of the models used in this report are provided in annexes. The two models used for the analysis are the world energy system model JRC-POLES and the global general equilibrium model JRC-GEM-E3.

Although the report considers GHG emission reductions in both the agriculture and land-use sectors, relying on aggregated information, it does not include an in-depth analysis of the mitigation options in these two sectors and the associated environmental, economic and social costs and co-benefits.

2 Scenarios

The GECO2016 scenarios were developed with the modelling framework described in Annexes 2 and 3. All scenarios were developed using a common set of socio-economic assumptions (population, economic growth) and energy resources. Energy prices are endogenously obtained with the interplay of energy supply and demand, and are thus scenario-dependent. Country- or region-level energy supply, trade, transformation and demand, as well as greenhouse gases emissions, are driven by income growth, energy prices and expected technological evolution, within the constraints defined by energy and climate policies. Scenarios differ on the climate and energy policies that are included. The main assumptions for each scenario are described below, with additional detail provided in Annexes 1 and 4.

2.1 Socio-economic assumptions

All scenarios share a common set of socio-economic assumptions: country-level population, GDP growth and economic activity at sectoral level represented by its value added. According to these assumptions, economic growth is sustained in all regions and the global average GDP per capita triples in the period 2010-2050. The strong growth in countries with low-income levels in 2010 would enable them to join middle-income levels by 2050.

These projections do not consider the impact on growth from unabated climate change. The macro-economic impacts of climate change mitigation are tackled in section 6.

2.1.1 Population

The world will see important changes in population distribution: while population growth in OECD slows down (decreasing to 15% of world population by 2050), the population in Africa has the highest growth rate by far, with its population more than doubling in 40 years. Asia sees its population stabilising by 2050 at around 4.5 billion inhabitants, with India becoming the single most populated country.

Population estimates are from UN (2015) for all world countries and regions (medium fertility scenario), except for the EU which are taken from the 2015 Ageing Report (EC, 2015).

Table 1: Population

Region	Million inhabitants			Annual growth rate	
	2010	*2030*	*2050*	*2010-30*	*2030-50*
EU28	503	519	525	0.2%	0.1%
Australia	22	28	33	1.3%	0.8%
Canada	34	40	44	0.8%	0.4%
Japan	127	120	107	-0.3%	-0.6%
Korea (Rep.)	49	53	51	0.3%	-0.2%
Mexico	119	148	164	1.1%	0.5%
USA	310	356	389	0.7%	0.4%
Rest of OECD	107	129	141	1.0%	0.4%
Russia	143	139	129	-0.2%	-0.4%
Rest of CIS	134	146	149	0.5%	0.1%
China	1342	1416	1349	0.3%	-0.2%
India	1231	1528	1705	1.1%	0.6%
Indonesia	242	295	322	1.0%	0.4%
Rest of Asia	820	1035	1173	1.2%	0.6%
Argentina	41	49	55	0.9%	0.6%
Brazil	199	229	238	0.7%	0.2%
Rest of Latin America	224	275	305	1.0%	0.5%
North Africa	168	226	274	1.5%	1.0%
Sub-Saharan Africa (excl. South Africa)	825	1393	2138	2.7%	2.2%
South Africa	52	60	66	0.8%	0.4%
Iran	74	89	92	0.9%	0.2%
Saudi Arabia	28	39	46	1.7%	0.8%
Rest of Middle-East	115	176	235	2.2%	1.5%
OECD	**1233**	**1359**	**1423**	**0.5%**	**0.2%**
Non-OECD	**5697**	**7151**	**8328**	**1.1%**	**0.8%**
World	**6930**	**8509**	**9750**	**1.0%**	**0.7%**

Source: UN (2015), EC (2015)

2.1.2 Income

Non-OECD regions will benefit from a higher economic growth rate than OECD regions by 2050, in line with the 1990-2010 developments and an expected further tertiarisation of their economy. OECD yearly growth rate remains lower by 1 point than the world average throughout 2050.

However this differential in growth rates is insufficient to induce a catch-up of GDP per capita of non-OECD regions to OECD, even when expressed in purchasing power parity (PPP). Furthermore, by 2050 a clear distinction is projected in GDP per capita between the Least Developed Countries (LDCs[4]) and other non-OECD countries.

[4] LDCs, as defined by the UN, gather countries mostly from Sub-Saharan Africa and South Asia

Table 2: Growth rate (yearly %) of GDP (left) and GDP per capita (right) ($2005)

Region	GDP			GDP per capita		
	1990-2010	2010-30	2030-50	1990-2010	2010-30	2030-50
EU28	1.8	1.1	1.5	1.5	1.0	1.5
Australia	3.2	2.7	2.2	1.8	1.5	1.4
Canada	2.4	2.0	1.9	1.3	1.1	1.5
Japan	0.9	0.7	0.9	0.7	1.0	1.5
Korea (Rep.)	5.5	2.8	1.1	4.8	2.5	1.3
Mexico	2.7	3.0	3.0	1.0	1.9	2.4
USA	2.5	2.1	1.6	1.5	1.4	1.2
Rest of OECD	2.8	2.7	1.9	1.5	1.7	1.5
Russia	0.4	1.5	0.7	0.5	1.6	1.1
Rest of CIS	0.5	4.5	3.2	0.3	4.1	3.1
China	9.8	5.9	2.7	9.0	5.6	3.0
India	6.5	6.9	4.5	4.7	5.8	4.0
Indonesia	4.7	5.4	3.8	3.2	4.3	3.4
Rest of Asia	5.1	4.7	4.1	3.3	3.5	3.4
Argentina	4.2	2.6	2.4	3.0	1.7	1.8
Brazil	3.1	1.6	2.4	1.7	0.9	2.2
Rest of Latin America	3.2	3.9	3.7	1.7	2.8	3.1
North Africa	4.6	4.2	4.0	2.8	2.7	3.0
Sub-Saharan Africa (excl. South Africa)	4.3	6.1	6.2	1.4	3.4	4.0
South Africa	2.6	2.7	2.8	0.9	1.9	2.4
Iran	4.4	3.0	3.4	2.9	2.1	3.2
Saudi Arabia	3.9	3.1	2.2	1.1	1.4	1.4
Rest of Middle-East	5.8	4.2	2.7	2.5	2.0	1.2
OECD	**2.1**	**1.7**	**1.6**	**1.4**	**1.2**	**1.4**
Non-OECD	**4.8**	**4.8**	**3.4**	**3.3**	**3.6**	**2.6**
World	**2.7**	**2.7**	**2.4**	**1.3**	**1.6**	**1.7**

Source: Historical years: World Bank (2016); projection 2015-2020: IMF (2016), EC (2015); projection 2030-2050: OECD (2013)

The countries' level of income remains differentiated[5]:

- North America remains the wealthiest region, followed by other high-income regions: Pacific and EU;
- emerging economies which are already upper-middle income countries, like China (which reaches one of the highest non-OECD per capita level in 2050: 38 k$ PPP), Latin America (Brazil, Mexico) or Middle-East further increase their income levels;
- for countries with currently lower-middle income or low-income levels, in which half the world population is located, GDP per capita remains comparatively lower

[5] GDP and GDP per capita levels in the entire report are expressed in real US dollars of 2005.

than in other regions: i.e. developing Asia (13 k$ PPP per capita) and Sub-Saharan Africa (6 k$ PPP).

Based on these differences, the INDC and 2°C scenarios differentiate the mitigation effort undertaken by countries according to their income per capita (see scenario definitions in section 2.2 below).

Table 3: Regional GDP per capita (k$ PPP / cap)

	1990	2010	2030	2050
EU28	20	28	34	45
Australia	24	34	46	61
Canada	27	35	44	58
Japan	27	31	38	51
Korea (Rep.)	11	27	44	57
Mexico	10	12	18	30
USA	33	44	58	73
Rest of OECD	12	17	25	35
Russia	13	14	20	25
Rest of CIS	6	6	14	26
China	1	7	21	38
India	1	3	9	20
Indonesia	2	4	9	18
Rest of Asia	2	3	7	13
Argentina	7	13	19	27
Brazil	7	10	12	18
Rest of Latin America	5	7	13	24
North Africa	4	6	10	19
Sub-Saharan Africa (excl. South Africa)	1	1	3	6
South Africa	8	9	14	22
Iran	6	11	17	31
Saudi Arabia	19	24	31	41
Rest of Middle-East	6	10	13	16
OECD	**23**	**30**	**39**	**52**
Non-OECD	**3**	**5**	**11**	**19**
World	**7**	**10**	**15**	**24**

The structure of GDP evolves slowly over time in all regions, with the share of Services gaining 5% to around 69% by 2050 (+4% to 78% in OECD, but +13% to 65% in non-OECD), at the expense of industry (from 30% to 25%), while the share of agriculture remains roughly stable in OECD and decreasing in non-OECD to 7% (the world average is even slightly expanding, due to the relative weight of regions and given that the aggregate non-OECD GDP is higher than the aggregated OECD GDP from 2020 onwards, when expressed in PPP).

Table 4: Regional GDP (tn$(2005) PPP) and sectoral disaggregation

	1990	2000	2010	2020	2030	2040	2050
World	**36**	**48**	**67**	**93**	**132**	**179**	**230**
Agriculture	*8%*	*5%*	*5%*	*5%*	*5%*	*6%*	*6%*
Industry	*33%*	*30%*	*30%*	*31%*	*30%*	*27%*	*25%*
Services	*59%*	*65%*	*64%*	*64%*	*65%*	*67%*	*69%*
OECD	**24**	**32**	**38**	**45**	**54**	**64**	**74**
Agriculture	*3%*	*2%*	*2%*	*2%*	*2%*	*2%*	*2%*
Industry	*32%*	*27%*	*24%*	*24%*	*23%*	*22%*	*20%*
Services	*65%*	*71%*	*74%*	*75%*	*76%*	*77%*	*78%*
Non-OECD	**11**	**16**	**30**	**49**	**78**	**116**	**156**
Agriculture	*17%*	*12%*	*10%*	*9%*	*8%*	*8%*	*7%*
Industry	*37%*	*36%*	*38%*	*37%*	*34%*	*31%*	*27%*
Services	*46%*	*52%*	*52%*	*54%*	*58%*	*62%*	*65%*

2.2 Policies considered

In summary, the following scenarios were modelled:

- **Reference**: Includes adopted policies for 2020 and assumed to be in place by then; thereafter, emissions are driven by income growth, energy prices and expected technological evolution with no supplementary incentivizing of low-carbon technologies[6]. GHG emissions continue to grow at a decelerated pace but reach no peak by 2050.
- **INDC**: All INDCs are implemented, whether expressed as unconditional or conditional contributions; countries where the Reference already lead to emissions at or lower than their INDCs, as well as countries with no INDCs or conditional-only INDCs, do not implement additional policies. Beyond 2030, regional carbon values increase, including for countries that previously had no climate policies, and progressively converge, at a speed that depends on their per capita income; on average, the world GHG intensity over 2030-2050 decreases at the same rate as for 2020-2030.
    - A variant scenario, **INDC (unconditional)**, was also developed, where only unconditional INDCs are implemented. The scenario follows a similar definition to the INDC scenario in terms of policy implementation, with distinct carbon values and world GHG intensity levels.
- **2°C**: Assumes a rapid intensification of policies across several world countries from 2016, leading to a peak in emissions as early as 2020. A progressive convergence of underlying carbon values after 2030, depending on their per capita income, leads to a "below 2°C-compatible" emissions profile by 2050.

[6] Except the EU, which follows GHG emissions up to 2050 from the EU "Trends to 2050 – Reference scenario 2013" (see EC 2013).

2.2.1 **Energy taxation and subsidies**

In all scenarios, the components of energy taxation are held constant by default: VAT is held constant as a percentage, and excise duties are held constant in volume (excluding the impact of the carbon value). Domestic prices thus evolve with the prices in the international markets and with climate-specific policies.

Similarly, energy subsidies are kept constant as ratios of international prices[7]. Subsidy is defined as the difference between the domestic energy price of a fuel and the level of the related reference price (when the latter is higher than the former). The reference price corresponds to the import price[8] (for importers) or the international market price at the closest market (for exporters). This assumption is specifically examined in the subsidies phase-out case study (see section 5.2).

2.2.2 **Reference scenario**

A number of energy and climate policies announced for the 2020 time horizon in energy and climate are taken into account in the Reference scenario. Policies are sourced from previous rounds of UNFCCC negotiations ("Copenhagen Pledges") or from objectives either submitted to UNFCCC (National Communications) or, more recently, announced as national policies.

Policy targets in terms of technological deployment or GHG emissions are reached via the combination of various instruments. First of all, some energy and GHG targets are reached, or even over-achieved, following the evolution of economic activity, energy prices, technology costs and substitution effects without specific policy intervention being necessary. For more constraining objectives the following instruments are introduced: imposed fuel standards for vehicles or capacity for nuclear, feed-in tariffs for renewable technologies in the power sector, carbon values for GHG emissions targets.

After 2020, fuel standards are relaxed, feed-in tariff policies are phased out, and carbon values are kept constant over time. Energy and emissions are thus then driven by income growth, energy and (2020) carbon values and expected technological evolution with no supplementary incentivizing of low-carbon technologies.

Few countries have adopted significant policies that apply to years beyond 2020 (except those listed in Table 5 and Annex 4). The EU is a notable exception: the extension of the EU ETS beyond 2020 has been firmly adopted (EC Decision 2010/634/EU), and it has been included in the Reference scenario in the form of a decreasing cap beyond 2020 (with a linear reduction factor of -1.74%/year). The Reference has been derived from the EU "Trends to 2050 – Reference scenario 2013" (EC, 2013), from which it follows the same trajectory for total GHG and CO_2 emissions by 2050. However it can differ in terms of sectoral distribution. *As such, the EU-28 results of the GECO2016 Reference should not be used as an official European Commission projection of energy and GHG emissions for the European Union*, as the purpose of this report is to focus on global emissions.

Table 5 and Table 6 below provide a list of the policies considered in the Reference scenario for G20 countries (full list is available in Annex 4), all of which refer to 2020 or the years around 2020. The only policy in addition to these that was considered and implemented was the extension of the EU ETS beyond 2020 as mentioned above.

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[7] This is a change in the policy conditions of the scenarios compared to the GECO2015 exercise, which assumed a phasing out of subsidies to fossil fuels by 2050. The analysis of the impact of a subsidy phase out by 2030 is presented in section 5.2 of this report.

[8] This corresponds to the international market price to which are added import taxes, transport and distribution duties and value-added taxes (differs with end-user price only on energy taxes or subsidies).

Table 5: Energy policies in and around 2020 in the Reference scenario for G20 countries

UN Party	Technology	Metric	Target year	Objective
EU	Renewables	Share of gross final demand	2020	20%
EU	Renewable fuels	Share in transport demand	2020	10%
EU	Private vehicles emissions	Emissions, in g/km	2021	95
EU	Primary energy demand	%reduction vs. BAU (2007)	2020	-20%
Canada	Private vehicles emissions	Emissions, in g/km	2025	88
Mexico	Non-fossil + cogeneration	Share in power capacities	2018	34.6%
Mexico		Capacity targets	2018	Nuclear: 1.4 GW Renewables: 23.3 GW
Mexico	Non-fossil	Share in power generation	2024	35%
USA	Wind, Solar, Geothermal	Power production	2020 vs 2012	Doubling
USA	Private vehicles emissions	Consumption, miles/gal	2020	54.5
Argentina	Renewables	Share in power generation	2017	8%
Brazil		Capacity targets	2024	Biomass: 18 GW Hydro: 117 GW + small hydro 8 GW Nuclear: 3 GW Solar: 7 GW Wind: 24 GW
Australia	Renewables	Share in power generation	2020	23.5%
Japan		Capacity targets	2020	Biomass: 5.5 GW Solar: 28 GW Wind: 6 GW
S.Korea	Renewables	Share in primary demand	2020	5%
China	Non-fossil	Share in primary demand	2020	15%
China		Capacity targets	2020	Hydro: 350 GW Nuclear : 58 GW Solar: 100 GW Wind: 200 GW
India		Capacity targets Additional vs. 2010	2022	Biomass: +10 GW Solar: +100 GW Wind: +60 GW
Indonesia	Renewables	Share in power generation	2019	19%

Turkey	Renewables	Share in gross final energy consumption	2023	20.5%
Turkey		Capacity targets	2023	Hydro: 34 GW Solar: 5 GW Wind: 20 GW
Turkey	Renewables	Share in power generation	2023	30%
South Africa		Capacity targets	2030	Solar: 9.4 GW Wind: 8.5 GW

Table 6: Climate policies in 2020 in the Reference scenario for G20 countries

UN Party	GHG coverage	Sectoral coverage	Target type	Target year	Objective
EU	All GHGs	All excl LULUCF	% reduction	2020 vs 1990	-20%
EU	All GHGs	ETS sectors	% reduction	2020 vs 2005	-21%
Canada	All GHGs	All excl LULUCF	Absolute	2020	727 $MtCO_2e$
USA	All GHGs	All	Intensity of GDP	2020 vs 2005	-17%
Brazil	All GHGs	All	% relative to BAU	2020	-36.1% to -38.9% (BAU: 2704 $MtCO_2e$)
Australia	All GHGs	All	% reduction	2020 vs 2000	-5%
Japan	All GHGs	All	% reduction	2020 vs 2005	-3.8%
South Korea	All GHGs	All excl LULUCF	% relative to BAU	2020	-30% (BAU: 776.1 $MtCO_2e$)
China	CO_2	All excl LULUCF	Intensity of GDP	2020 vs 2005	-40% to -45%
India	GHG	All excl agriculture	Intensity of GDP	2020 vs 2005	-20% to -25%
Indonesia	All GHGs	All	% relative to BAU	2020	-26%
Russia	All GHGs	All	% reduction	2020 vs 1990	-15% to -25%
South Africa	All GHGs	All	% relative to BAU	2020	-34% (BAU: approx. 800 $MtCO_2e$)

2.2.3 **INDC scenario**

All INDCs are implemented, whether expressed as unconditional or conditional contributions; countries where the Reference already lead to emissions at or lower than their INDCs, as well as countries with no INDCs or conditional-only INDCs, do not implement additional policies. Beyond 2030, regional carbon values increase, including for countries that previously had no climate policies, and progressively converge, at a speed that depends on their per capita income; on average, the world GHG intensity over 2030-2050 decreases at the same rate as for 2020-2030.

A variant scenario, **INDC (unconditional)**, was also developed, where only unconditional INDCs are implemented. The scenario follows a similar definition to the INDC scenario in terms of policy implementation, with distinct carbon values and world GHG intensity levels.

For countries modelled individually, the INDC targets were taken directly. For regions modelled as a grouping of several countries, the individual countries' INDCs were aggregated. This provided a target for the region: if the summed countries constituted all or nearly all of the historical emissions of the region (e.g. Morocco and Tunisia), their aggregated INDCs were taken as the INDC target of the region; if they represented only a share of the region (e.g. rest of Gulf, rest of sub-Saharan Africa), the aggregated INDCs expressed as a percentage growth compared to the summed historical emissions of 2010 was taken as the target for the whole region.

Several countries (notably non-OECD countries) have expressed their INDCs as reductions compared to a Business-As-Usual (BAU) scenario. In certain cases, the GECO2016 Reference scenario was found to have lower emissions compared to the country's (or region's) announced BAU scenario or to its INDC target. This can be due to a number of factors (among which differences in the assumptions in economic growth, in the modelling frameworks, in energy prices, in energy consumption growth); however, the explanation of these differences is beyond the scope of this report. In the cases where the INDC targets were reached or exceeded with the policies that were already present in the Reference scenario, no additional policies were implemented.

In particular for the EU, the extension of the EU ETS beyond 2020 has been firmly adopted, and it has been included in the Reference scenario, in the form of a decreasing cap beyond 2020 (with a linear reduction factor of -1.74%/year), according to EC Decision 2010/634/EU.

Table 7 and Table 8 below provide a list of the policies considered in the INDC scenarios for G20 countries for the 2025-2030 time horizon (full list is available in Annex 4).

The INDC target was calculated considering the perimeter of the INDC policy in each case (e.g. energy-only emissions, or all sectors excluding LULUCF[9], etc.). Climate-related policies were modelled using carbon values that impacted all sectors of the economy, including agriculture and land use. Emissions reductions in each sector were achieved depending on the economic attractiveness of mitigation options across sectors. As a result, reductions in LULUCF were calculated endogenously by the modelling (via two LULUCF marginal abatement cost curves for each country/region); LULUCF-specific policies were not necessarily met.

Most countries' INDCs were formulated for 2030, with some countries having targets for 2025 or 2035. Beyond the time horizon of the INDCs, the scenarios were designed so as to represent a world where the level of policy ambition continues at a similar pace at the global level, instead of phasing out these policies and shifting towards a world similar to that described in the Reference scenario. Beyond 2030, regional carbon values increase, including for countries that previously had no climate policies; they progressively converge towards a "lead" worldwide carbon value, at a speed that depends on their per capita income (three groups of countries were distinguished[10], with the first group converging in 2040 to the lead price, the second group reaching 50% of the lead price in 2050 and the third group reaching 25% of the lead price in 2050 - countries with a carbon value higher than the lead price already in 2030 kept this price until the lead price caught up). The lead carbon value trajectory was chosen so as to have, on average, the world GHG intensity decrease over 2030-2040 and 2040-2050 to be at the same rate as for 2020-2030 (-2.8%/year and -3.3%/year in the INDC (unconditional) and INDC scenarios, respectively).

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[9] LULUCF: land use, land use change and forestry (deforestation, reforestation and afforestation, forest management, cropland management, grazing land management and revegetation)

[10] Distinguished based on their income per capita in 2030 (expressed in $2005 PPP: >30 k$/cap, 20-30 k$/cap, <20 k$/cap).

Table 7: Climate policies in the INDC scenarios for selected countries

UN Party	GHG coverage	Sectoral coverage	Metric	Base year	Target year	INDC "low ambition"	INDC "high ambition"	Emissions at Base Year (Mt)
EU	All GHGs	All sectors	Emissions	1990	2030	-40%	-40%	
Canada	All GHGs	All sectors (LULUCF net-net)	Emissions	2005	2030	-30%	-30%	
Mexico	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-22%	-36%	973
USA	All GHGs	All sectors (LULUCF net-net)	Emissions	2005	2025	-26%	-28%	
Argentina	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-15%	-30%	670
Brazil	All GHGs	All sectors	Emissions	2005	2025	-37%	-37%	
Australia	All GHGs	All sectors	Emissions	2005	2030	-26%	-28%	
Japan	All GHGs	All sectors excl sinks	Emissions	2013	2030	-26%	-26%	1408
Korea (Republic)	All GHGs	All sectors excl LULUCF	Emissions	2030 (BAU)	2030	-37%	-37%	850.6
China	CO_2	Energy	CO_2 intensity of GDP	2005	2030	-60%	-65%	
India	All GHGs	All sectors	GHG intensity of GDP	2005	2030	-33%	-35%	
Indonesia	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-29%	-41%	2881
Russian Federation	All GHGs	All sectors	Emissions	1990	2030	-25%	-30%	
Saudi Arabia	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-130 $MtCO_2e$	-130 $MtCO_2e$	n/a
Turkey	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-21%	-21%	1175.0
South Africa	All GHGs	All sectors	Emissions		2030	2020-2035: plateau at 398-614 $MtCO_2e$		n/a

Several policies objectives are reached without specific policy instrument, as a result of energy prices and technological evolution, or as a result of the climate policies feedback on the energy system (carbon values). For the remaining energy policies in the power sector, technology-specific feed-in tariffs were added; they extend to 2020 and are progressively phased out by 2030. The carbon values and the supports to technologies by 2020 in the INDC (unconditional) scenario were set to be at least as high as in the Reference scenario. Similarly, the carbon values and the technology supporting schemes in the INDC scenario were set as being at least as the levels in the INDC (unconditional) scenario by 2030. This was done in order to maintain the definition of a higher-ambition scenario for the INDC scenario, despite potential spill-over effects and/or carbon leakage (through lower international prices).

Table 8: Energy policies in the INDC scenarios for selected countries

UN Party	Target year	Policy (includes only countries >0.15% of global 2010 emissions)
EU	2030	At least 27% of renewable energy consumption (binding target)
EU	2030	At least 27% energy savings compared with BAU (binding target)
Brazil	2030	18% sustainable biofuels in energy mix
Brazil	2030	45% of renewables in energy mix
Brazil	2030	28-33% of renewables (other than hydro) in the total energy mix
Brazil	2030	23% renewables (other than hydro) in power supply
Japan	2030	20-22% nuclear
Japan	2030	2-24% renewables
China	2030	20% non-fossil fuels in primary energy consumption
India	2030	40% cumulative electric power installed capacity from non-fossil fuel based energy sources (relative to 2005?)
Indonesia	2025	Minimum 23% energy from renewable sources (binding target)
Turkey	2030	Increasing capacity of production of electricity from solar power to 10 GW
Turkey	2030	Increasing capacity of production of electricity from wind power to 16 GW
Turkey	2030	Tapping the full hydroelectric potential
Turkey	2030	Commissioning of a nuclear power plant
Turkey	2030	Reducing electricity transmission and distribution losses to 15%
South Africa	2050	Decarbonised electricity by 2050 (US$349bn 2010-2050)
South Africa	2050	CCS: 23 Mt CO_2 from coal-to-liquids plant (US$0.45bn)
South Africa	2050	Investment in electric vehicles (US$513bn 2010-2050)
South Africa	2030	Hybrid electric vehicles: 20% by 2030 (US$488bn)

2.2.4 **2°C scenario**

The 2°C scenario was designed so as for 2010-2050 cumulative CO_2 emissions to be consistent with a likely chance to meet the long-term (2100) goal of a temperature increase over pre-industrial levels below 2°C, while reflecting the need for a global transition towards a low-emission economic development pattern. The scenario leads to a total carbon budget of 1160 $GtCO_2$[11] over 2011-2050, which fits a probability to keep global temperature rise below 2°C of close to 50% or above[12].

[11] Cumulated CO_2 emissions of 1160 $GtCO_2$ including LULUCF, or 1200 $GtCO_2$ excluding LULUCF (LULUCF behave on average as a sink of CO_2 emissions).
[12] From IPCC AR5 WGIII Table 6.3 (IPCC 2014): 1160 $GtCO_2e$ falls within the range of scenarios 430-480 ppm with overshoot >0.4 W/m2 (likely below 2°C over 21st century), as well as within the range of scenarios 480-530 ppm with overshoot <0.4 W/m2, and

The 2°C scenario builds upon the INDC scenario, and maintains the same energy policies. The abovementioned carbon budget is respected by implementing additional climate policies (in the form of higher carbon values). These policies increase in ambition from 2016 in all regions of the world, including countries with low income or whose INDC target was already reached without any policies in the INDC scenarios or that did not submit an INDC.

To account for the different financial capacity across regions, the scenario also differentiates the intensity of mitigation between regional groups[13]. Middle-income and low-income countries converge in 2030 to the common "lead" carbon value of high-income countries. Regions with very low income per capita are allowed a longer transition period (with no full convergence by 2050 yet). Additionally, carbon values are set as being at least as high as in the INDC scenario, thus taking into account that some INDC targets can lead to carbon values higher than the common "lead" value (relevant for 2020-2030)[14].

Table 9 gives the resulting carbon values in 2030 for selected countries:

Table 9: Carbon values used in the Reference, INDC and 2°C scenarios, 2030[15]

$/t$CO_2$	Reference	INDC	2°C
EU *	29	53	53
USA**	0	53	53
Canada	1	42	53
Australia	20	32	53
China	0	29	53
India	0	0	26
Brazil**	0	5	53
Mexico	0	28	53
World average	2	23	48

**: EU average value over all sectors (ETS and non-ETS).*
***: USA and Brazil in INDC scenario: values reached in 2025.*

2.2.5 Beyond 2°C

The Reference, INDCs and 2°C scenarios explore pathways that cover alternative outcomes for climate change ranging from exceeding 3°C to staying below 2°C. The GECO scenarios can be compared to the scenarios compiled by the IPCC in its latest Assessment Report (AR5, IPCC 2014) and mapped against the emissions over 2011-2050 seen as limits so as to remain below a 2°C warming by the end of the century. It is interesting to note that 2°C scenarios differ little in the cumulative CO_2 emissions over 2011-2050 and over 2011-2100, implying that annual emissions would have to become on average zero over the second half of the century, possibly implying some "negative" emissions.

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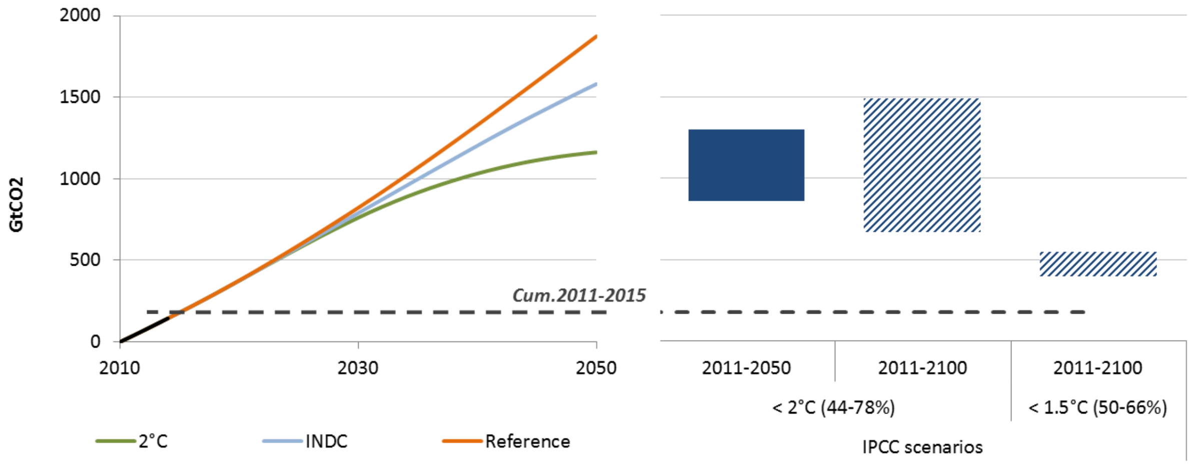
scenarios 480-530 ppm with No exceedance of 530 ppm CO_2-eq. Over all these scenarios, the probability of exceeding 2°C is between 22-56%.

[13] Country groupings based on income per capita in 2030; similar country groupings to the INDC scenarios (see footnote 10), with an additional fourth group for very low-income countries (<10 k$/cap).

[14] This is relevant for South Korea, Thailand, USA, Canada, Morocco and Tunisia.

[15] Values expressed here are in real US dollars of 2015

Figure 2: Cumulative CO_2 emissions and probabilities of temperature change



Note: Percentages refer to probabilities to remain below that temperature increase at the end of the century. <2°C figures were obtained from IPCC AR5 WGIII Table 6.3: 430-480 ppm with overshoot >0.4 W/m2, 480-530 ppm with overshoot <0.4 W/m2 and 480-530 ppm with no exceedance of 530 ppm. < 1.5°C from IPCC AR5 Synthesis Report Table 2.2.
Note: Cumulated CO_2 emissions for GECO2016 scenarios include LULUCF emissions.

The Paris Agreement foresees climate mitigation effort that could be extended beyond the "below 2°C" limit to the "1.5°C" limit. In order to fulfil this second target, global emissions would have to decrease even further and the mitigation options would have to be more massively and more quickly adopted.

The scientific literature for scenarios with a high probability of keeping global warming below 1.5°C by 2100 is still scarce. The IPCC mentions a carbon budget over the entire century (2011-2100) of 400 to 550 $GtCO_2$ to be in line with keeping temperature increase below 1.5°C[16]. Taking into account the fact that cumulative emissions over 2011-2015 were already of approximately 180 $GtCO_2$, this leaves little room for net emissions to take place for the rest of the century (220 to 370 $GtCO_2$). One possible emissions trajectory would be for the world to engage in a more ambitious mitigation effort compared to the 2°C scenario by 2020-2030, become entirely carbon-neutral by 2050 and have negative emissions over the second half of the century (involving technologies like "BECCS" that would allow CO_2 removals through using biomass energy (BE) – assumed to be carbon neutral – combined with carbon capture and storage (CCS)).

[16] IPCC AR5 Synthesis Report Table 2.2

3 GHG emissions

Resulting greenhouse gases emissions for the scenarios analysed are discussed in this section[17], including emissions from the energy sector. More detail concerning the structure of energy supply and demand is provided in section 4.

3.1 Reference scenario

Total GHG emissions are expected to continue growing, reflecting increasing economic activity and energy consumption, and despite climate and energy policies already in place and foreseen technological learning.

In the Reference scenario, GHG emissions (excluding natural sinks from LULUCF[18]) would increase from 48.3 $GtCO_2e$ in 2010 to 63.1 $GtCO_2e$ in 2030 and 73.6 $GtCO_2e$ in 2050[19] (i.e. 2050 emissions are about 50% higher than 2010 emissions, or about 100% higher than 1990 emissions). Power generation remains the dominant source, ahead of industry and transport, followed by "other" energy sectors (primary supply, transformation), agriculture, buildings, LULUCF and waste. In the figure below, GHG emissions are reported sector-wise. Emissions from Land Use, Land-use Change and Forestry (LULUCF) are reported separately from the corresponding sinks (in which the degree of uncertainty is higher)[20].

The rate of increase of global GHG and CO_2 emissions will slow down but do not peak by 2050. After reaching a historical maximum by exceeding 2%/year during the past decade, it would slowly decrease to 0.5%/year by the 2040-2050 decade.

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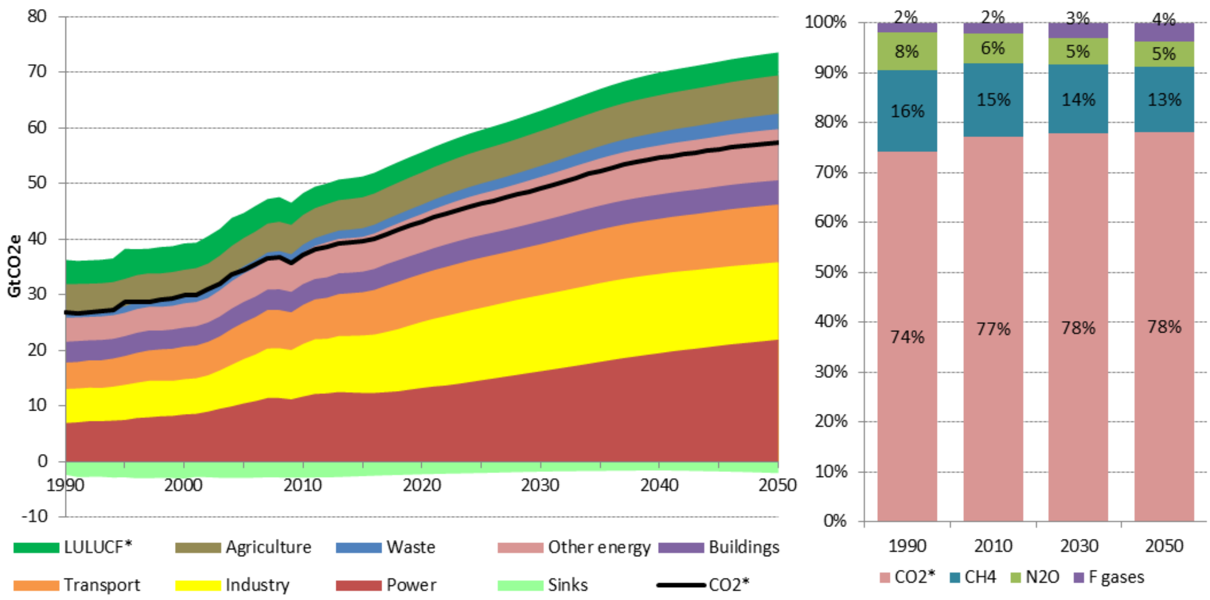
[17] GHG emissions from the different gases are aggregated into CO_2-equivalent values, using the 100-year global warming potentials of the IPCC Second Assessment Report (see Table 4 of the Technical Summary of IPCC (1996)).

[18] Sinks are defined as negative CO_2 emissions from land-use related activities. Sinks from afforestation and forest management could represent 3 $GtCO_2$ in 2010 and about 2 $GtCO_2$ in 2050, but the uncertainty on the historical estimates of sinks is significant and the modelling of the future contribution of sinks on emissions reductions goes beyond the scope of this report; the focus of this report is on analysing the projected evolutions of emissions from all sources, excluding LULUCF sinks.

[19] Global GHG emissions are higher than in the GECO2015 Baseline scenario, mostly because of the revised assumption on fossil fuel subsidies, which increases energy consumption and related CO_2 emissions in oil and gas producers as well as in coal-intensive economies, and the revision of historical coal use in China (which mechanically pushes up the country's emissions by 2020 and beyond).

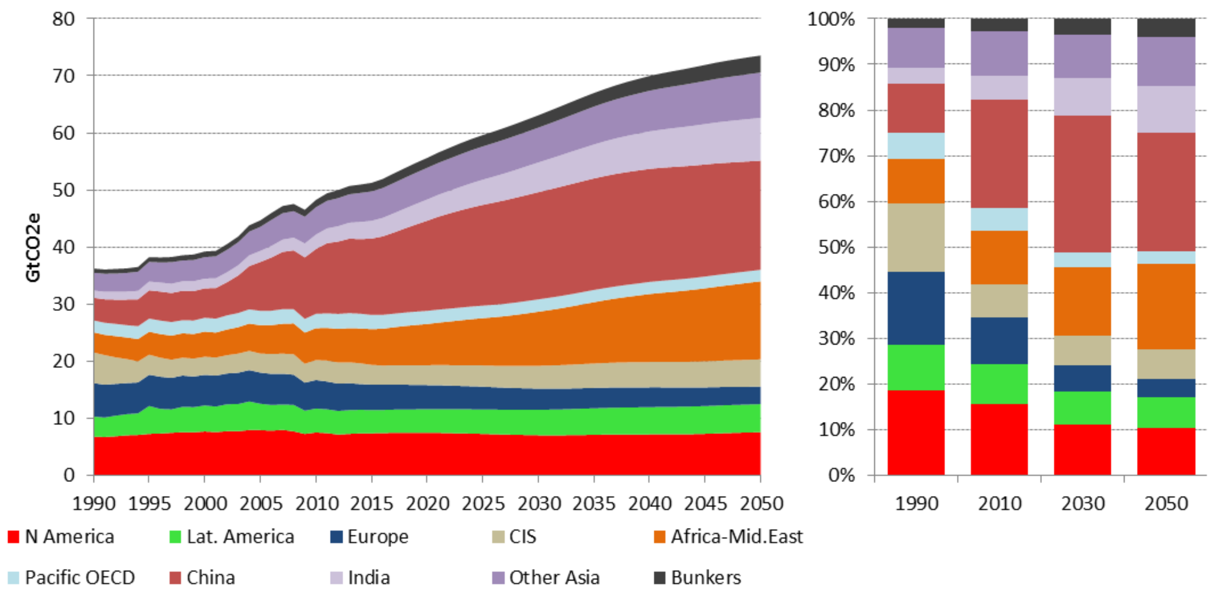
[20] Projected CH_4 and N_2O agriculture emissions and CO_2 land-use emissions are derived from the GLOBIOM model (Global Biosphere Management Model) which has been linked to the JRC-POLES model – for more information on the GLOBIOM model see IIASA (2016) and Havlík P. et al. (2014).

Figure 3: World GHG emissions in the Reference scenario by sector (left) and by GHG gas (right)



Note: Historical data: CO_2 emissions from combustion are derived from national and regional energy balances; emissions from industrial processes (CO_2, CH_4, N_2O, PFC, HFC, SF6) and emissions from agriculture (CH_4, N_2O) refer for Annex I countries to UNFCCC (2015) and for Non-Annex I countries to EDGAR (EC JRC 2014); CO_2 LULUCF emissions refer for Annex I countries to UNFCCC and for Non-Annex I countries to FAO-Stat (FAO 2015). All historic emissions for Brazil and Mexico as well as peat emissions from Indonesia refer to national inventories.
** In these graphs LULUCF CO_2 sinks are singled out and not included in the LULUCF and CO_2 categories.*

Figure 4: Regional GHG emissions, Reference scenario



The regional evolution (Figure 4 right) shows clearly the role of Asia in future GHG emissions in the Reference scenario, which should represent about 50% of the total from

2030 onwards. Africa and Middle-East would also experience a continuous increase, representing about 20% of the total by the mid-century.

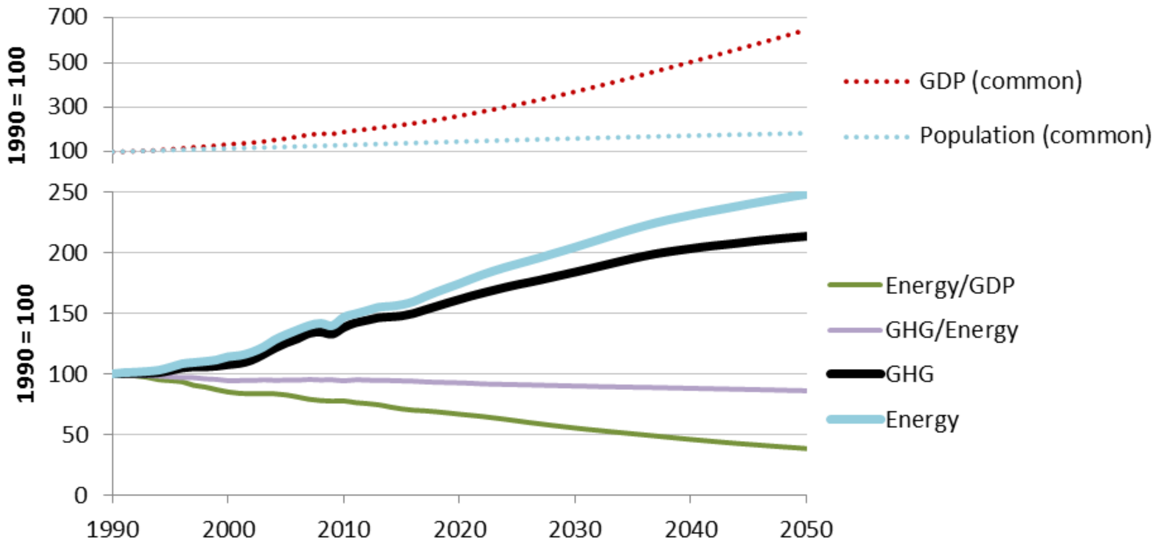
North America, Europe and Pacific, which still represent about 30% of the total in 2014, fall to 15%, followed by Latin America (7%) and CIS (6%), both with slightly decreasing shares

Figure 5 shows the expected evolution of the GHG emissions' GDP intensity – the GHG emissions content of the economy. This indicator is expected to decrease steadily over the time period analysed, halving its value by 2040 with respect to the 1990 reference.

GHG emissions intensity decreases at around 2%/year over the next three decades. This value is similar to emission intensity improvement over 1990-2010[21], the growth of emissions having been slower than the growth of economy in recent history.

The decomposition[22] of world GHG emissions shows that the energy intensity of the GDP keeps decreasing (it is half that of 2010 in 2050) and the GHG content of the energy mix declines slightly over time; despite that, the policies envisaged in the Reference scenario are far from allowing a decoupling of emissions and economic growth sufficient to stay below 2°C. The average GDP per capita triples in 2010-2050 while the GHG emissions per capita remain fairly stable throughout the period, around 6.5 tCO_2e per capita.

Figure 5: Decomposition of world GHG emissions, Reference scenario



Technological change and market dynamics are the main mechanisms leading to this emissions trajectory, with little or no effect attributable to new GHG mitigation policies. The average world price on carbon emissions[23,24] is very low, only of 1 $/tCO_2$ in 2020

[21] Emission intensity improvement was relatively lower in 2000-2010 due to the important role of coal in some emerging economies.

[22] Decomposition of the emissions into the following four explanatory variables: the GHG content of energy use, the energy intensity of GDP (expressed in real US dollars of 2005), the GDP per capita, and the population: GHG = [GHG / Energy] * [Energy / GDP] * [GDP / Pop] * [Pop]

[23] Carbon prices of individual countries averaged over countries' GHG emissions.

[24] Carbon values expressed in this section are in real US dollars of 2015.

and 2030. Several regions of the world are not subject to carbon pricing in this scenario, including countries like China and India that are able to reach their 2020 policies without the need of a carbon value. In the few countries where a carbon value is applied on GHG emissions in 2020, prices range from 1 $/tCO_2$ in Canada to 20 $/tCO_2$ in Australia and 40 $/tCO_2$ in South Korea.

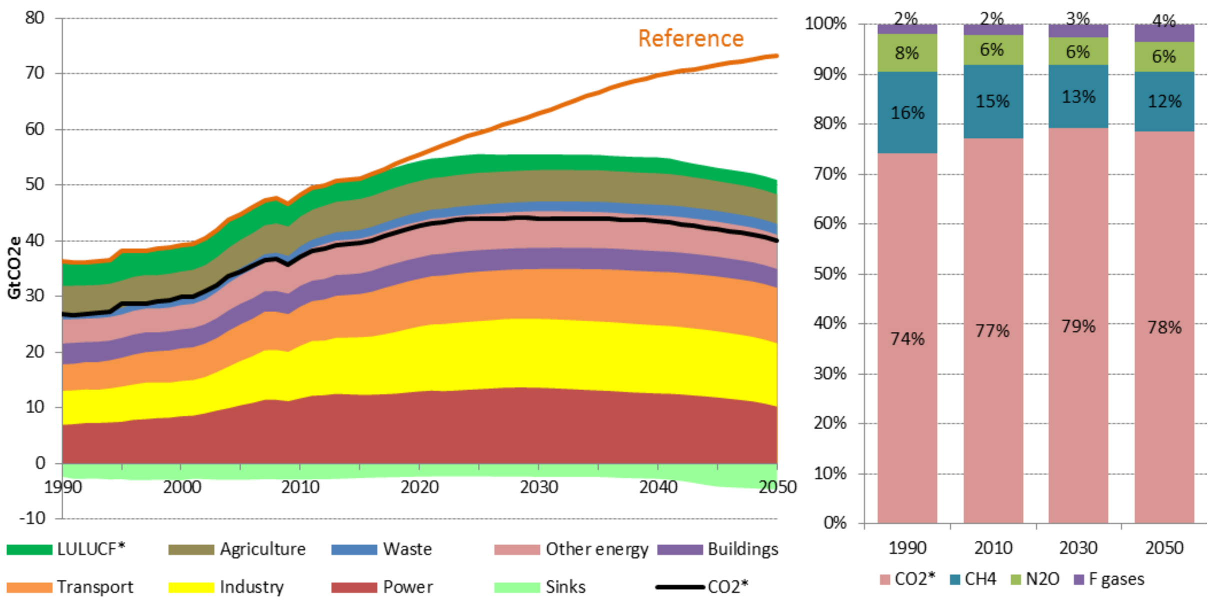
3.2 INDC scenario

The full implementation of the INDCs has a worldwide aggregated effect for total GHG emissions to continue growing until they peak and start decreasing if the effort (expressed in improvement of emission intensity of the GDP) is pursued beyond 2030. The level and date of the GHG emissions peak depends on the INDC scenario considered: emissions (excluding sinks) could peak as early as 2025 at 55.6 $GtCO_2e$ (15% above 2010) in the INDC scenario, which also integrates pre-2030 efforts that are conditional on the international context or on the provision of international financial assistance, or in 2035 at 60.3 $GtCO_2e$ (24% above 2010) in the INDC (*unconditional*) scenario.

In the former case, emissions (excluding sinks) reach 55.5 $GtCO_2e$ in 2030 and 50.9 $GtCO_2e$ in 2050 (5% above the 2010 level, 40% higher than 1990 emissions).

Unlike in the Reference scenario, the weight of the emissions from power generation is greatly reduced; between 2030 and 2050 it is surpassed by emissions from industry and transport. Following are emissions from agriculture, "other" energy sectors, buildings, LULUCF and waste.

Figure 6: World GHG emissions in the INDC scenario by sector (left) and by GHG gas (right)



** In these graphs LULUCF CO_2 sinks are singled out and not included in the LULUCF and CO_2 categories.*

In terms of regional evolution, the picture is still dominated by Asia, although China has a lower share of total emissions (27% in 2030 and 19% in 2050) compared to the

Reference scenario (respectively 30% and 26%). Indeed, after increasing for decades the share of China starts contracting after 2030 and a large part of that share is absorbed by India, the rest of Asia and Africa-Middle East. North America, Europe and Pacific represent 19% of total GHG in 2030, 16% in 2050. Because international bunkers are not covered by the INDCs, their emissions remain the same and their share in global GHG emissions increases to 6% of total GHG by mid-century.

Figure 7: Regional GHG emissions, INDC scenario

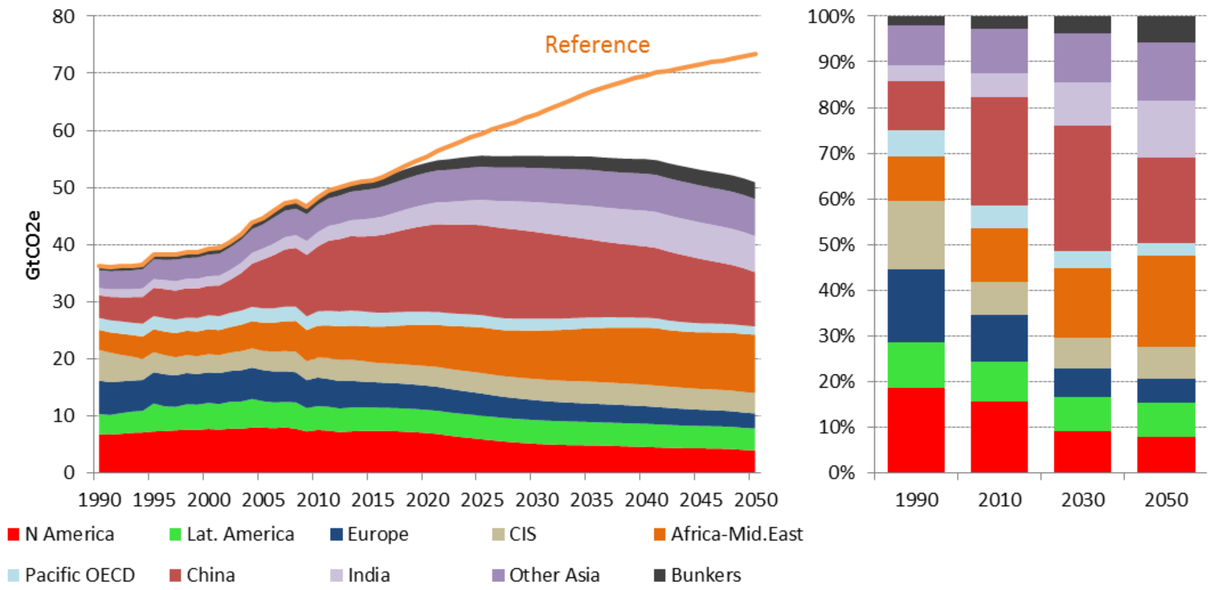
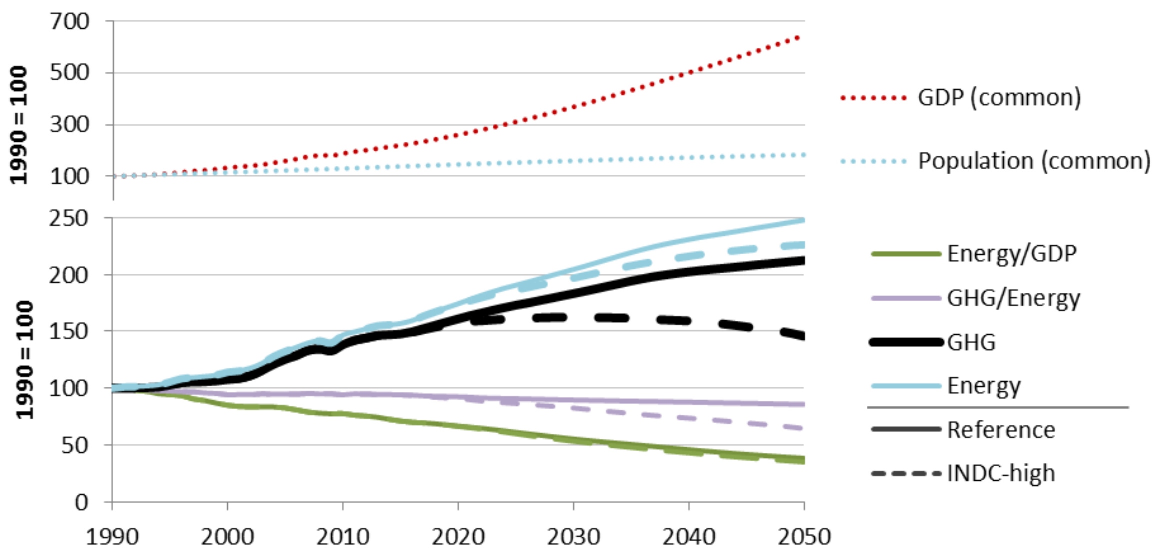


Figure 8: Decomposition of world GHG emissions, INDC scenario

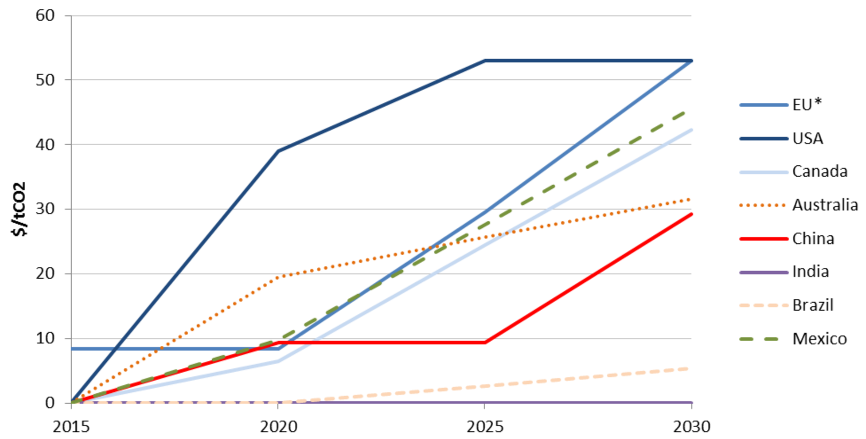


Climate policies included in the INDC scenarios would change the energy landscape substantially and have a significant impact on the global emissions trajectory compared to the Reference scenario. The rate of increase of GHG and CO_2 emissions decelerates to zero by 2030; by the 2040-2050 decade it would actually decrease by 0.9%/year. The rate of change of the emissions intensity of the economy is also impacted; it would average -2.8 to -3.2%/year over the 2020-2050 decade according to the scenario, more than 50% above the rate over 1990-2010.

Overall, the emissions intensity of GDP would be about a third lower than in the Reference scenario in 2050. This is firstly achieved by a lower emissions content of energy (-25% vs. Reference in 2050), and secondly via a lower energy intensity of GDP (-9%).

The policies implemented in a different manner in countries across the world result in emissions that correspond to an average "implicit" world price on carbon emissions of 23 $/tCO_2$ in 2030 (11 $/tCO_2$ in the INDC (unconditional) scenario). While some world regions still do not face a carbon value, due to non-constraining INDC policies (e.g. India, Turkey, Saudi Arabia, Ukraine), most emissions around the world would be subject to a constraint. Carbon values in 2030 range from 5 $/tCO_2$ in Brazil to 53 $/tCO_2$ in the USA and the EU (averaged over the entire economy, ETS and non-ETS sectors).

Figure 9: Carbon values by 2030 in the INDC scenario for selected countries



**: EU price refers to the ETS sector's price until 2020, then to the average price over all emissions for 2025 and 2030.*
Note: very constraining INDCs for South Korea and New Zealand lead to higher prices not shown on the graph (120 $/tCO_2$)

It is also important to note the relationship between the carbon value mentioned in the report and other policy measures affecting GHG emissions. For example, where renewable energy or vehicle emission standards are employed this has the effect of lowering the value needed to meet a given target, as some emissions reductions are achieved by these other measures. This is particularly notable in the case of the EU (see Figure 9) where the carbon value is lower than would otherwise be the case due to the effect of other policies contained in the INDC scenario (such as support to renewable energy and vehicle emission standards and individual policies of Member States). As a comparison, the detailed requirements from the USA Clean Air Act[25] have not been considered in this analysis (beyond fuel standards for light vehicles), leading to a relatively higher carbon value over 2020-2025 for this country.

[25] In particular the USA Clean Air Act standards for new power plants as well as the mandatory reduction of methane emissions from waste landfills and from the oil and gas industry; see: https://www.epa.gov/clean-air-act-overview/air-pollution-current-and-future-challenges

3.3 2°C scenario

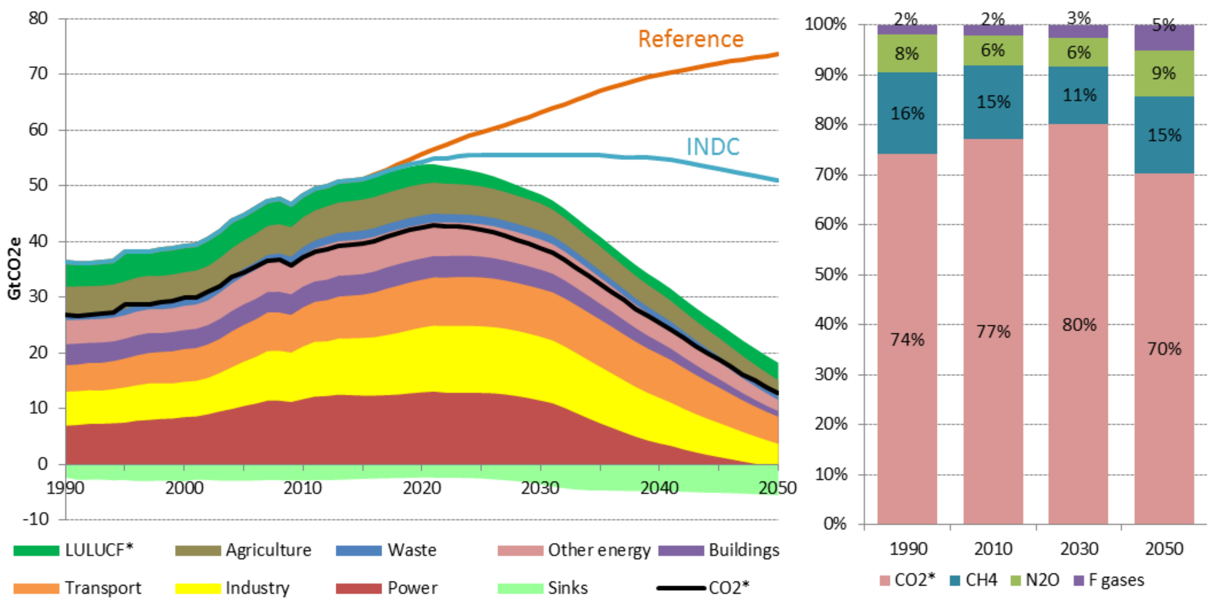
Quick and decisive action to fully close the gap towards a 2°C world would require a significant further emissions reduction compared to what is achieved with the implementation of the INDCs.

In this scenario, total GHG emissions would be allowed to grow only until the end of the current decade; they would reach a peak soon after 2020 at 53.8 $GtCO_2e$ (excluding sinks), 11% higher than in 2010. Afterwards, they would start to decrease strongly, first at a rate of -1.3%/year in the 2020-2030 decade, then at -3.8%/year and -5.7%/year in the following decades. They reach 48.5 $GtCO_2e$ in 2030 (slightly below 2010 emissions) and 18.2 $GtCO_2e$ in 2050 (62% lower than 2010 emissions, and 50% lower than 1990 emissions).

The power sector, which is historically the largest emitting sector and, at the same time, the one with largest technological flexibility, would react quickly and strongly to the policies put in place. It would reach full decarbonisation over the next 35 years at the world level: its emissions first stabilize throughout 2030, then decline and by 2050 even become negative (thanks to the use of biomass and CCS; see section 4.2). The "other energy" transformation sector (which includes production of fossil fuels) would also be very quickly impacted by the policies put in place, especially given the relatively higher abatement potential in non-CO_2 gases (see section 3.4.2 for more details) that make the bulk of this sector's emissions.

In 2050, the remaining emitting sectors are, by order of importance, transport and industry, followed by LULUCF (without sinks), agriculture, "other energy" sector, buildings and waste.

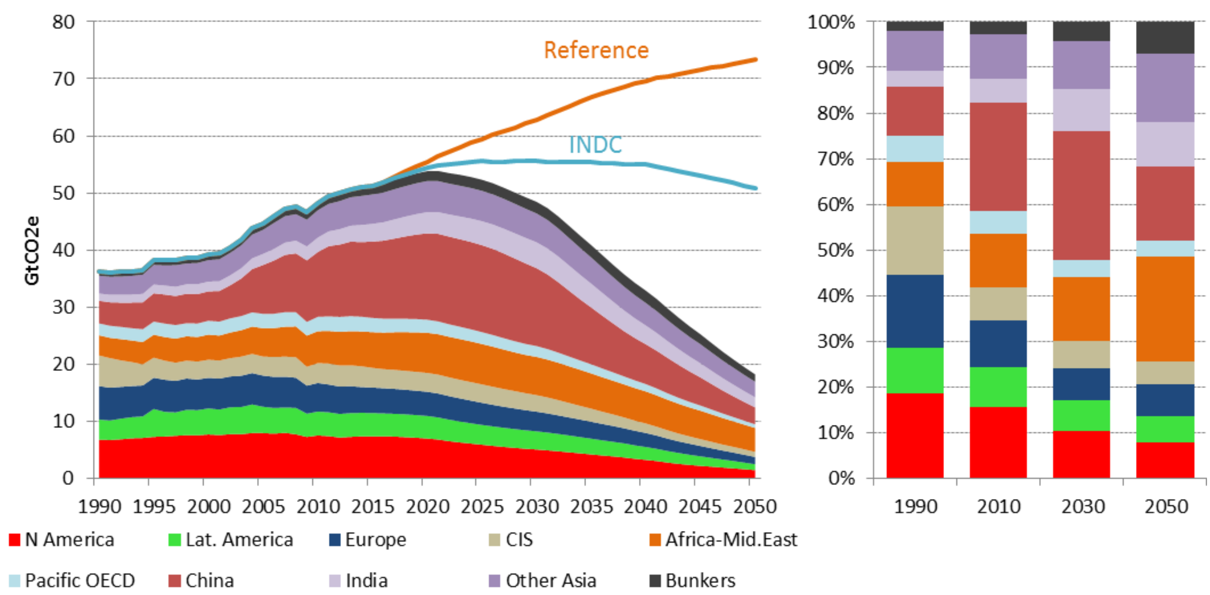
Figure 10: World GHG emissions in the 2°C scenarios by sector (left) and by GHG gas (right)



** In these graphs LULUCF CO_2 sinks are singled out and not included in the LULUCF and CO_2 categories.*

Within this scenario, all regions would drastically reduce their emissions decrease over time (see Figure 11), although Africa - Middle East less so than others (the region's share of total GHG emissions increases to 24%). This stems from the differentiated participation to the mitigation global effort considered in the scenario design and that benefits LDCs.

Figure 11: Regional GHG emissions, 2°C scenario

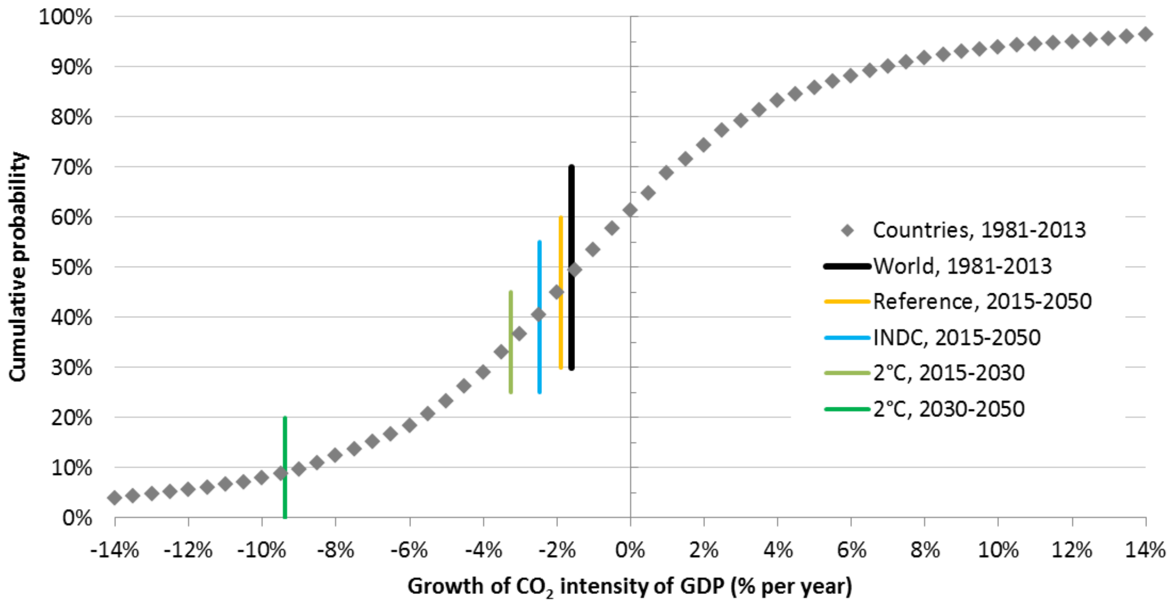


This significant decarbonisation implies strongly decreasing average world GHG emission intensity of GDP. Already in the current decade (2010-2020), it reaches -4.5%/year in 2020-2030, then -6.6%/year and -8.0%/year in the next decades, averaging to -7.4%/year over 2030-2050.

Figure 12 shows how the year-on-year evolution of CO_2 emissions intensity of GDP, i.e. the annual decarbonisation rate, has evolved in the past. It considers the frequency with which any given decarbonisation rate has been observed in the past (annual evolution for 32 years, over 1981-2012) for 125 countries (i.e. 3700 points); it plots the cumulated frequency of occurrence. It can be observed that the global energy-CO_2 emissions intensity of GDP has reduced over 1981-2012 on average by 1.6%/year (which fits the 50% cumulative probability of observed historical situations over all countries and considered years).

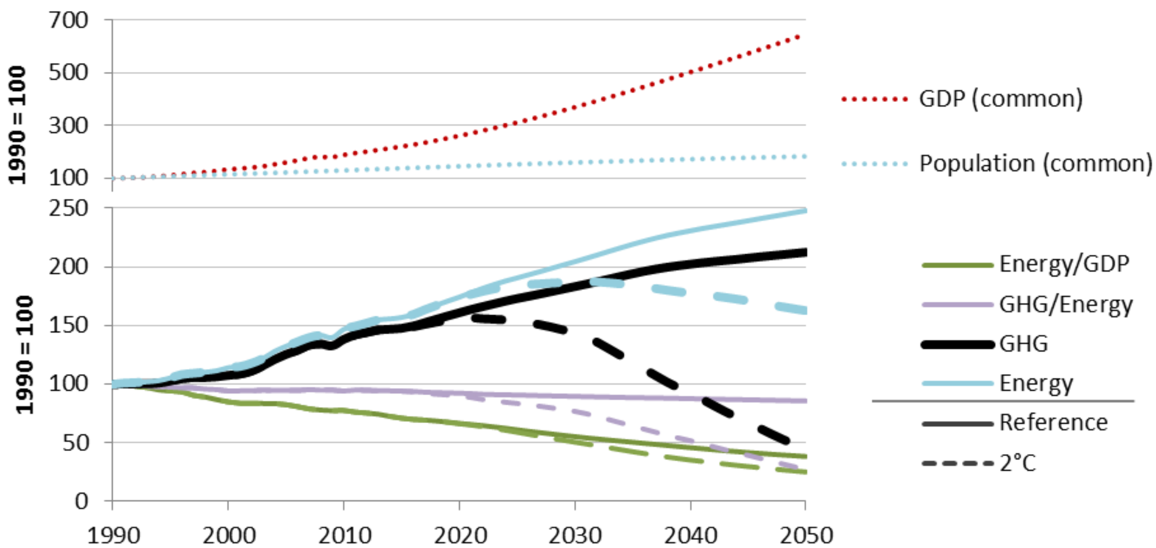
The INDC scenario changes the expected world average to -2.5%/year, a slight shift towards a cumulative probability of 40% of observed historical situations. Even though the range over all observed situations is fairly wide (the figure is purposely limited to [-14%;+14%] of evolution of energy-CO_2 intensity of GDP across countries and years) the 2°C scenario would result in near-unprecedented decarbonisation rates compared to recent history. After a 2015-2030 average equalling a performance reached only in 30% of the observed historical situations (-3.3%/year), the average world improvement of CO_2 emission intensity reaches 9.4%/year, a situation seen in less than 10% of the years/countries combinations shown in Figure 12.

Figure 12: Frequency of occurrence of annual decarbonisation rates across world countries (1980-2010) and world averages (scenarios, 2015-2050)



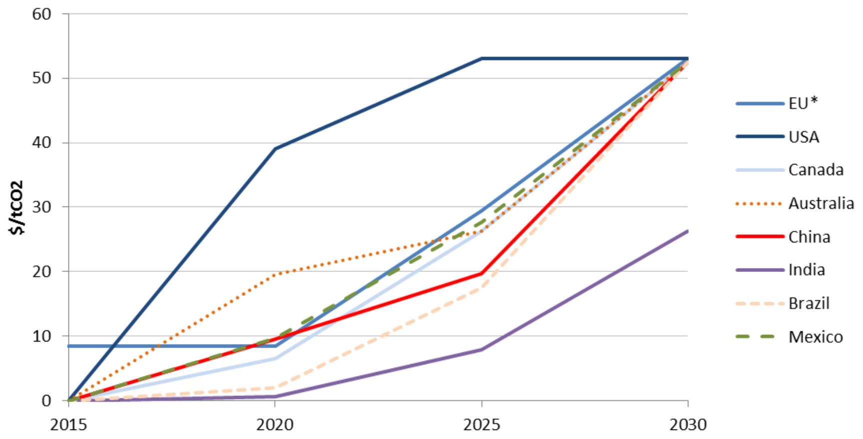
As shown in Figure 13, the 2°C scenario thus leads to a further improvement of the energy intensity of GDP compared to the Reference and INDC scenarios (a decrease by a factor of four from 1990 to 2050 at world level); and to a very strong decarbonisation of the energy mix (a decrease by a factor of 3.5 of GHG emissions per energy consumed from 2010 to 2050 at world level). This can only take place with an accelerated fuel and technology shift towards GHG-neutral options. It must be noted that these results do not consider the impact of policies on income – a detailed assessment of the macro-economic impacts is carried out in section 6.

Figure 13: Decomposition of world GHG emissions, 2°C scenario



In order for these changes to occur in such a rapid pace, policies are implemented in the scenario very quickly and across all sectors of the economy, starting from 2016, and with a clear signal that they will be strengthening in the future. The average world carbon value would reach 48 $/tCO_2$ in 2030 (see Table 9 above). All countries are subject to a carbon value from 2016 (Figure 14 below) and most countries converge to 53 $/tCO_2$ in 2030[26]; in other regions where convergence is slower (e.g. China, India, Brazil) this is because of the scenario assumptions concerning financial capacity (see Section 2.2.4), and in particular countries with very low income[27] rise to a lower level (26 $/tCO_2$ in 2030).

Figure 14: Carbon values by 2030 in the 2°C scenario for selected countries



**: EU price refers to the ETS sector's price until 2020, then to the average price over all sectors (ETS and non-ETS) for 2025 and 2030.*

Table 10 reports GHG emission growth at country- and region-level. Different behaviour can be expected from OECD and non-OECD countries in their pattern to reduce GHG emissions (see Table 10). While OECD countries have been undergoing a stabilization of GHG emissions over the last years, most non-OECD countries have experienced a fast increase (notice that the small 1990-2000 emission increase rate is heavily influenced by the sharp reduction in the countries of the Commonwealth of Independent States (CIS[28])). The average world emissions growth in 2010-2020 is half that of 2000-2010: OECD countries decrease their emissions, while non-OECD countries reduce substantially their growth (more than halved growth for China, notably). In the 2020-2030 decade most countries have their emissions already declining, except countries with low income, and thus a low financing capacity for a transition to a low-carbon economy. From 2030 onwards the yearly decline is steep, with both OECD and non-OECD reaching -4%/year over 2040-2050. These emission reduction rates are consistent with scenarios described by the IPCC (AR5 WGIII, IPCC 2014).

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[26] The carbon value of the USA, in particular, remains higher in the short-term in order to reach their INDC targets – see footnote 25 explaining what has not been explicitly considered in the scenario setting.
[27] Countries with income per capita in 2030 lower than 10 k$ PPP; see also footnote 13
[28] CIS: Commonwealth of Independent States, a regional organisation formed during the breakup of the Soviet Union, whose participating countries are former Soviet Republics: Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Uzbekistan.

Table 10: Annual average GHG emissions growth, 2°C scenario

	'90-'00	'00-'10	'10-'20	'20-30	'30-'40	'40-50
EU28	-1%	-1%	-2%	-2%	-4%	-7%
Australia	2%	1%	-1%	-1%	-5%	-11%
Canada	2%	-0.2%	0.1%	-2%	-7%	-14%
Japan	1%	-1%	-2%	-2%	-6%	-9%
Korea (Rep.)	6%	2%	0.5%	-2%	-3%	-6%
Mexico	2%	2%	0.2%	-0.2%	-3%	-5%
USA	1%	-0.3%	-1%	-3%	-4%	-7%
Rest of OECD	3%	2%	2%	-1%	-4%	-11%
Russia	-4%	1%	-1%	-2%	-6%	-9%
Rest of CIS	-6%	2%	1%	0%	-4%	-6%
China	3%	8%	3%	-1%	-6%	-8%
India	3%	4%	4%	2%	-3%	-6%
Indonesia	3%	3%	2%	1%	-3%	-8%
Rest of Asia	3%	3%	3%	1%	-3%	-6%
Argentina	2%	1%	-1%	-1%	-4%	-9%
Brazil	3%	2%	1%	-1%	-3%	-11%
Rest of Latin America	2%	3%	1%	0.3%	-4%	-10%
North Africa	2%	4%	2%	1%	-2%	-4%
Sub-Saharan Afr. (excl. SoA)	2%	2%	3%	2%	-0.4%	-6%
South Africa	1%	2%	-0.2%	-1%	-5%	-5%
Iran	5%	4%	3%	-0.1%	-4%	-4%
Saudi Arabia	4%	5%	2%	-1%	-4%	-6%
Rest of Middle-East	4%	4%	2%	0.3%	-3%	-5%
OECD	**1%**	**-0.2%**	**-1%**	**-2%**	**-4%**	**-7%**
Non-OECD	**1%**	**5%**	**2%**	**-0.2%**	**-4%**	**-7%**
World	**1%**	**3%**	**1%**	**-1%**	**-4%**	**-7%**

Note: Excludes LULUCF

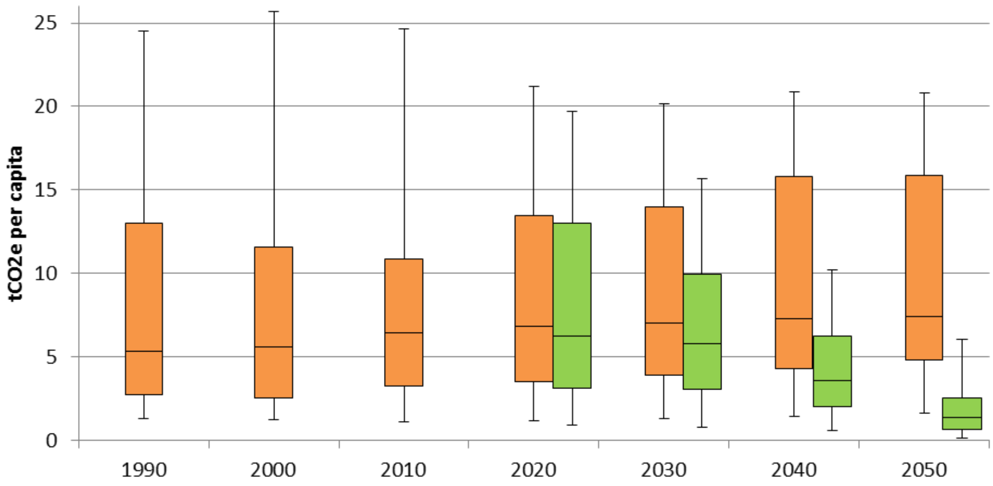
While the Reference scenario maintains large regional differences in emissions per capita throughout the entire period, the strong climate policies in the 2°C scenario assumed to be worldwide lead to a greater convergence among countries (as Table 11 reports and Figure 15 shows). World average emissions reach 1.4 tCO_2e per capita in 2050 (median is 2 tCO_2e per capita), slightly above the level of the least emitting region in 2010 (Sub-Saharan Africa).

Table 11: GHG emissions per capita, 2°C scenario (tCO_2e/cap)

tCO_2e/cap	1990	2000	2010	2020	2030	2040	2050
EU28	9.9	8.9	7.9	6.5	5.2	4.3	2.1
Australia	20.5	21.5	20.6	16.6	13.6	9.2	2.7
Canada	18.1	20.0	17.7	16.3	12.7	7.2	1.5
Japan	8.0	8.4	7.7	6.7	5.5	3.9	1.5
Korea (Rep.)	6.0	9.7	11.3	11.3	8.7	7.8	4.2
Mexico	4.6	4.7	5.0	4.5	4.0	3.3	2.0
USA	20.4	20.6	18.3	15.5	10.4	7.6	3.5
Rest of OECD	2.7	3.3	3.5	3.8	3.3	2.4	0.8
Russia	19.1	12.3	13.5	11.8	9.7	6.3	2.5
Rest of CIS	12.3	6.5	7.3	7.6	7.3	5.5	3.1
China	2.9	3.4	7.1	9.0	8.1	5.0	2.2
India	1.2	1.3	1.7	2.2	2.5	2.0	1.0
Indonesia	1.8	2.1	2.5	2.8	2.8	2.3	1.0
Rest of Asia	1.9	2.1	2.4	2.8	2.7	2.2	1.1
Argentina	6.3	6.5	6.7	5.7	4.8	3.4	1.2
Brazil	3.5	4.0	4.1	4.1	3.4	2.9	0.9
Rest of Latin America	3.1	3.1	3.6	3.6	3.4	2.7	0.9
North Africa	2.6	2.7	3.2	3.4	3.4	2.9	1.9
Sub-Saharan Afr. (excl. SoA)	1.1	1.0	0.9	1.0	0.9	0.8	0.4
South Africa	8.0	7.5	8.3	7.4	6.3	4.4	2.5
Iran	4.5	6.0	8.0	9.2	8.6	6.6	4.6
Saudi Arabia	10.9	12.7	16.4	17.0	13.2	9.6	4.9
Rest of Middle-East	5.5	6.0	6.7	6.7	5.7	4.2	2.1
OECD	**11.4**	**11.5**	**10.5**	**9.1**	**6.9**	**5.2**	**2.4**
Non-OECD	**2.6**	**2.9**	**4.0**	**4.4**	**3.9**	**2.7**	**1.2**
World	**4.1**	**4.6**	**5.2**	**5.2**	**4.4**	**3.1**	**1.4**

Note: Excludes LULUCF emissions

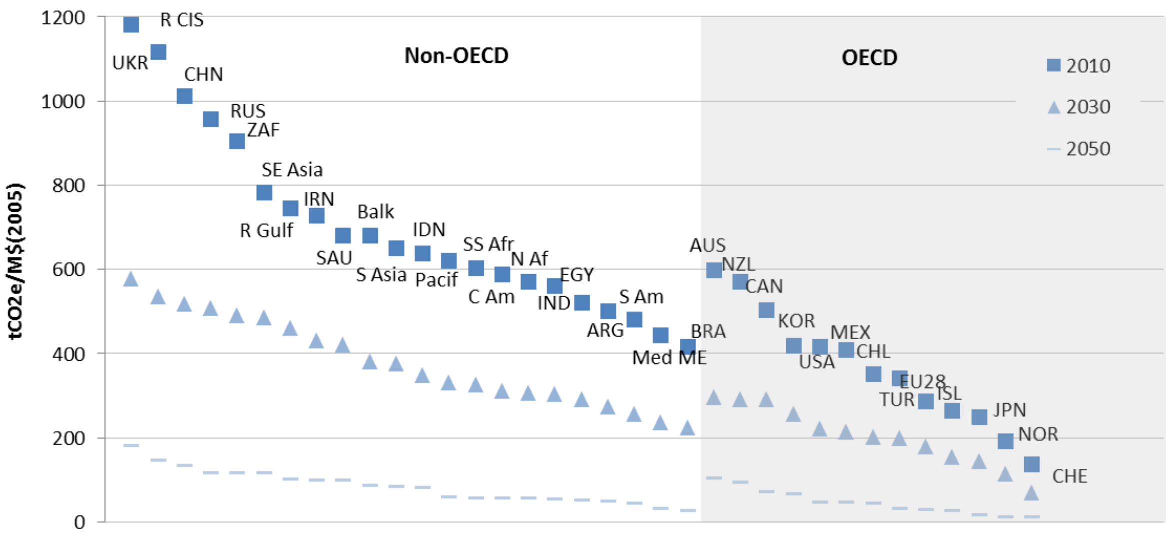
Figure 15: Distribution of GHG emissions per capita, Reference (orange) and 2°C (green)



Note: The distribution is done on the basis of countries and regions disaggregation shown in Annex 2, considering EU-28 as a single entity and EFTA as a single entity (i.e. 39 countries/regions). The boxes indicate 20th, 50th and 80th percentiles of occurrence, with whiskers showing minimum and maximum values (e.g. in 2000 half the countries/regions had GHG emissions per capita value lower or at 5.6 tCO_2e/cap). Includes all GHG emissions except LULUCF.

Global convergence also appears when looking at the emission intensity of GDP in the 2°C scenario (Figure 16, Table 12). It becomes lower than 150 tCO_2e/M$ for all countries in 2050, hence at the level of best performing economies in 2010 (Norway and Switzerland). World average GDP intensity is halved between 2010 and 2030 (from around 530 to 280 tCO_2e/M$), and halved again between 2030 and 2050 to reach 60 tCO_2e/M$.

Figure 16: GHG emissions intensity of GDP, 2°C scenario (tCO_2e/k$(2005))



Note: Excludes LULUCF emissions; GDP in PPP

Table 12: Emission intensity of GDP, 2°C scenario (tCO_2e/M$(2005))

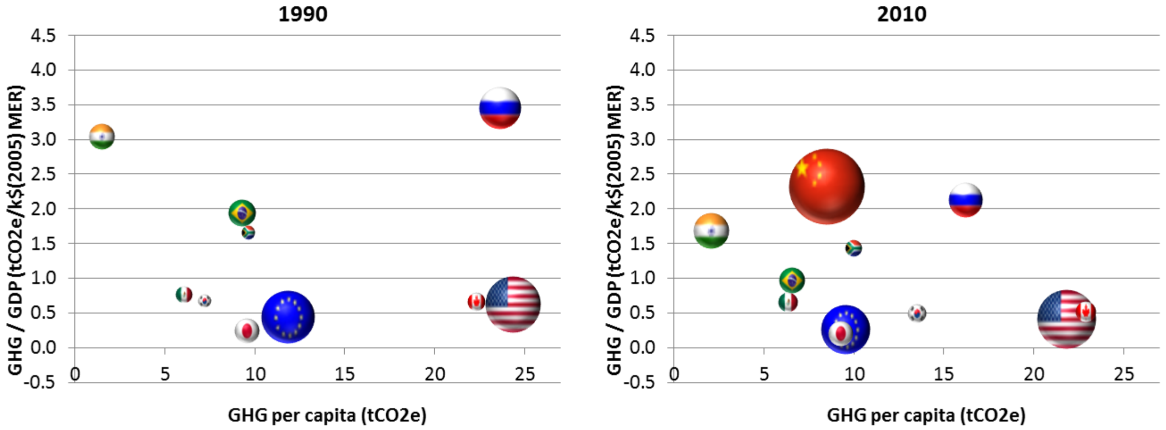
tCO_2e/M$	1990	2000	2010	2020	2030	2040	2050
EU28	483	359	286	217	154	108	47
Australia	862	728	599	425	295	174	45
Canada	670	616	503	422	291	144	26
Japan	297	289	249	200	144	88	30
Korea (Rep.)	530	510	418	329	198	154	73
Mexico	452	392	408	310	221	141	66
USA	627	513	423	314	188	119	46
Rest of OECD	347	344	304	262	183	112	30
Russia	1503	1427	957	750	490	266	102
Rest of CIS	2013	1932	1160	857	529	279	120
China	2389	1211	1011	687	382	167	58
India	1008	778	560	428	274	144	52
Indonesia	878	785	637	469	303	176	56
Rest of Asia	1089	898	742	602	401	233	84
Argentina	846	637	502	372	256	151	46
Brazil	494	504	416	431	293	193	51
Rest of Latin America	647	577	507	392	268	152	39
North Africa	703	570	572	485	330	205	100
Sub-Saharan Africa (excl. South Africa)	1036	975	602	476	307	190	57
South Africa	1046	1006	904	723	461	242	117
Iran	738	806	728	804	518	279	147
Saudi Arabia	581	675	681	624	420	260	118
Rest of Middle-East	995	642	648	640	453	289	130
OECD	**513**	**422**	**352**	**271**	**177**	**117**	**46**
Non-OECD	**755**	**929**	**775**	**595**	**360**	**184**	**66**
World	**614**	**587**	**536**	**437**	**285**	**160**	**60**

Note: Excludes LULUCF emissions; GDP in PPP

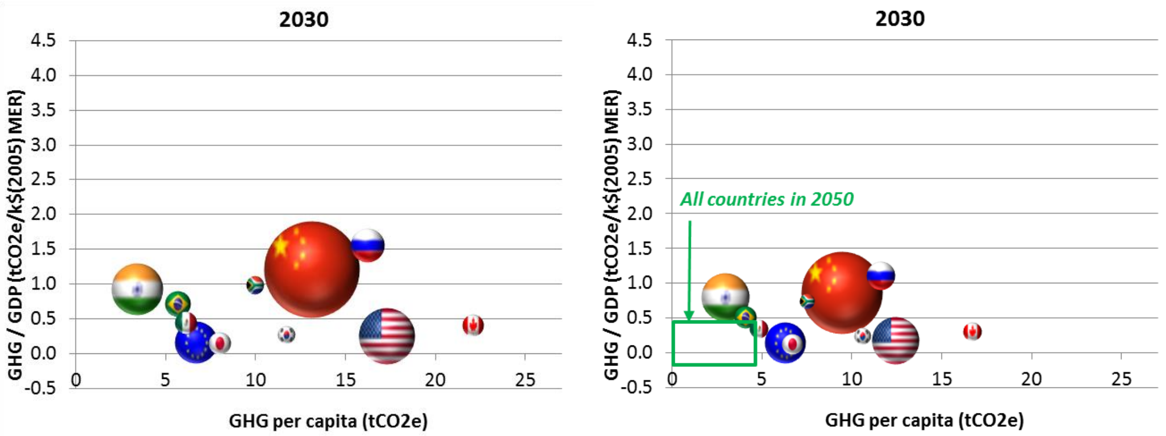
Figure 17 summarises the evolution of emissions for the different countries between 1990 and 2030 for the Reference scenario and the 2°C scenario, and the impact of climate policies along the 2 above-discussed indicators (GHG emissions per capita on the x axis, and GHG emissions per GDP on the y axis). It shows that the decarbonisation path depends on the countries and their economic and demographic structure. OECD countries would primarily reduce their emission per capita (they move to the left from the Reference scenario to the INDC scenario) while non-OECD countries tend to move primarily "downwards", with emission intensity of GDP decreasing – some even with increasing emissions per capita (India for instance). By 2050, the 2°C moves all countries in the left-down green box appearing in the 2030 2°C graph, showing that all countries undertake drastic reductions of emissions per capita and per GDP.

Figure 17: GHG emissions intensity vs GDP per capita for major economies (size: total emissions)

a) History



b) 2030: Reference (left) and 2°C (right)



Note: China 1990 beyond the scaling: 5.2 tCO_2e/k$ at 3.4 tCO_2e/cap with a size of 3.9 $GtCO_2e$ (vs. 11.3 $GtCO_2e$ in 2010)

Overall, it can be observed that all countries and regions would have to converge to low levels of emissions, of emissions/cap, and significantly improve the emission intensity of their economy. This would necessarily imply a diversification of their energy mix towards low-emission sources. However, they all would follow very diverse ways to move to such a low-emissions future, relying on different mitigation options and experiencing different paces of emissions reduction. The key characteristics determining the emission reduction path would be their initial energy mix and economic structure, their emission profile and their economic and social growth model.

Across all countries and regions, investments in the energy sector determine the transition from the Reference scenario to the INDC scenario and then to the 2°C scenario. However, there is no uniform pattern: countries are taking up different sectoral policies and investment options according to their national circumstances.

3.4 Mitigation options

The following section provides an overview of the contribution of different sectors to mitigation options by 2050, by comparing the Reference, INDC and 2°C scenarios, as well as the contribution of technological options by sector in 2030.

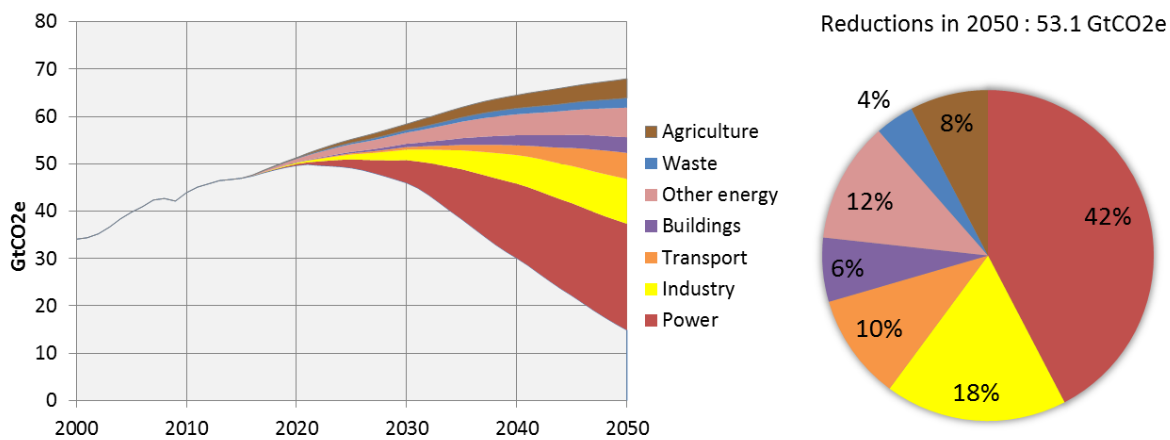
By 2030 the worldwide gap in emissions between the Reference scenario and the 2°C scenario is 12.5 GtCO_2e, whereas the INDC scenario would achieve 6.7 GtCO_2e, i.e. 54% of the total. In terms of cumulated reductions obtained over the entire 2015-2030 period, this share rises to 60%.

With more ambitious emissions reductions taking place after 2030, these figures are different when comparing the mitigation effort over the entire period of 2015-2050: the total mitigation in 2050 is of 53 GtCO_2e, of which only 42% would be reached in the INDC scenario; in terms of cumulated reductions, the INDC scenario achieves 44% of the 2°C reductions (this drops to 28% in the INDC (unconditional) scenario).

3.4.1 Emissions reductions by sector

The power sector would be able to carry out 39% of the mitigation to close the gap with the 2°C scenario in 2030, followed by the other energy[29] (19%), industry (18%), agriculture (10%), buildings (6%), transport and waste (4% each). "Other energy" is a sector that is particularly flexible, with reductions taking place in fugitive methane emissions in coal, oil and gas production and gas transport quickly when the climate policies are put in place.

Figure 18: Sectoral emissions mitigation from the Reference to the 2°C scenarios, World (excl. LULUCF)



Note: excludes LULUCF emissions

The power sector would therefore contribute largely to reaching the INDC scenario (49% of cumulated reductions by 2050 – see Figure 19) and also to go beyond towards the 2°C objective (38% of additional reductions).

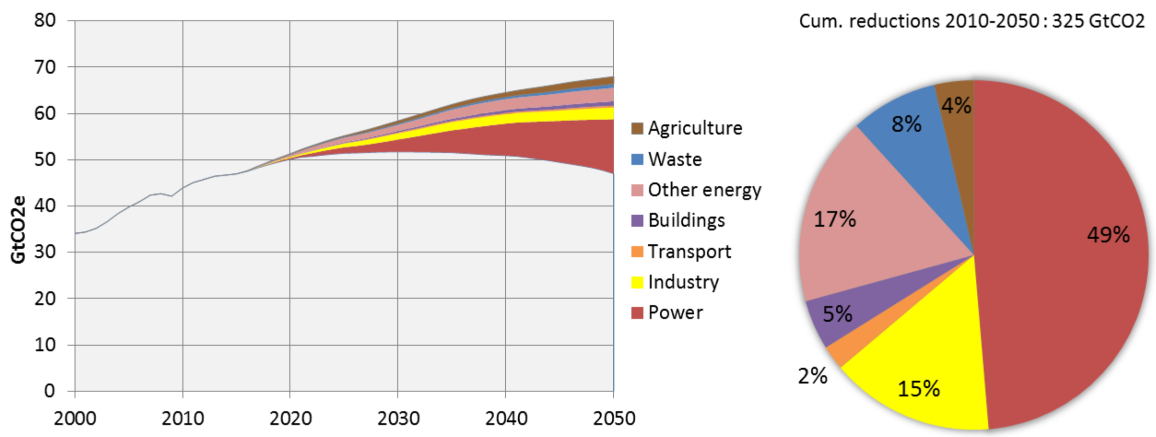
[29] The "Other energy" sector includes: fuel extraction industry, fuel transport and fuel refining activities.

After the power sector, the INDC scenario builds upon the "other energy" sector (17% of the cumulative reductions), industry (15%) and waste (8%).

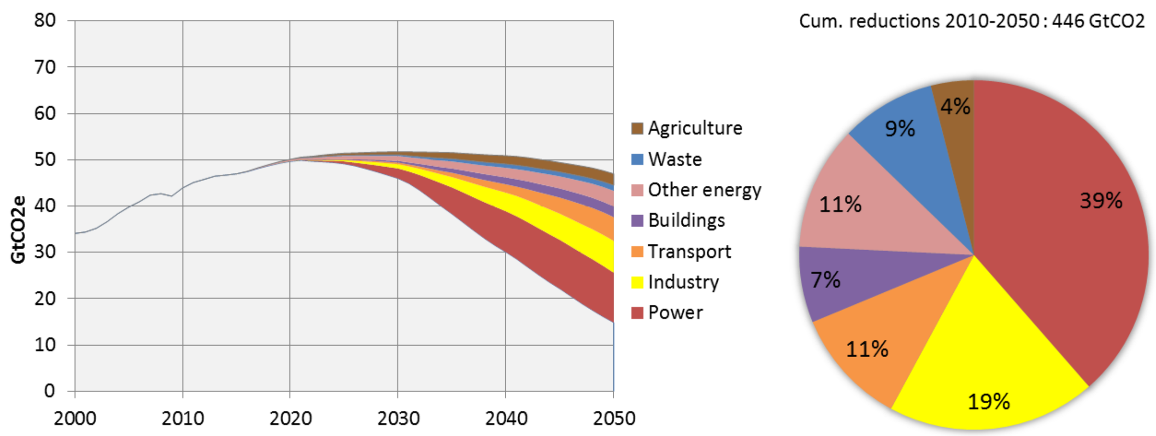
Going further to the 2°C scenario relies on more ambitious reductions in the industry (19% of the additional effort), buildings (7%) and, notably, transport, which represents 11% of the cumulative effort, vs. only 2% shifting from the Reference to the INDC scenario. This illustrates the relatively higher cost of mitigating CO_2 emissions in this sector due to the growing needs for mobility and its low elasticity to energy and carbon values. Waste and agriculture contribute in the same proportion as in the INDC scenario (respectively 9% and 4% of cumulative reductions).

Figure 19: Sectoral emissions mitigation, World (excl. LULUCF)

a) From Reference to INDC



b) From INDC to 2°C



Note: excludes LULUCF emissions

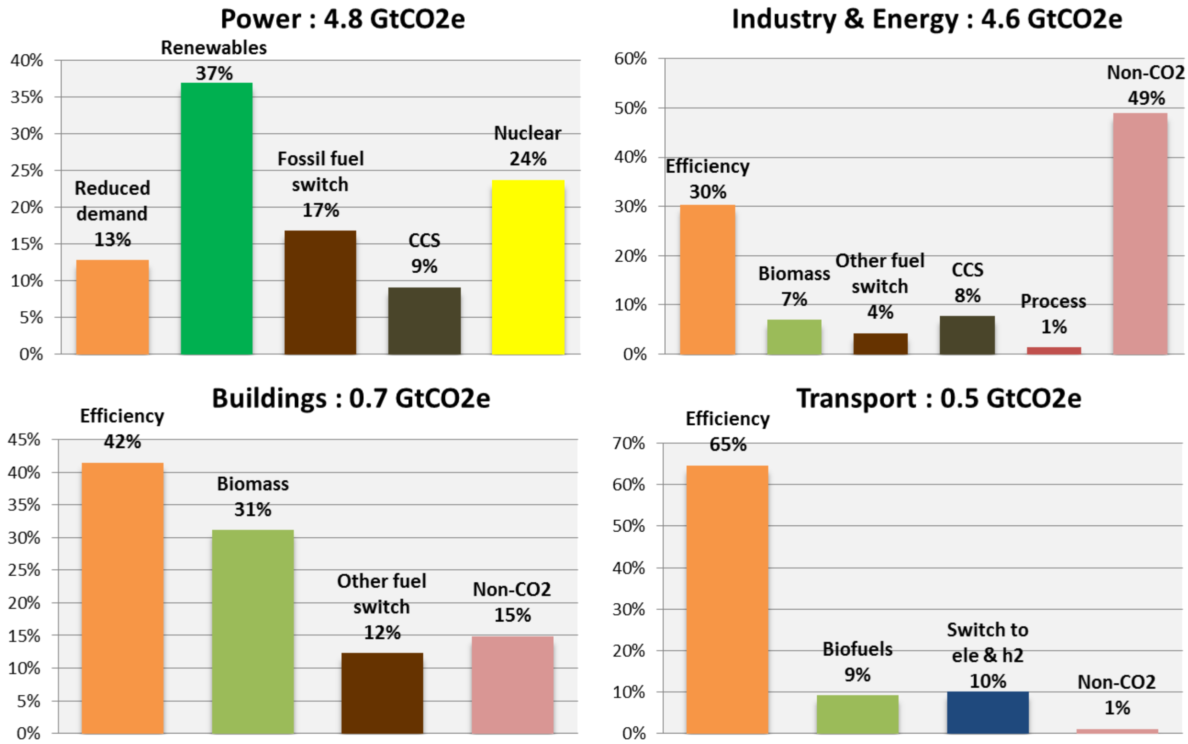
Regarding the role of technological options to reach the 2°C scenario (see Figure 20), energy demand reduction plays undoubtedly a key role in all sectors (including electricity demand), representing around 40%-50% of the reductions in the final demand sectors both in 2030 and in 2050, up to 65% of the reductions in transport by 2030 (which contribution remains still limited at that time horizon). Renewable energy sources also contribute to the reductions, especially in the power sector (35% in 2030 to 41% in 2050) and in buildings (biomass ensuring around a third of total reductions). The contribution of fuel switch to gas or electricity varies across sectors and time, in the range 6%-17%.

Within the power sector, nuclear's contribution would progressively decline from 24% in 2030 to 14% by 2050, while in the final demand sectors reductions of non-CO_2 GHGs play a significant role by 2030 (respectively 33% and 15% in industry-energy and in buildings) and less so by 2050 (down to respectively 20% and 7%). Finally, it is worth to mention that, given the technology assumptions for the analyses in this report, CCS does not seem develop much by 2030, while it becomes a key option in the longer run, with 35% of the emission reductions of the power sector in 2050 (total CCS is then almost equivalent to the total reductions from buildings and the transport sector).

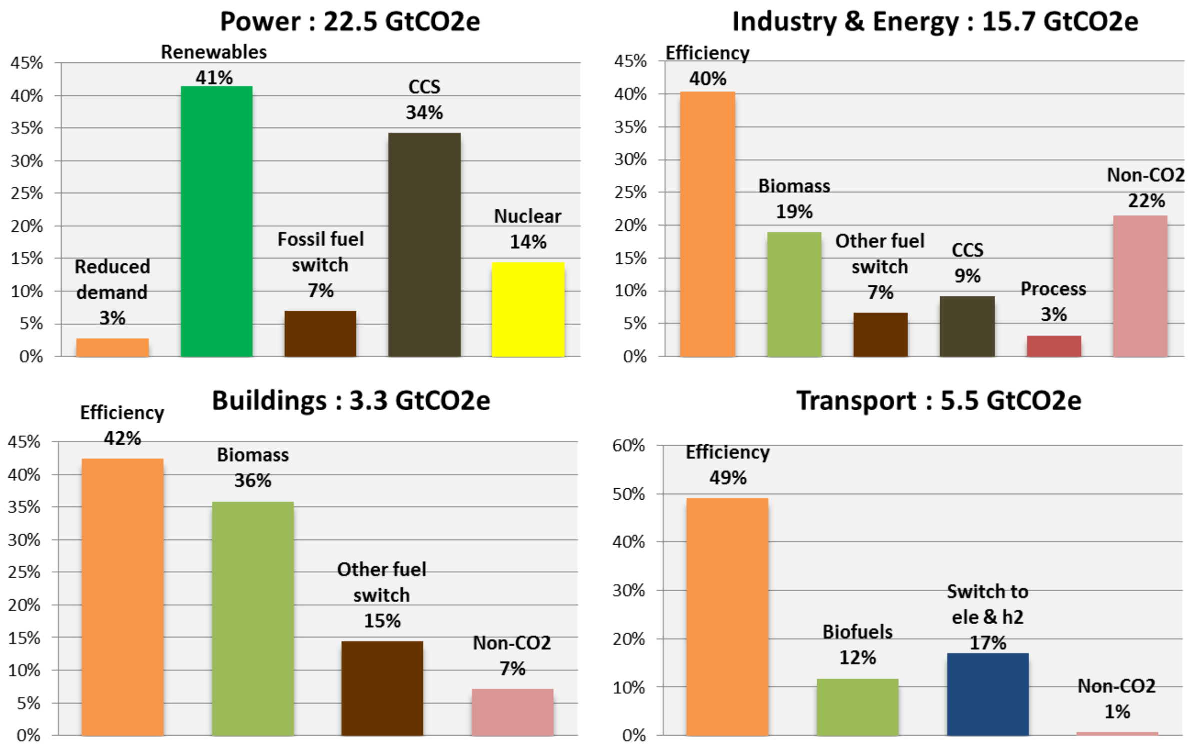
For more detail on mitigation options in the power sector specifically, see section 4.2.4.

Figure 20: Emissions mitigation options from the Reference to the 2°C scenarios, World, 2030 (excl. LULUCF)

a) 2030



b) 2050



Note: "Fossil fuel switch" refers to shifts from high-carbon content fossil fuels towards lower-carbon content fossil fuels (generally from coal to gas). "Industry & Energy" refers to the manufacturing industry, construction, mining and to the energy transformation industry excluding the power sector (fuel extraction, refining, transport). Options not displayed: waste, agriculture.

3.4.2 Emissions reductions by greenhouse gas

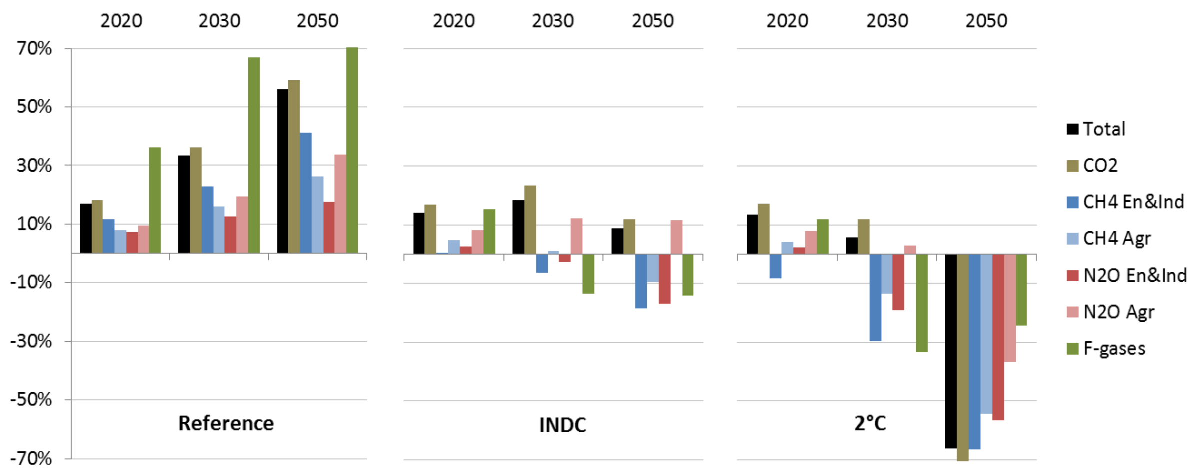
The technology options considered determine the relative shares of the different GHGs within each emission reduction scenario.

Implementing the INDCs in a cost-effective manner across all greenhouse gases, by applying the carbon value on a single comparable metrics (CO_2-equivalent)[30], would result in different emissions reductions profiles across gases (see Figure 21). While total emissions in the INDC scenario would be roughly at the same level by 2050 as in 2010, CO_2 from combustion and N_2O from agriculture would still be above 2010 levels, while CH_4, N_2O from energy and industry and fluorinated gases would be below (-10% to -20%).

A 2°C scenario would consistently require emissions reductions in all sectors and sources, including international aviation and shipping, and very significant reductions in the levels of CO_2 emissions. The contributions to total reductions from the various gases would develop according to different dynamic profiles over time: the reductions of CO_2 emissions take place progressively over time (+10% in 2030 to -70% in 2050 compared to 2010), non-CO_2 gases in energy and industry tend to react faster while emissions in agriculture have less mitigation potential (especially N_2O).

The behaviour of fluorinated gases emissions is noticeable: without additional climate policies, in the Reference scenario they would exhibit a substantial growth in industrial sectors; whereas they are expected to stabilize or reach lower levels compared to 2010 as soon as additional mitigation policies are implemented.

Figure 21: Evolution of GHG emissions by gas compared to 2010, Reference, INDC and 2°C scenarios (excl. LULUCF)



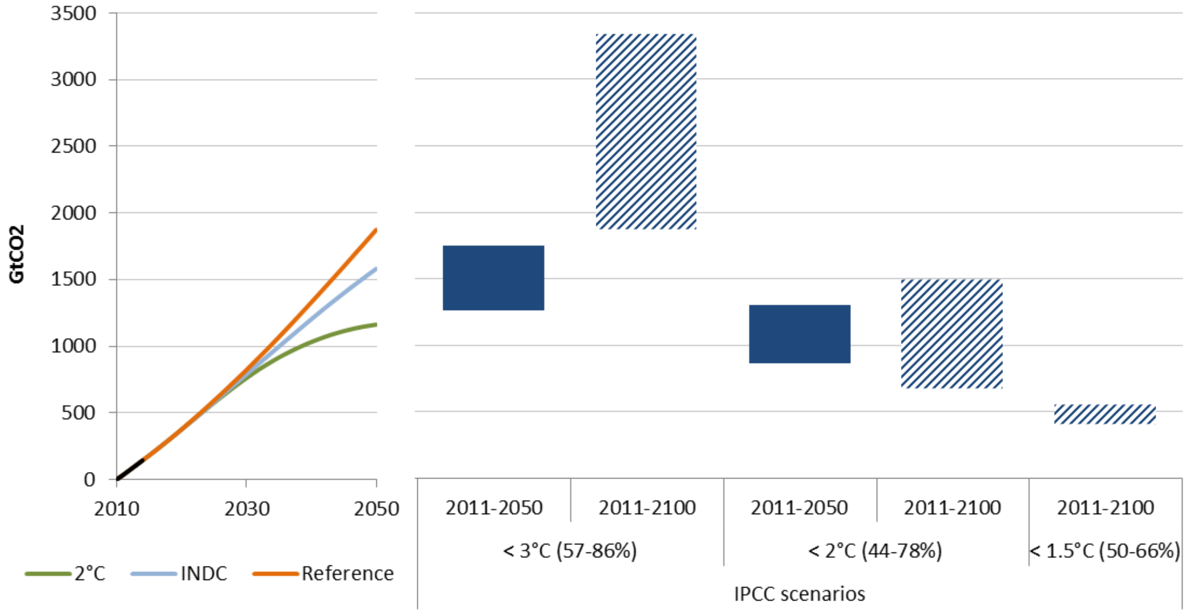
Note: Reference, 2050, F-gases: 130%

[30] Using the 100 years global warming potential from the IPCC Second Assessment Report (IPCC 1996).

3.5 Climatic response

The expected long-term global temperature increase for each of the scenarios addressed in this report is discussed in this section. Figure 22 below compares the cumulative 2011-2050 CO_2 emissions of the GECO scenarios with CO_2 budget corresponding to different long-term temperature increase (see IPCC AR5 Working Group III (2014)[31]): lower than 3°C (probability of staying below of 57%-86%), lower than 2°C (44-78%), lower than 1.5°C (50-66%).

Figure 22: Ranges of cumulative CO_2 emissions and probabilities of temperature change



Note: Percentages refer to probabilities to remain below that temperature increase at the end of the century. Figures were obtained from the relevant scenarios in the IPCC AR5 WGIII database: 580-650 and 650-720 ppm for < 3°C; 430-480 ppm with overshoot >0.4 W/m2, 480-530 ppm with overshoot <0.4 W/m2 and 480-530 ppm with no exceedance of 530 ppm for < 2°C (IPCC AR5 WGIII Table 6.3). < 1.5°C from IPCC AR5 Synthesis Report Table 2.2 (only cumulated emissions for 2011-2100 available).
Note: Cumulated CO_2 emissions for GECO2016 scenarios include LULUCF emissions.

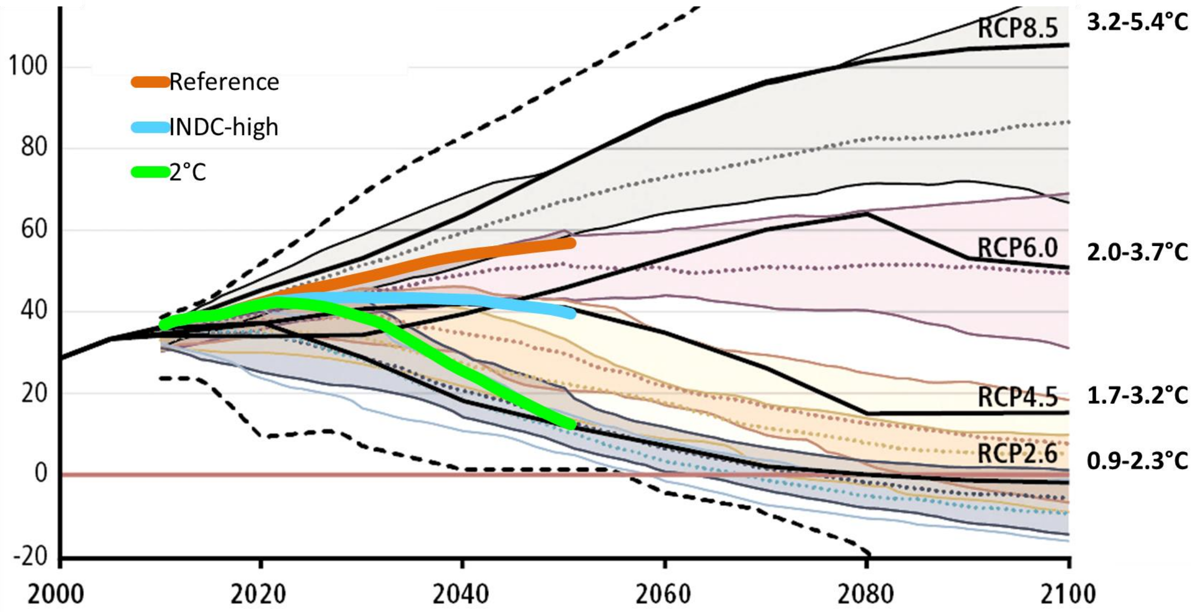
According to Figure 22 and Figure 23, and considering the dynamics beyond 2050, the temperature response of each scenario would be:

1. the Reference scenario would lead to a temperature change of above 3°C: cumulated CO_2 emissions 2011-2050 1870 $GtCO_2$; trajectory between high-end of RCP6.0 and RCP8.5, corresponding to a range between 3.8 and 4.7°C;
2. the INDC scenarios to around 3°C: cumulated emissions 1580 $GtCO_2$; trajectory close to RCP4.5 corresponding to a likelihood of "staying below 3°C over the 21st century" of "likely" and "more likely than not";
3. and the 2°C scenario to 2°C: cumulated emissions 1160 $GtCO_2$; trajectory starting between RCP4.5 and RCP2.6 and getting progressively closer to RCP2.6 by 2050.

[31] See IPCC AR5 (IPCC 2014) Working Group III, TS.2.2, Figure TS.8 and Table TS.1

Figure 1 in the Executive Summary gives a summary of emissions trajectories and temperature change.

Figure 23: World GHG emissions in IPCC and GECO scenarios



Note: IPCC scenarios from AR5 WGIII Ch.6 Figure 6.7. RCPs temperature ranges from IPCC 2013, WGI SPM Table SPM.2.

4 Energy

4.1 Primary energy

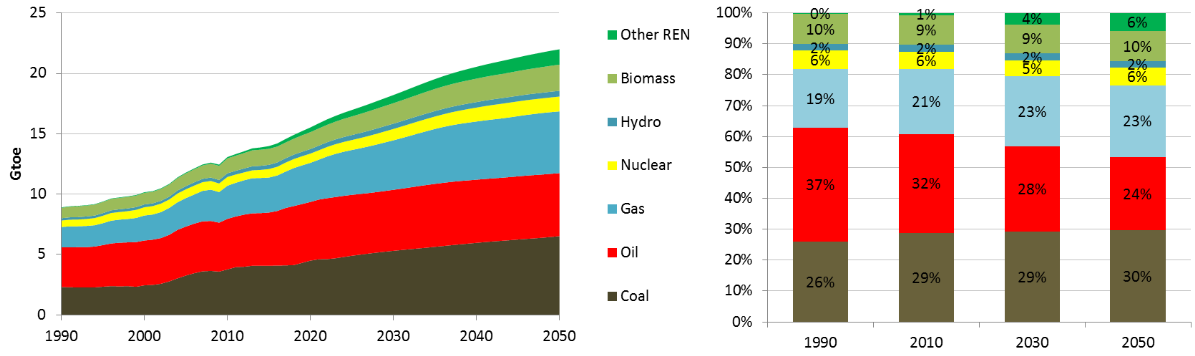
4.1.1 Primary energy demand

At the global level, primary energy demand[32] would increase from circa 13.8 Gtoe in 2015 to 17.8 Gtoe in 2030 (twice the energy demand of 1990) in the Reference scenario, and further to 21.8 Gtoe by 2050 (twice the energy of the early 2000s).

This energy demand dynamics, driven by a growing population, further needs for energy services and increasing living standards, would be partially mitigated by the decline of the energy intensity of GDP.

The evolution of the energy intensity is expected to decrease to a rate averaging -1.8%/year over 2015-2050, a pace comparable to the one experienced over the decade 1990-2000 (-1.6%/year) and definitely faster than the one corresponding to the years 2000-2010 (-0.9%/year). As a consequence, by 2030, the world economy is twice size level of 2010, while energy demand grows by 37% only.

Figure 24: World primary energy demand, Reference scenario



The structure of demand by fuel is expected to evolve according to each fuel's relative scarcity and the growing role of new technologies. The share of oil progressively declines, in line with a longer trend since the 1970s; gas maintains a fairly constant share whereas coal's contribution would increase in this Reference scenario to a third of the total energy supply in 2050, a share it corresponds to the 1960s when it was overtaken by oil due to growing mobility needs. Renewable forms of energy increase their share significantly, representing 19% of the total mix in 2050 vs. 13% in 2010, mainly through the increased contribution of wind and solar ("Other REN" in Figure 15).

Figure 25 illustrates that the effects of energy and climate policies at the global level are felt progressively after 2020-2025. The INDC scenario builds a difference with the Reference scenario in terms of total energy that reaches 9% in 2050, and a correspondingly decelerated annual growth, as a result of fuel substitution and energy

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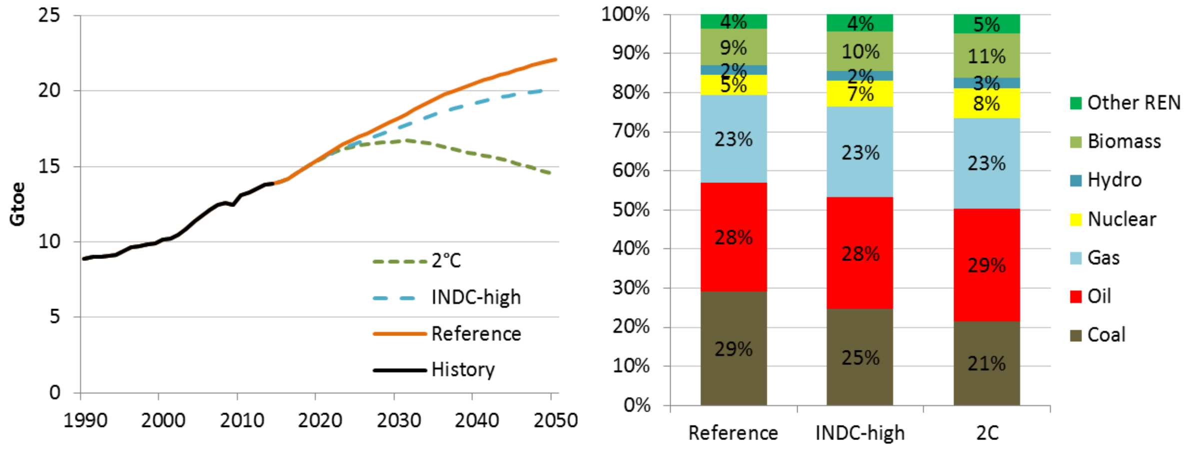
[32] Primary energy demand is calculated using heat-equivalence for electricity from nuclear (efficiency of 33%) and geothermal (efficiency of 10%).

efficiency. The 2°C scenario triggers deeper and earlier changes in the energy system, with a peak in total demand at 16.5 Gtoe in 2030 followed by a decrease.

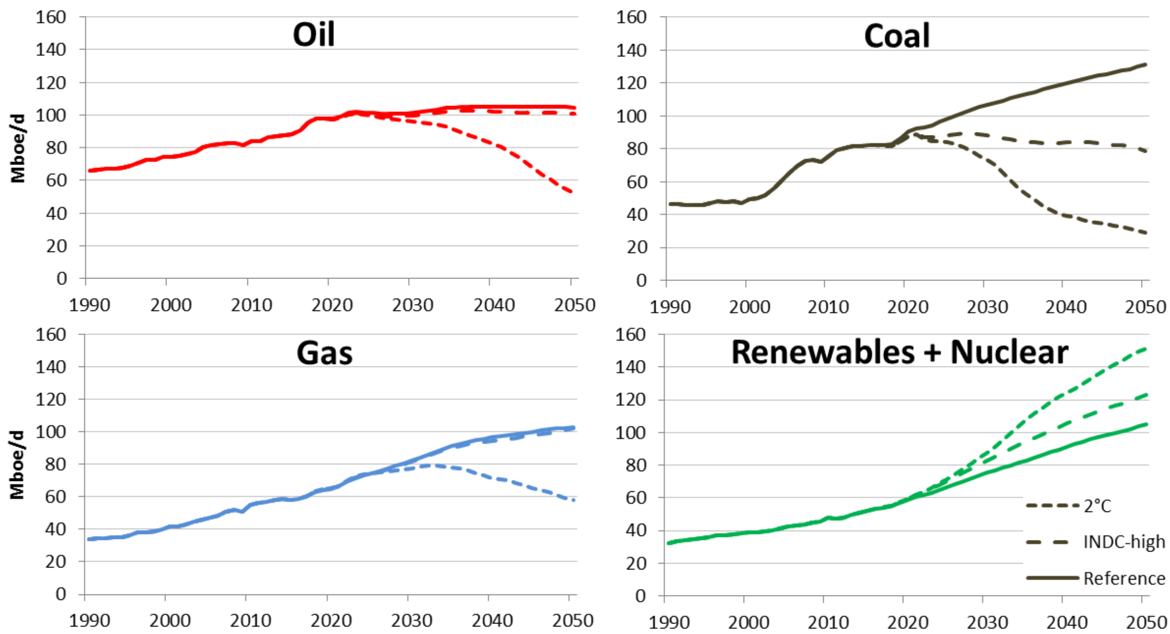
Figure 25: World primary energy demand: Reference, INDC and 2°C scenarios (left), fuel shares in 2030 (right)



By 2030, each scenario would entail different fuel mixes, mainly differing in the contribution of renewable and nuclear energies. Their shares in the primary energy mix would increase with the level of ambition of the climate policies considered towards a 2°C world, mainly at the expense of coal.

In terms of fuel consumption (Figure 26), it is notable that the oil and gas markets would be only marginally affected in the INDC scenario compared to the Reference scenario; the largest changes in that case are expected to be a significant reduction in coal consumption, followed by deeper penetration of nuclear (see section 4.1.7) and especially renewables (see sections 4.1.8 and 4.1.9).

Figure 26: World primary energy demand by fuel, Reference, INDC and 2°C scenarios

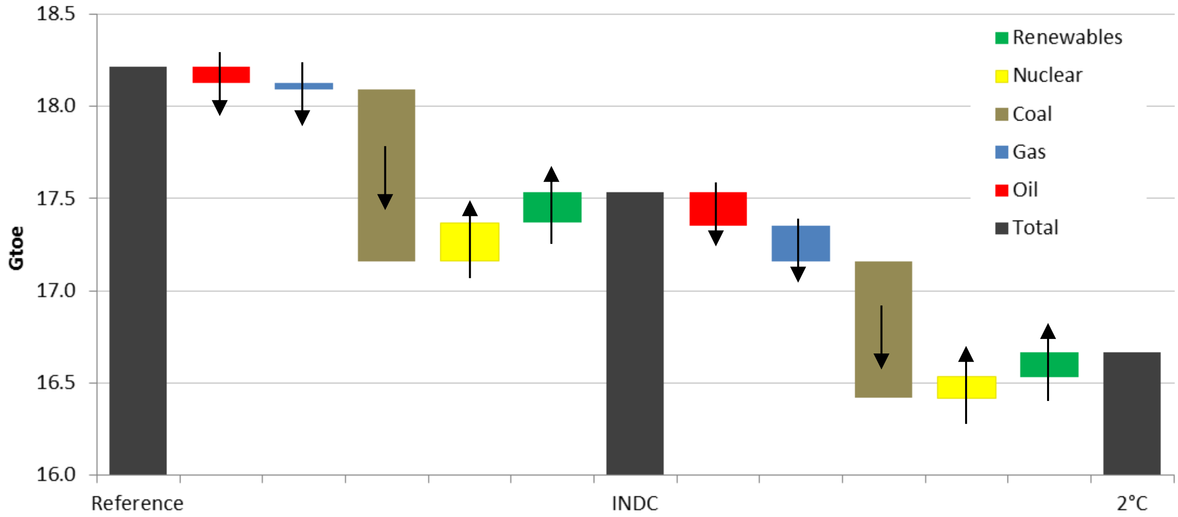


Note: Conversion in Mboe/d using a conversion factor of 7.33 boe/toe

In the 2°C scenario, coal is reduced significantly compared to the Reference scenario from 2020 and falls back to 1990 level by 2040, followed by oil and gas that are being reduced from around 2030 (by 2050 oil would reach the 1990 level, while gas remains at 2010 level); the only growing primary energy carriers throughout 2050, in all scenarios but notably in the 2°C scenario, are the renewables and nuclear.

Figure 27 shows how each fuel contributes to the differences between scenarios in 2030. All fossil fuels decrease between Reference and INDC and between INDC and 2°C, with coal decreasing the most; the coal decrease between Reference and INDC is larger than the total primary energy decrease. Conversely, nuclear and renewables both increase between all scenarios.

Figure 27: World primary energy demand changes by fuel across scenarios, 2030



The cross-country analysis shows a progressive convergence and contraction of energy demand per capita. In OECD countries, energy demand per capita keeps decreasing over time throughout the 2°C scenario. In non-OECD countries, by contrast, it would increase up to 2030 on average, before stabilising afterwards. Crucially, Brazil, the rest of Latin America and India would show an increase in energy demand per capita up to 2050. However, non-OECD regions with currently very low domestic energy prices (mostly oil and gas exporters: CIS, Middle East) are expected to undergo a decrease in their energy per capita consumption compared to 2010 due to a high potential in energy intensity improvement.

Table 13: Primary energy demand per capita and average annual growth, 2°C scenario

ktoe per capita	1990	2010	2030	2050	'90-'10	'10-'30	'30-'50
EU28	3.5	3.5	2.9	2.5	-0.1%	-0.9%	-0.7%
Australia	5.3	5.6	4.9	3.7	0.2%	-0.7%	-1.4%
Canada	7.7	7.4	6.8	4.6	-0.2%	-0.4%	-1.9%
Japan	3.6	4.0	3.5	3.3	0.4%	-0.6%	-0.4%
Korea (Rep.)	2.2	5.2	6.1	5.9	4.4%	0.8%	-0.2%
Mexico	1.4	1.5	1.6	1.7	0.3%	0.4%	0.1%
USA	7.8	7.3	6.0	4.9	-0.3%	-0.9%	-1.1%
Rest of OECD	1.5	2.1	2.3	2.0	1.5%	0.5%	-0.6%
Russia	6.1	5.0	4.4	3.0	-1.0%	-0.6%	-1.9%
Rest of CIS	4.0	2.4	2.9	2.2	-2.5%	0.9%	-1.5%
China	0.8	2.0	2.9	2.3	4.8%	2.0%	-1.2%
India	0.4	0.6	0.9	0.8	2.3%	2.6%	-0.7%
Indonesia	0.5	0.8	1.1	0.9	2.2%	1.4%	-0.9%
Rest of Asia	0.5	0.8	1.0	0.8	2.0%	1.1%	-0.8%
Argentina	1.4	2.0	1.7	1.4	1.9%	-0.9%	-0.7%
Brazil	0.9	1.4	1.4	1.7	2.1%	0.2%	1.0%
Rest of Latin America	0.9	1.1	1.3	1.3	0.9%	1.2%	0.0%
North Africa	0.7	1.0	1.2	1.0	1.9%	1.1%	-0.9%
Sub-Saharan Af. (excl. SoA)	0.4	0.4	0.4	0.3	0.0%	0.1%	-0.6%
South Africa	2.4	2.7	2.1	1.7	0.6%	-1.2%	-1.0%
Iran	1.2	2.8	3.5	2.6	4.1%	1.2%	-1.5%
Saudi Arabia	3.8	6.6	5.7	3.6	2.8%	-0.8%	-2.2%
Rest of Middle-East	1.6	2.3	2.4	1.5	1.9%	0.2%	-2.2%
OECD	**4.3**	**4.4**	**3.9**	**3.3**	**0.1%**	**-0.7%**	**-0.8%**
Non-OECD	**1.0**	**1.3**	**1.5**	**1.1**	**1.4%**	**0.9%**	**-1.4%**
World	**1.6**	**1.8**	**1.9**	**1.4**	**0.6%**	**0.1%**	**-1.3%**

The share of low-carbon energy in total primary energy consumed expands very fast in the 2°C scenario. In OECD it would exceed 50% as early as 2040 and then would keep increasing to almost 75% by 2050, while non-OECD would follow lying just 10% below over the 2030-2050 period. Including internal air and maritime bunkers, the world average would reach a 66% share of low carbon primary energy by 2050, as opposed to 18% in 2010. Large fossil fuel exporters have a slower uptake of these technologies, but they also see a fast increase beyond 2030.

Table 14: Low-carbon energy in primary energy, 2°C scenario, share

	1990	2000	2010	2020	2030	2040	2050
EU28	17%	21%	25%	31%	39%	55%	73%
Australia	6%	6%	5%	10%	17%	43%	74%
Canada	25%	23%	26%	30%	43%	68%	90%
Japan	16%	20%	19%	23%	35%	57%	73%
Korea (Rep.)	18%	17%	18%	25%	40%	54%	70%
Mexico	13%	13%	11%	14%	24%	48%	63%
USA	14%	14%	17%	20%	38%	59%	74%
Rest of OECD	31%	27%	25%	29%	36%	56%	73%
Russia	6%	8%	9%	11%	18%	43%	63%
Rest of CIS	5%	10%	10%	10%	17%	40%	59%
China	24%	19%	12%	13%	24%	54%	74%
India	46%	36%	28%	22%	21%	41%	62%
Indonesia	45%	36%	31%	31%	30%	46%	67%
Rest of Asia	52%	48%	45%	43%	46%	59%	72%
Argentina	11%	11%	13%	19%	25%	55%	79%
Brazil	45%	40%	46%	43%	50%	67%	84%
Rest of Latin America	28%	23%	21%	23%	31%	51%	74%
North Africa	5%	5%	4%	4%	7%	29%	49%
Sub-Saharan Afr. (excl. SoA)	81%	81%	78%	69%	62%	63%	74%
South Africa	11%	13%	10%	14%	23%	54%	70%
Iran	1%	0%	1%	1%	4%	27%	47%
Saudi Arabia	0%	0%	0%	0%	2%	21%	35%
Rest of Middle-East	1%	1%	1%	1%	5%	25%	41%
OECD	16%	18%	20%	24%	37%	57%	73%
Non-OECD	22%	22%	18%	17%	24%	47%	66%
World*	18%	19%	18%	19%	27%	48%	66%

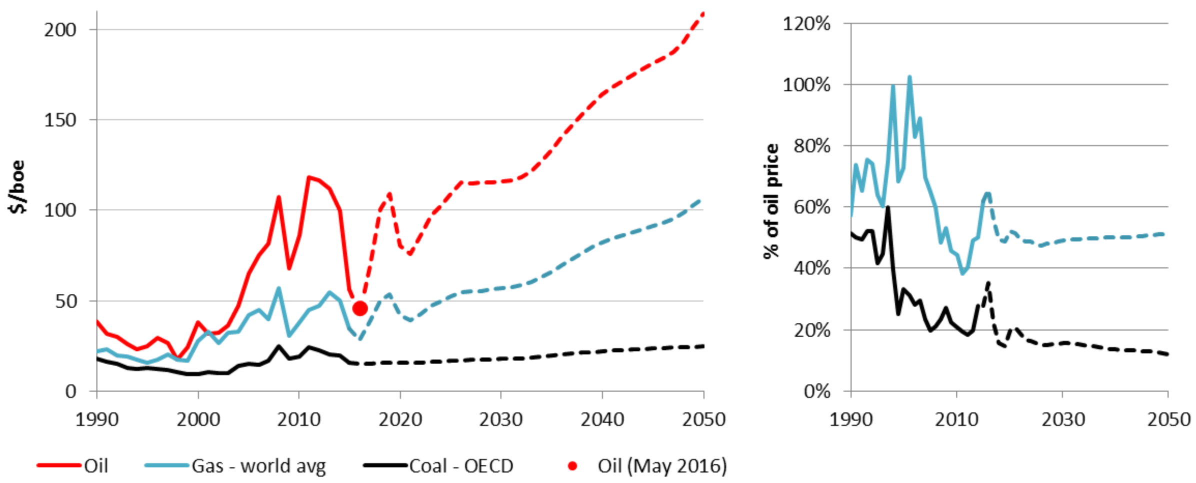
**: World includes international bunkers*
Note: Low-carbon energy includes renewables (hydro, biomass, wind, solar, geothermal, ocean), nuclear, fossil fuels with carbon capture and sequestration. Biomass includes traditional biomass, which is high in certain regions (e.g. Asia, sub-Saharan Africa).

4.1.2 **Energy prices**[33]

In the Reference scenario, after a period of volatility in the coming decade due to supply-demand dynamics, the oil price would resume a long-term rising trend as the one experienced in the 2000s decade (Figure 28).

Oil price projections presented in this report take into consideration the recent (2014-early 2016) drop in prices; an additional sensitivity analysis exploring an extended period of low oil prices is explored in section 5.1.

Figure 28: Fossil fuel prices and gas-to-oil and coal-to-oil price ratios in the Reference scenario, 1990-2050



In the short term, the fall of oil prices since late 2014 would trigger in a resurgent oil demand growth worldwide that soon encounters supply constraints. Oil demand is expected to increase over 2016-2020 by almost 7 Mbl/d, most of which taking place in non-OECD countries and bunkers, while OECD countries would lower their demand over that period (see Figure 29). In particular, oil demand for international bunkers[34] reached 11% of total oil demand in 2014; it has grown faster than oil demand in road transport and is expected to keep growing with increasing international flows of freight and passengers.

Despite the emergence of alternatives to oil in transport like liquid biofuels and electric cars, their expected role in the short-run will still remain close to marginal: liquid biofuel production is expected to remain stable in 2016 (IEA 2016a); world electric car sales, although increasing fast over the last years (sales have increased 10 fold in 2011-2015), make up only 0.6% of total car sales in 2015 at world level (DoE 2016, OICA 2016). The evolution of mobility tends to increasing fuel demand, particularly in the large and inefficient categories[35], which is only partially offset by the fuel efficiency standards implemented in different countries.

The recent fall in oil prices should result in a reduction of the most expensive oil production; for instance, in 2016 US production is foreseen to decrease by 9% compared

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[33] All figures in this section are in real USD of 2015

[34] International bunkers include both international air transport and international maritime transport

[35] Highest sale increase was in the following categories: SUV, Pickup, CUV - see: http://www.autoalliance.org/auto-marketplace/popular-vehicles

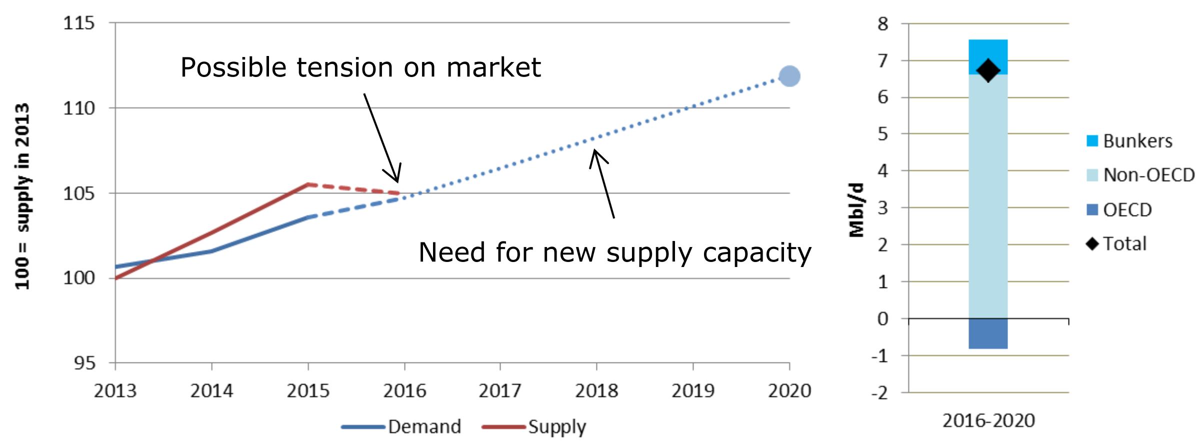
to 2015 (EIA 2016a) and total OECD by 3% (IEA 2016a). In addition, investment in exploration and production has been decreasing substantially since 2015 (-17% in 2015, and an expected further -11% in 2016[36]), while discoveries of new oil reserves over 2015-2016 reached their lowest level since the mid-50s[37], pointing to possible supply problems in the forthcoming decade.

These two opposite trends would result in a need for additional oil production, from OPEC countries in particular, which might need to increase their production by 25% compared to 2014 before 2020. As a consequence the oil market should shift form the abundantly supplied situation experienced in the past two years towards a tighter configuration, leading to possibly rising oil prices by 2020.

This supply bottleneck is likely to occur regardless the pace of implementation of climate policies. Global climate protection policies are expected to have an effect on the international oil market only after 2020-2025 (see Figure 26 above for the effect on the oil demand and Figure 31 below).

Beyond 2020, growing extraction costs and additional investments would suggest a long-term oil price increasing trend. Further detail on the long-term trends of oil supply and demand is provided in section 4.1.4.

Figure 29: Oil demand vs. supply (left), new demand 2016-2020 (right)



Note: 2013-2015 data and 2016 estimates from IEA (2016a), demand in 2020 from this report.

The gas and oil markets are expected to be progressively decoupled, although regional market-specific indexation of gas prices on oil prices can persist. After a period of increase of the gas to oil price ratio in the medium term due to low oil prices, the ratio would remain fairly stable beyond 2020 (Figure 28).

Gas prices are expected to keep increasing over the next 10 years, while retaining regional differences reflecting supply patterns and transport costs. However convergence across regional price signals will gradually take place with the development of international LNG trade – about a third of international trade in 2014, half in 2030 – and

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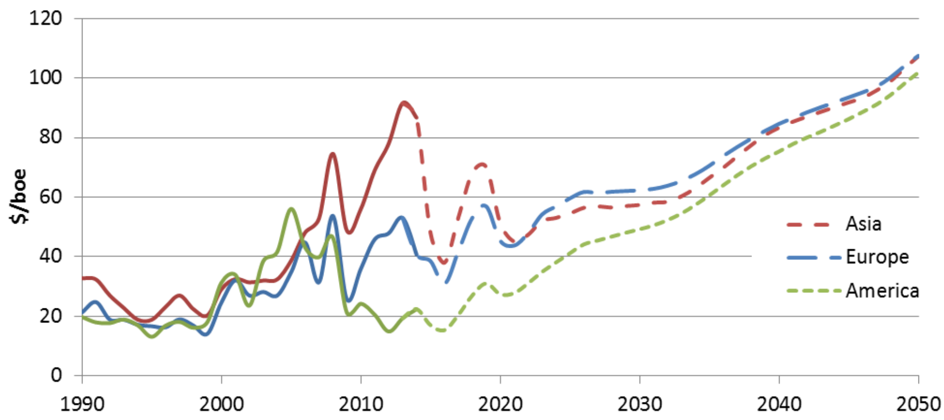
[36] According to a report by Barclays on E&P Spending Outlook published in January 2016, see: http://www.ogj.com/articles/2016/01/barclays-global-e-p-budgets-to-see-double-dip-in-2016.html

[37] According to a survey by IHS quoted in the Financial Times (8th May 2016): http://www.ft.com/intl/cms/s/0/1a6c6032-1521-11e6-9d98-00386a18e39d.html#axzz4BZJuRsWY

the further integration of Asian and European markets via Russian supply (see section 4.1.5 for more detail).

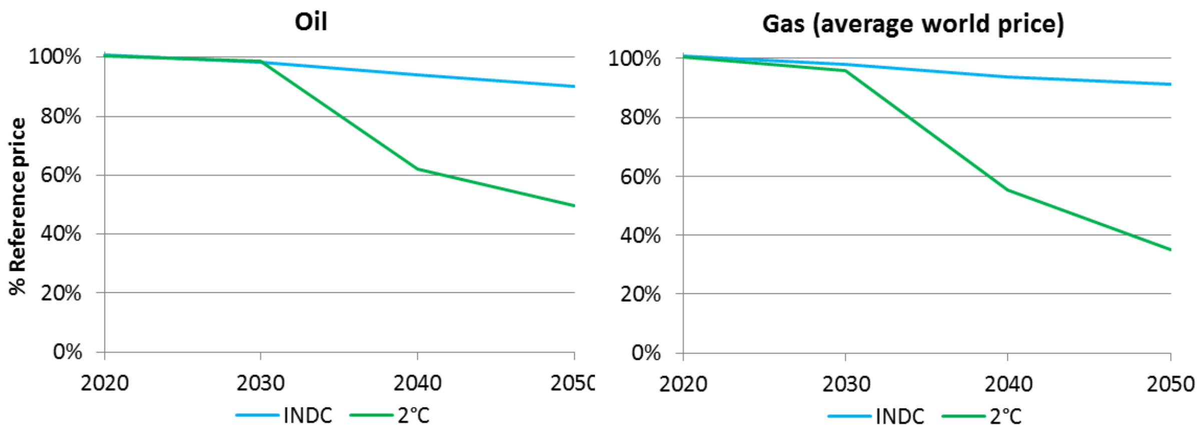
Figure 30: International gas price, Reference scenario



Coal prices, currently at their lowest level, should follow a moderate rising trend, driven by growing freight costs and, in the long term, by increasing mining costs also. The decrease of the coal to oil price ratio infers an increasing competitiveness of coal, most notably compared to gas with which it competes in the power sector.

The oil market dynamics would not be much different in the INDC scenario, but going to 2°C would entail more structural changes in the transportation sector, leading to a relatively lower price (Figure 31). It must be kept in mind that a substantial part of oil production is highly energy-intensive and emits CO_2, and would therefore be negatively affected by ambitious climate policies. This is all the more true for non-conventional liquids that require heat usually produced from fossil fuels. As a consequence, the expensive oil is likely to become even more expensive with the pricing of related-CO_2 emissions, which would limit the downward impact on the price of the lowering demand.

Figure 31: Impact of climate policies on the oil and gas prices



Climate-protecting policies should also reduce the gas market price, even further than the oil price. This is due to the fact that gas production is, and will increasingly be, less energy and carbon intensive on average than future oil production relying on non-conventional oil. As a consequence the pricing of carbon emissions will not affect the structure of the production cost of gas as much as it will affect the one of oil. Gas being a power-oriented fuel, the increased penetration of renewables in the power sector would further decrease gas demand and gas prices. Gas prices could be up to 60% lower than in a world without any climate policy, vs. -50% for oil.

4.1.3 Energy trade

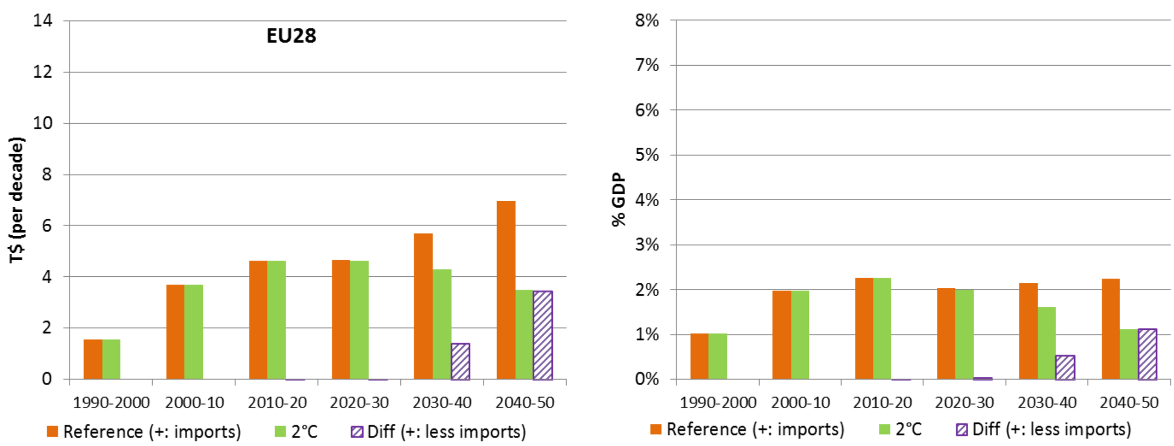
International trade of energy will undergo an increasing trend in the future in the Reference scenario, both in terms of traded volume and associated financial flows.

The future of energy markets will depend to a large extent on the geopolitical relations between on the one hand Gulf and CIS countries (the major net exporters) and on the other hand Asia (from where the largest share of net demand will come).

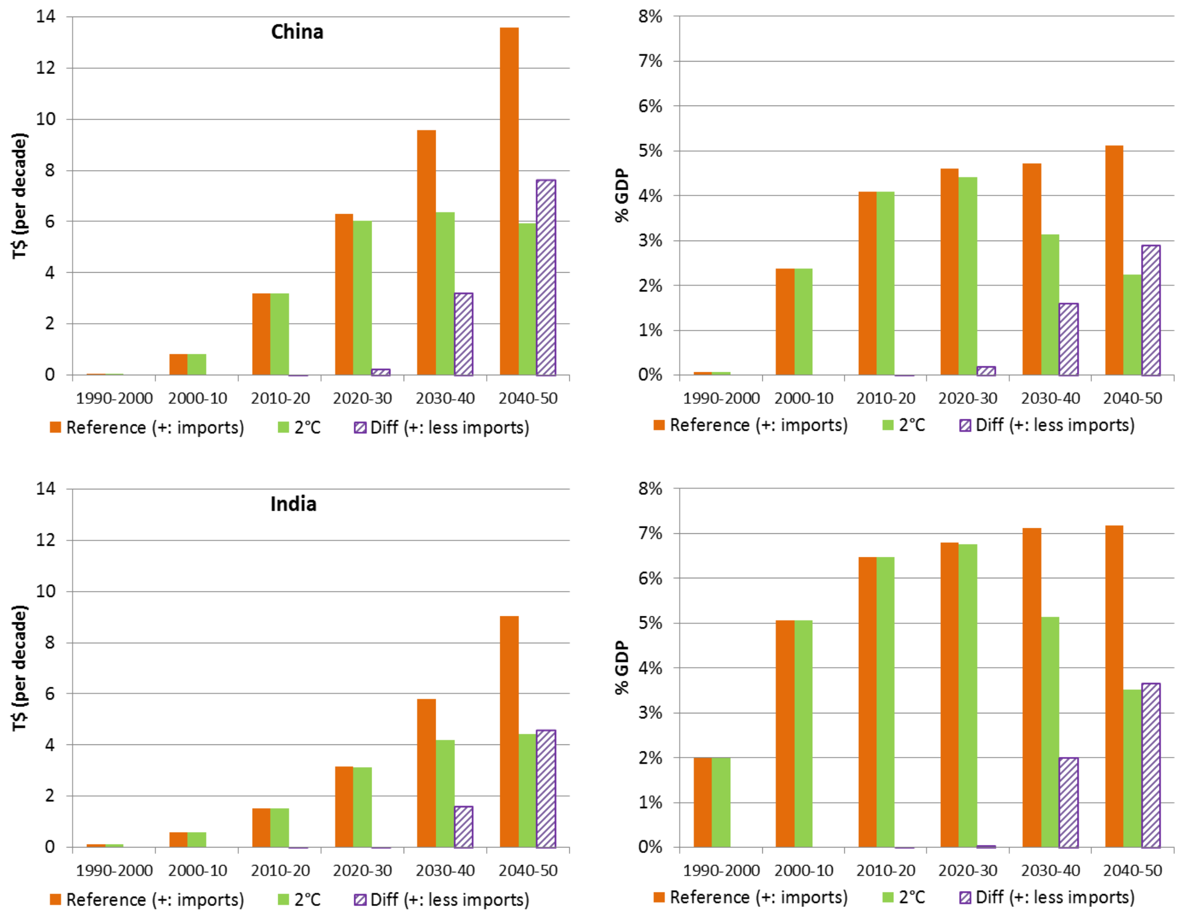
The trading situation of the main importers evolves as follows (see Figure 32 and Table 15):

- Europe is expected to remain a large importer of energy throughout the whole period even though its weight in energy trade keeps decreasing over time. The energy importing cost for European economies would lower to 1% of GDP in the 2°C scenario by mid-century (vs. 2.5% in the Reference scenario), i.e. close to the share observed during the 1990-2000 decade;
- Asian countries, and most notably China, will increasingly become very large importers in the coming decades; the cost compared to GDP is expected to increase in the absence of climate policies (to a substantial 5% of GDP for China, as high as 7% for India); these countries would improve substantially in terms of energy importing expenditure in the 2°C scenario (where cost goes down to respectively 2% and 3% of GDP by mid-century, i.e. below the share observed during the 2000-2010 decade).

Figure 32: Total energy trade in volume and as a percentage of GDP for EU-28, China and India, Reference and 2°C scenarios[38]



[38] Trade volumes are in real USD of 2015; shares of GDP were calculated with volumes using GDP MER.



Note: includes oil, gas, coal and biomass trade.

Table 15: Regional energy trade (Mtoe), Reference and 2°C scenarios

Mtoe (>0: net imports)		INDC		2°C	
	2010	2030	2050	2030	2050
Europe	880	760	740	750	500
North America	390	-440	-1070	-260	10
OECD-Pacific	430	200	110	200	130
China	340	1210	940	1160	480
India	200	780	1170	720	600
Other Asia	620	2200	3200	150	410
Latin America	-190	-210	20	-90	-700
Sub-Saharan Africa	-290	-320	-200	-280	-70
CIS	-680	-960	-1380	-960	-660
Middle East & North Africa	-1130	-1900	-2350	-2020	-1110

Note: includes oil, gas, coal, biomass trade; in 2010 oil represented most of the trade (75% in volume), ahead of gas (15%) and coal. Demand for international air and maritime bunkers are not reported in this table (they make up the balance, total global exports being null).

For other regions, energy trade is expected to experience substantial changes over time:

- North America would become a net exporter by 2030 in the context of INDC policies implementation, and presents a balanced energy trade in the 2°C scenario;
- Gulf and CIS remain the dominant suppliers; energy trade is a major source of income for these regions even with the climate policies implemented in the INDC and 2°C scenarios;
- Sub-Saharan Africa also remains a net exporter throughout the period;
- Latin America becomes progressively a net importer of energy in volume, even though trade value remains positive thanks to (oil) exports.

Climate policies would have an impact on expensive production that would be shut down first in the face of lower total demand, in addition to being made more expensive by the carbon pricing for CO_2 intensive fuels (tar sands, oil shale, ...). As a consequence, traditionally importing countries, which tend to have a more expensive production, would reduce their output while maintaining some imports from large (and cheaper) exporting regions.

Overall, traded volumes are expected to remain fairly similar across the Reference and 2°C scenarios by 2030, whereas the traded value is slightly lower in the 2°C scenario because of lower international prices (see Figure 31 in section 0). The global picture could change after 2030 when both the oil price and volumes traded, especially between Asia and Gulf/CIS, could reduce significantly.

Total net energy import expenditure of net importing countries increases to 40-50% above the 2010 level by 2030. It then increases further by 2050 in the Reference and INDC scenarios (to twice the 2010 level), whereas it decreases in the 2°C scenario (reaching a level 30% above 2010).

4.1.4 **Oil**

The global transport sector is the main consumer of world oil production (almost 60% in 2014, against 45% in the early 90s), ahead of industry, buildings and the power sector. Substitution by other fuels in this sector has been historically low, with liquid biofuels and natural gas emerging recently in road transport but to a limited volume (respectively less than 5% and 2% of total oil used in transport). This report considers alternative fuels to provide road mobility: electricity and hydrogen. For technical reasons (weight of electric batteries and the requirements for long range autonomy), it is considered that these are more suited for passenger road mobility rather than for goods road transport, and even less so for air and sea transport. Although substitution of liquid fuel by electricity in goods road transport is possible, it comes at a higher cost relatively to substitution in passengers transport. Hydrogen shows a limited development in all cases, hampered by the high cost of fuel cells and hydrogen production.

In spite of these expected developments, oil demand can be foreseen to increase in the future, possibly at a slower pace compared to the past two decades; in 2050 it is 20% higher than 2014 in the Reference scenario. This is the result of opposite trends in OECD and non-OECD countries.

In 2012, oil demand (excluding international bunkers[39]) was equally shared between OECD and non-OECD countries. This ratio may progressively change until by 2050 when non-OECD would cover three quarters of total demand. OECD demand, after reaching a peak in 2005, decreased due to increasing efficiency in transport or displacement by

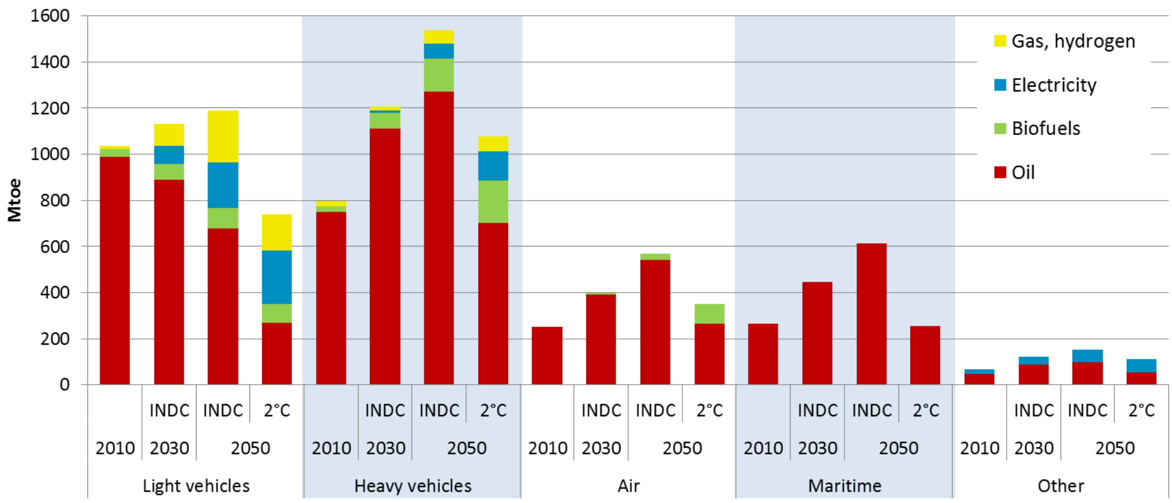
[39] International bunkers are international air and maritime transport

other fuels in industry and buildings. This trend continues, with demand in OECD reducing by 40% over 2014-2050.

Non-OECD demand, on the contrary, would increase by over half over 2014-2050. Most of that increase is expected come from the transport sector, which would double in size over 2014-2050, mainly driven by mobility demand in fast-growing Asian countries. Indeed, the number of private cars in non-OECD countries could triple over the same period.

Road transport, which alone represents 40% of global oil demand, is a sector that is particularly difficult to decarbonize due to price-inelastic demand, especially in the absence of affordable substitutive technologies in freight transport. As shown in Figure 33, oil as a share of total light vehicles consumption decreases to 60% in Reference and INDC (partially substituted by electricity due to techno-economic improvement of electrical batteries and the better coverage of the road network with recharging facilities), whereas it decreases only to 85% in heavy vehicles. In addition, international bunkers are not covered by the INDCs: they keep increasing their oil consumption over time driven by rising international trade and passenger mobility, both being strongly correlated to economic activity (+50% of oil consumption by 2030, doubling by 2050, on the same trend as the historical doubling over 1990-2014). This explains why the implementation of the INDCs does not change significantly the dynamics of the oil market (see Figure 26).

Figure 33: Energy demand in transport



Most transport sectors undertake an important energy demand reduction in the 2°C scenario, combined with increased penetration of electricity in the case of road transport and, to a lower extent, of liquid biofuels in road and air transport. Total energy demand falls back current levels in the Maritime and Air sectors, is much lower in the case of light vehicles (partially due to the higher efficiency of electrical engines) and stays above in the case of heavy vehicles.

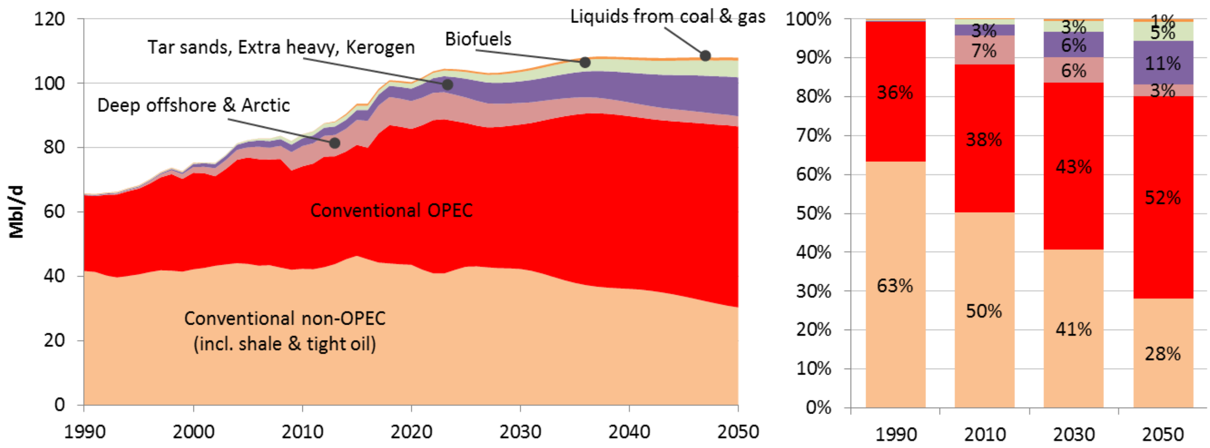
From the supply side, the main driver is the growing scarcity of conventional oil resources[40] and consequent increasing market power of OPEC. This upward evolution of scarcity signals is also sustained by the progressive substitution of conventional resources by expensive energy-intensive liquid fuels: tar sands, extra heavy oil and

[40] Estimates from fossil fuel resources used in this report come from BGR (2014) and USGS (USGS 2013 and Schenk, C.J., 2012).

kerogen / oil shale would represent together 11% of the total liquids supply in 2050; liquids from transformed fuels (biomass, coal, gas) would reach 6% of total liquids supply. Production of expensive conventional oil in deep-water reservoirs is foreseen to expand in the medium term (Brazil, USA, Nigeria and Angola). The bulk of non-conventional production is concentrated in Canadian tar sands and Venezuelan extra-heavy oil throughout the forecasted period, to which US shale oil can be added for the mid-term.

For conventional oil, the expected increase in production in the medium term would take place in the Middle East (Saudi Arabia, Iraq, UAE), followed by the USA and Central Asian countries (Kazakhstan, Turkmenistan). In the longer term beyond 2030, in a context of overall decline in conventional output, only two regions, Middle East and Africa, continue to increase production.

Figure 34: World liquids production, INDC scenario



Note: includes crude and LNG production; does not include liquid processing gains.

In the medium term, the demand increase induced from the present low oil prices would mean that significant investments will need to be made in production for it to grow.

In the longer term, total liquids demand are only slightly increasing after 2020 throughout 2050, around 105 Mbl/d, with crude oil supply remaining at an undulating plateau at around 100 Mbl/d for several decades.

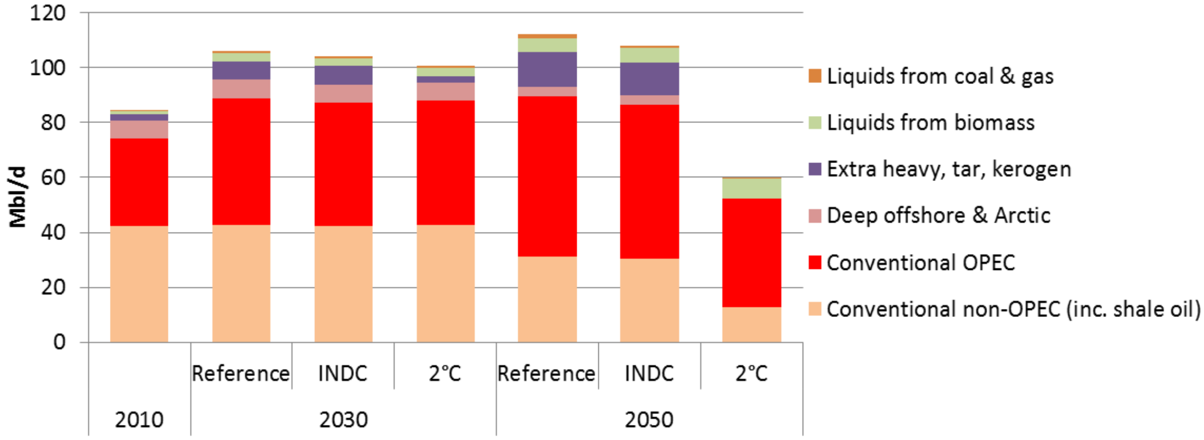
In the INDC context, cumulated production of oil rises from about 1.3 Tbl in 2014 to twice that in 2050, i.e. from 20% to 40% of total technically recoverable oil resources[41]; for conventional oil these figures are 35% and 70%, respectively. These figures reflect increasing oil scarcity and a shift in international oil flows, with an expected growing role of Asia (see section 4.1.3). Even though conventional oil supply makes up less and less in total liquid fuel supply, it would mainly be due to the decreasing conventional production in non-OPEC countries whereas the OPEC importance would become greater due to its ability to tap into their significant and relatively cheap resources.

As shown in Figure 35, a more stringent climate policy (2°C scenario) would affect first the most CO_2-intensive productions (extra heavy, tar and kerogen), and the depressing impact of demand on price affects (more expensive) non-OPEC and deep-offshore

[41] Technically recoverable oil resources: 3.7 Tbl for conventional and environmentally-sensitive oil; 2.8 Tbl for non-conventional oil (see BGR (2014)).

production. Cumulated production by 2050 still reaches 2.5 Tbl in this case, or 37% of total resources[41].

Figure 35: Impact of climate policies on oil production



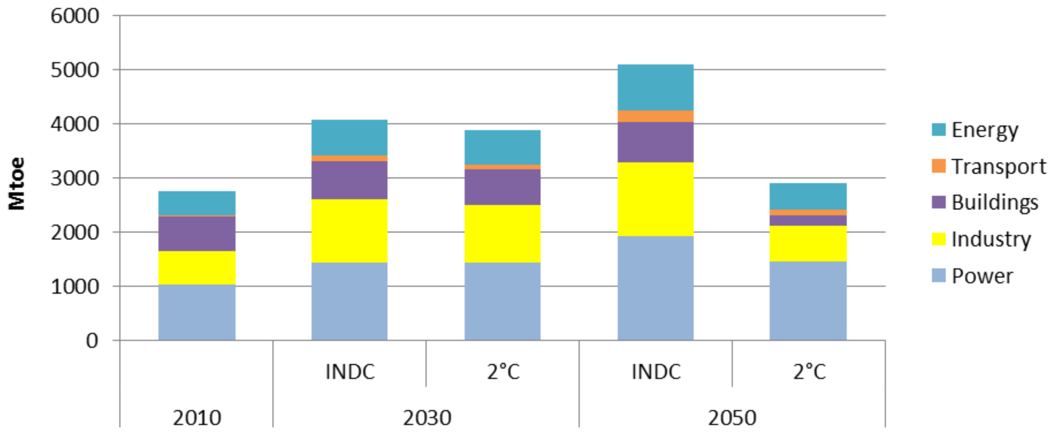
Note: in the 2°C scenario residual liquids from coal are associated with CCS

4.1.5 **Gas**

Demand of gas is expected to keep a growing pace in future decades, albeit at a decelerated growth rate. In both the Reference and the INDC scenarios, gas demand would be 50% and 90% higher in 2030 and 2050 than in 2010, respectively. This is particularly motivated by additional demand in industry and the power sector, two sectors that would continue being responsible for about two thirds of total gas demand throughout 2050.

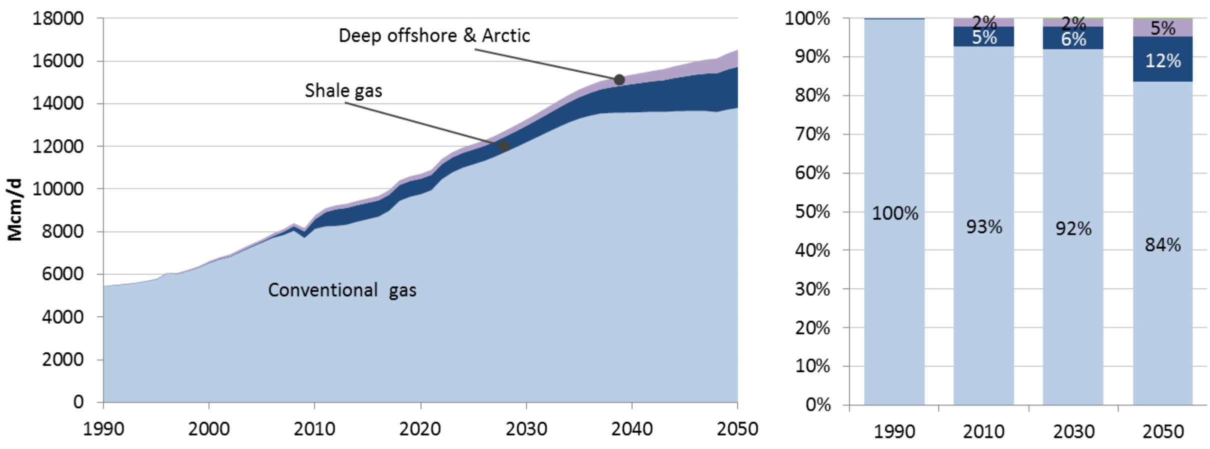
Gas demand would maintain an important role in the power sector in the case of stringent climate policies (2°C scenario), due to its comparative advantage with coal. However, demand in other sectors is projected to shrink, due to both energy efficiency and substitutions by carbon-neutral energy vectors. In this case, total demand comes back to 2010 level by 2050.

Figure 36: Gas demand by sector



Future natural gas production is still dominated by conventional gas. While Russia and the Caspian region are foreseen to continue to be major producers in the future and expand their supply, it is the Middle East that could experience the most important increase in production and market share through LNG exports. Conventional gas remains relatively abundant, with about 40% of accessible resources having been produced by mid-century (13% in 2014)[42].

Figure 37: World natural gas production, INDC scenario



In all the scenarios addressed, the contribution of shale gas does not exceed 12% of total gas supply by 2050. Due to production costs differing across regions and competition with other gas sources, the "shale gas revolution" would take off with difficulty in countries outside the USA; growing production, mostly in China, South Africa and Russia, make up for the eventual decline of US production starting from the next decade. Gas produced in environmentally sensitive regions (deep-water and the Arctic) remains a marginal source, with USA, Brazil, Nigeria and Russia making up most of what is produced.

Gas is increasingly traded in the form of liquefied natural gas (LNG). The LNG market is expected to reach 2500 mcm/d in 2030 and would nearly triple in volume compared to 2015, regardless of the scenario considered. By 2030, it could represent half of the internationally traded gas and 20% of global gas supply (compared to 33% and 10% in 2014, respectively; see BP, 2015).

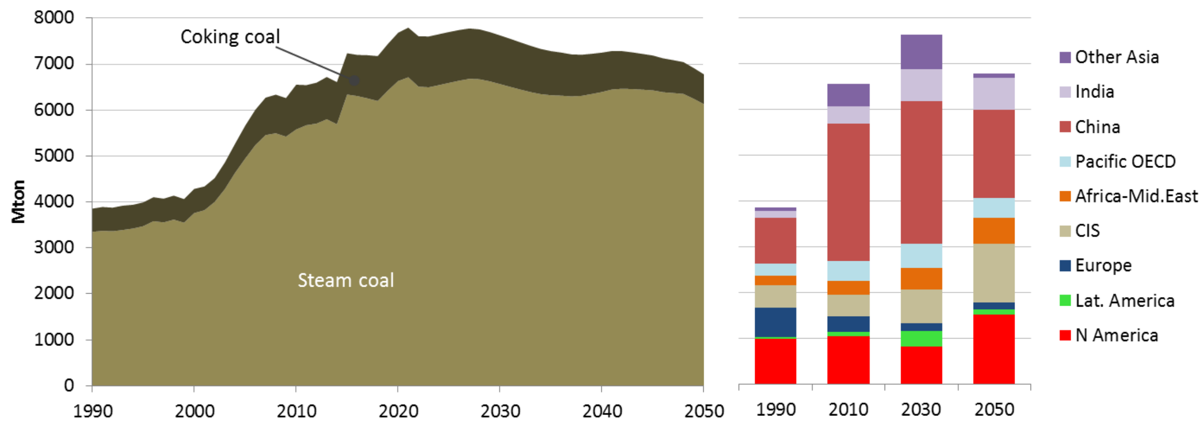
4.1.6 Coal

World demand for solid fossil fuels could continue to increase from 6 Gt in 2010 to 7.5 Gt by the mid-2020s in the INDC scenario and then stabilises around 7 Gt by 2050. As seen in Figure 26 coal is the primary energy carrier the most heavily impacted if climate policies are implemented worldwide: while it keeps increasing without climate policies, reaching 11.5 Gt in 2050 in the Reference scenario, in the 2°C scenario it peaks in the early 2020s at 7.4 Gt and sharply decreases afterwards (-4.4%/year).

By 2030 all regions see their production increase in the INDC scenario compared to 2010, except Europe, which decreases, and China, which stabilises. Over the longer run, total production in Asia is declining, substituted by production in America and CIS.

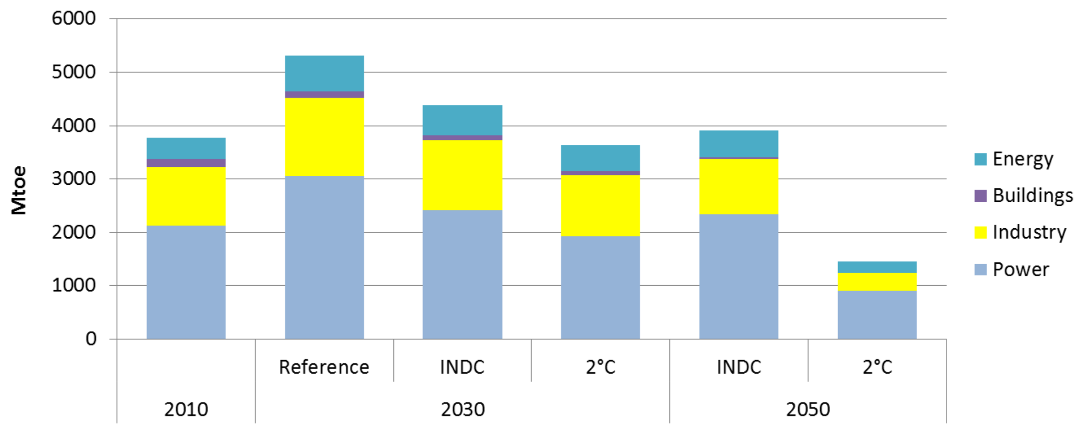
[42] Technically recoverable gas resources: 650 Tm^3 for conventional and environmentally-sensitive gas; 150 Tm^3 for non-conventional gas (see BGR, 2014).

Figure 38: World supply of steam and coking coal (left), by region (right), INDC scenario



The power sector would remain the largest coal consumer in all cases, followed by industry. Demand in buildings would virtually disappear, due to the additional environmental negative externalities of coal use in cities. Most of the consumption/production remains steam coal, the share of coking coal, which follows the demand for steel, reducing to 10% by 2050 in the INDC scenario (vs. 15% in 2010).

Figure 39: Coal demand by sector



Out of these volumes, only a minor part is traded across borders – although the share of trade is increasing in all scenarios considered. 17% of steam coal was traded internationally in 2014; in the Reference scenario this figure rises to 26% and 40% in 2030 and 2050, respectively. Imports for emerging economies in Asia are the driving force behind this growth.

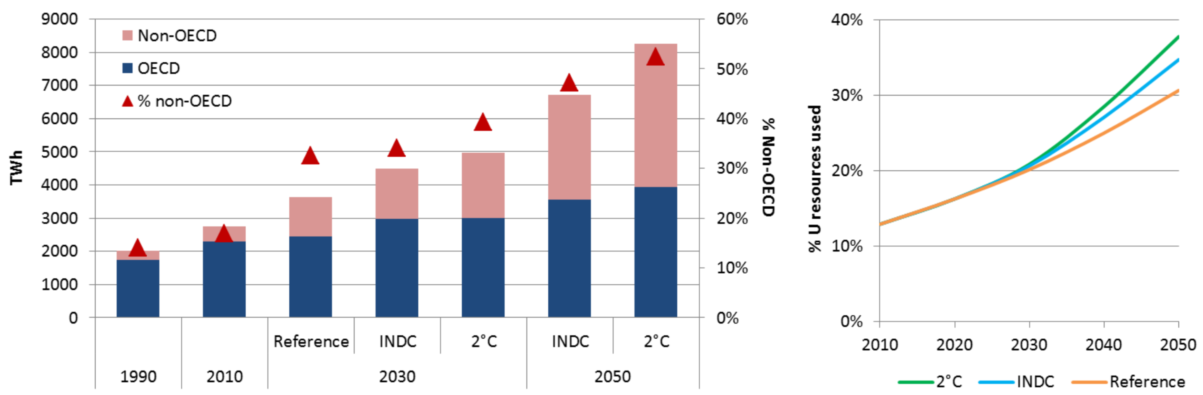
4.1.7 Nuclear

World nuclear supply is foreseen to grow in the coming decades, in all scenarios (see Figure 40) – from a 37% increase in the Reference scenario to 87% in the 2°C scenario (2030 vs. 2014).

The increase largely comes from non-OECD countries (mostly concentrated in China, India, South-East Asia, Central Asia and Russia) which come to account for around half the nuclear production by 2050, compared to a less than 20% in 2010 (around 20% in in 2014).

This represents a substantial increase of generation capacity, which would expand by 40-90% in 2030 compared to 2010, depending on the scenario, and more than double by 2050.

Figure 40: World nuclear supply (left) and % of uranium resources used (right)



World uranium consumption increases accordingly. As a result, by mid-century 30% to 40% of uranium resources[43] have been consumed.

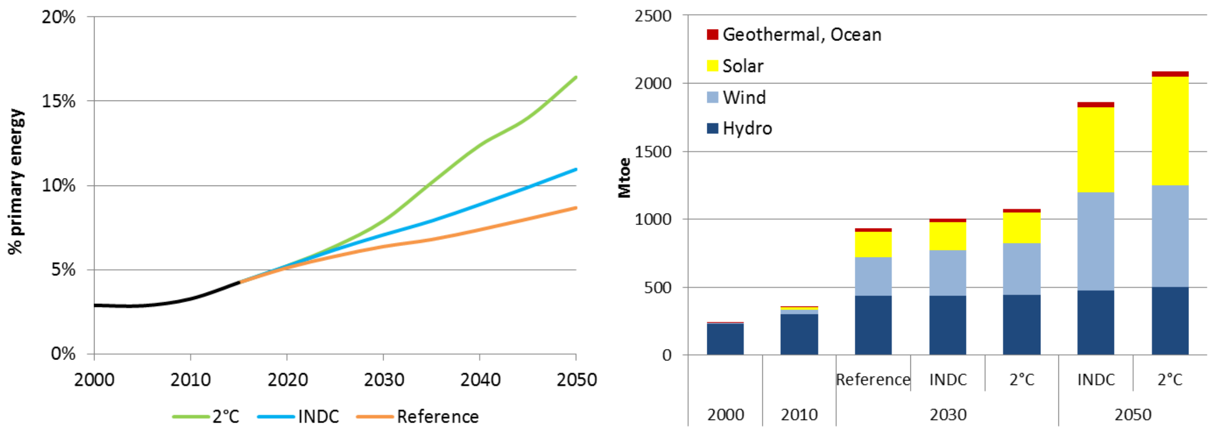
4.1.8 Non-biomass renewables

The contribution of non-biomass renewables to the total energy mix is projected to grow in all scenarios, both in share and in volume: its share will increase from 3% of the total energy supply in 2010 to 5-7% in 2030, and to more than 10% with the implementation of GHG policies.

Although hydro only increases slowly over time, given its relatively limited potential for additional installations, wind and solar are foreseen to exhibit a considerable growth. They overtake hydro already in 2030, to reach 0.5 Gtoe in 2030 and 1.5 Gtoe by 2050 thanks to sustained average growth rate of 13% by 2030 and of 4% for wind and 7% for solar over 2030-2050.

[43] Non-oceanic uranium resources only, estimated at 23.5 MtU (see: OECD 2014).

Figure 41: World non-biomass renewables in total energy (left), by technology (right)



Note: Geothermal accounted for in direct equivalent (electricity only); solar includes thermal solar, electricity from PV and concentrated solar; wind includes both on-shore and off-shore

4.1.9 **Biomass**

The use of biomass for energy is projected to increase in the future; as an alternative to fossil fuels for combustion or for the production of liquid fuels, its use would be further enhanced by climate policies. By 2030 its demand grows by 30-44% compared to 2014 (depending on the scenario). The largest increase come from cellulosic sources: forestry residues and dedicated short rotation crops for biomass-to-energy conversion.

Current biomass exceeds 50 EJ/year; by 2050 it nearly doubles in the Reference and INDC scenarios and nearly triples in the 2°C scenario, to 130 EJ/year. This raises a number of questions on the impact the increasing use will have on land-related issues, most notably food production, biodiversity conservation or water cycles.

Figure 42 plots long-term biomass-to-energy potentials estimates[44] from a comparative study that provides various ranges of bio-energy potentials across biomass source types; estimates vary on a multitude of criteria such as social, political and economic factors but also the stringency of sustainability criteria. According to Creutzig et al. (2015)[45] there is a medium agreement in the literature for a potential of about 200 EJ/year, which is higher what is used by 2050 in the GECO scenarios, and a high level of agreement of 90 EJ/year, which is reached or exceeded in the case of 2°C scenario.

The scenarios presented in this study were produced considering a maximum potential for bio-energy of 240 EJ/year in 2050 (using information from the GLOBIOM model, see IIASA, 2016), and taking into account the future development of yields and an increasing cost of production as more of the potential is being used. This comparison with literature assessments raises questions about the sustainability of this energy source over the long run.

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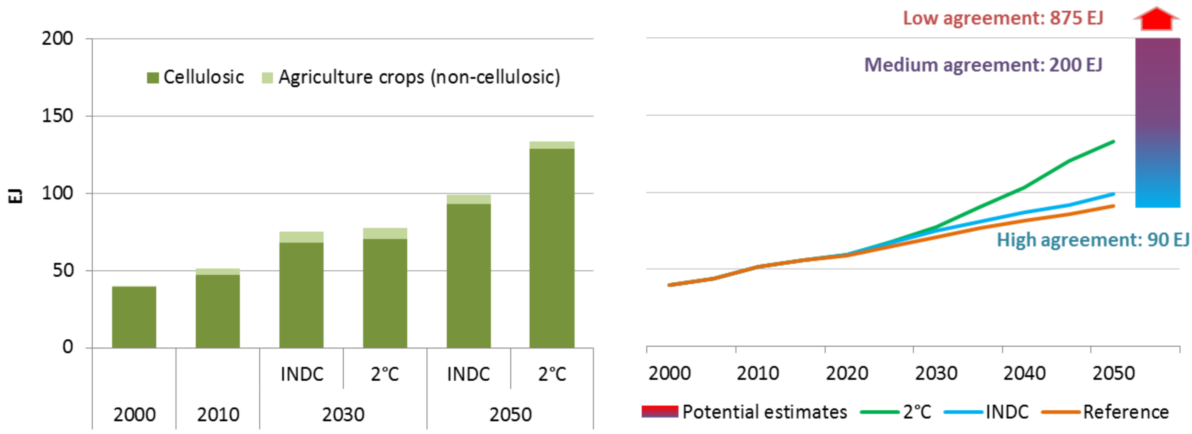
[44] Accessible potentials regardless of time horizon considered
[45] http://onlinelibrary.wiley.com/doi/10.1111/gcbb.12205/full

Figure 42: Biomass production by type (left), vs. potential (right)

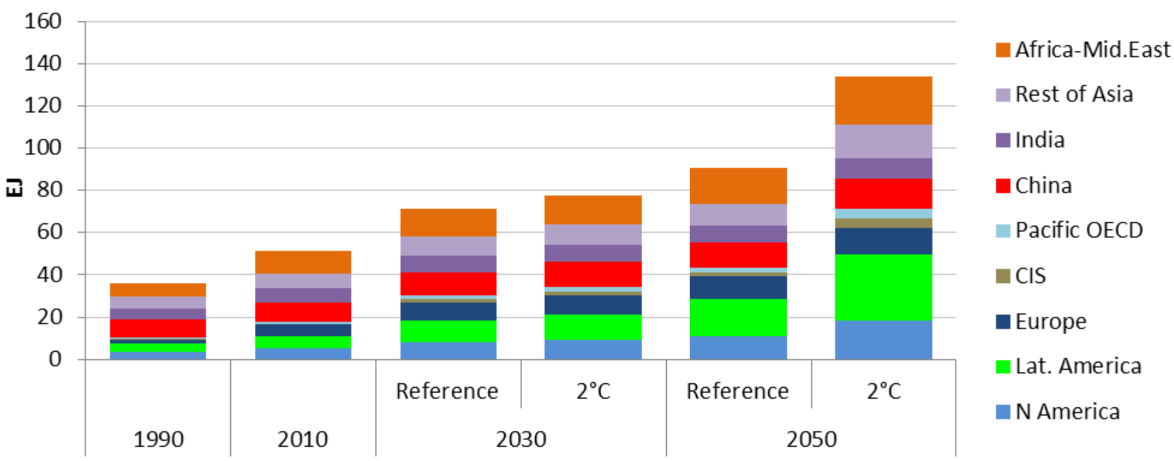


Source for potential estimate and qualification of agreement in literature: Creutzig et al. (2015).

Global biomass production and trade is therefore projected to expand, North America and Latin America being the regions that increase their share in global production most significantly. The regions most using their potential are Europe, Middle East, North Africa, India and China. OECD and, especially in the 2°C scenario, China, would be the most salient importing regions in 2050.

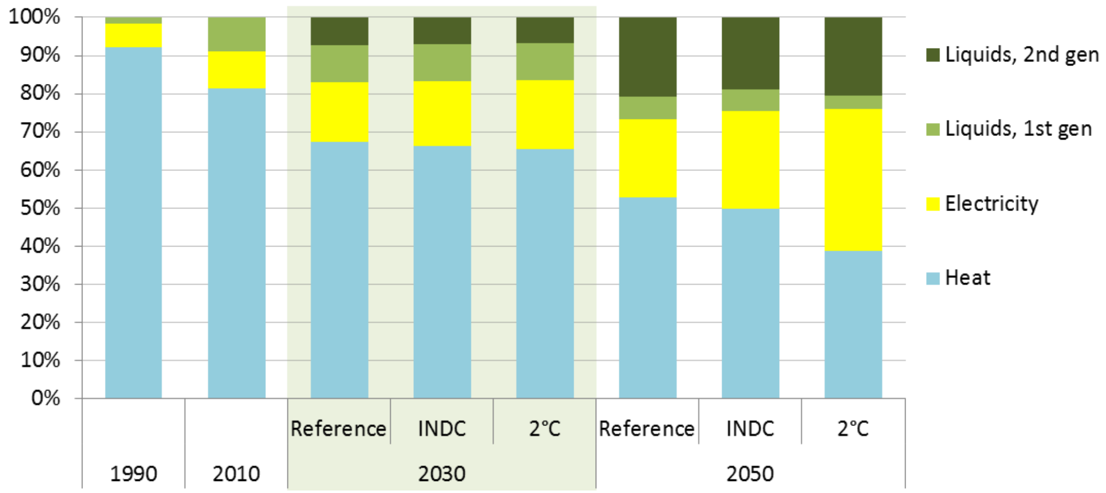
Non-OECD large resource countries (Africa, China and India) are expected to see their use of traditional biomass much reduced and progressively replaced to supply the energy needs of their economy by "modern" biomass produced with more efficient exploitation methods.

Figure 43: Primary bio-energy production by region



80% of the biomass consumption in 2010 went to thermal applications, with only some development of liquid biofuels over the last 10 years. In contrast, it seems that future demand growth will be driven by power production and second generation biofuels in all scenarios. The share of first generation biofuel is expected to decrease significantly after 2030. In the ambitious climate scenario 2°C, the development of biomass with CCS in the power sector, a potential important contributor to emissions reduction (BECCS, accounted for as technology providing negative CO_2 emissions), would draw significant amounts of biomass. By 2050 biomass in power production reaches the same market share as biomass for heat.

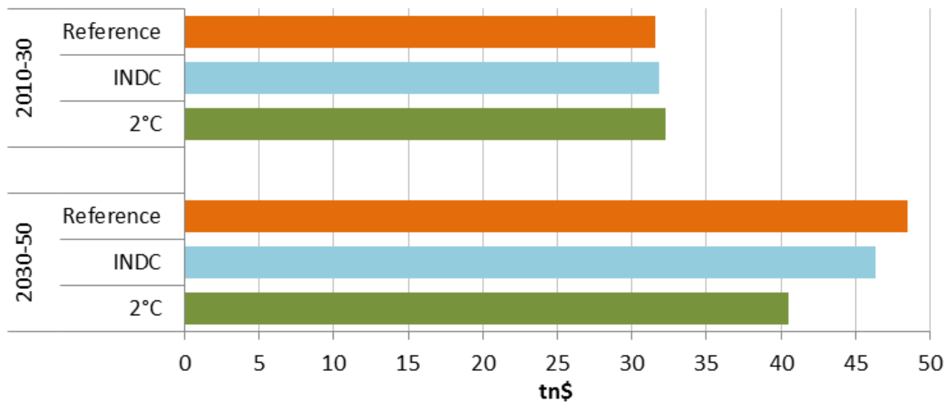
Figure 44: Primary bio-energy demand by use, share



4.1.10 **Investment requirements in energy supply and transformation**[46]

The total investments required in the energy sector for supply and transformation (fossil fuel production, power, hydrogen, biofuels) would exceed 30 tn$ over 2010-2030 and reach 50 tn$ over 2030-2050 in the Reference scenario.

Figure 45: World investment in energy supply and transformation, total



Over 2010-2030 investment costs are similar in INDC and 3% higher in 2°C compared to the Reference, with a higher share of investment in the power sector (and lower in fossil fuels). This reflects the transition towards a low-carbon energy system, with a deeper electrification trend of the final energy mix and a more capital-intensive power production cost structure.

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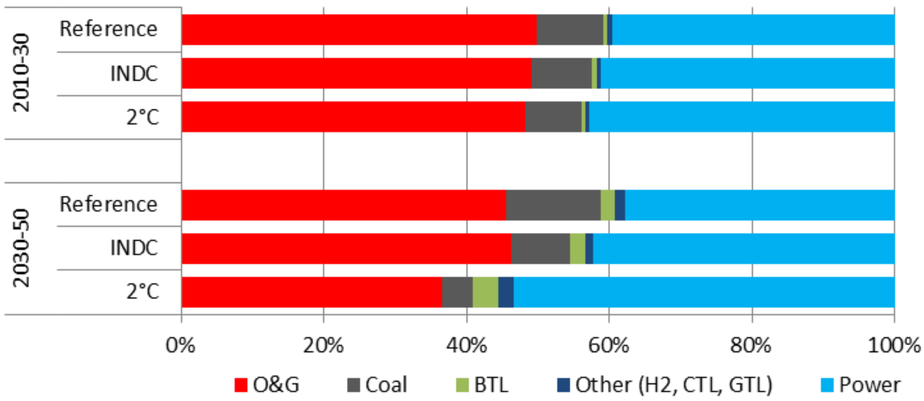
[46] All figures in this section are expressed in real USD of 2015

Beyond 2030 there is greater differentiation: investments are as much as 11% lower over 2030-2050 in the 2°C scenario, driven by a reduced energy demand that lowers the needs in supply and transformation. In addition, the reduction of investments in fossil fuels accelerate (40% of the total, mostly in oil and gas), compared to 54-59% in Reference and INDC, respectively. Investment in the power sector would reach about 35 tn$ by 2050, representing more than half of the total investments (54%) in the 2°C scenario, compared to 38-42% in Reference and INDC, respectively.

Figure 46: World investment in energy supply and transformation, shares



Note: BTL: biomass-to-liquids, H2: hydrogen, CTL: coal-to-liquids, GTL: gas-to-liquids.

These investments refer to the energy supply and transformation sectors. They do not, however, represent the total investments in the energy sector since they do not include investments in the energy demand sector to improve the efficiency of consuming equipment (in transport, industry and appliances in buildings) and to improve insulation in buildings. In particular, additional investments in more energy efficient building envelopes could reach 15 tn$ by 2050 in the scenarios with climate policies, amounting to 40-50% of the total investment needs in the power sector.

4.2 Power sector

4.2.1 Demand and production

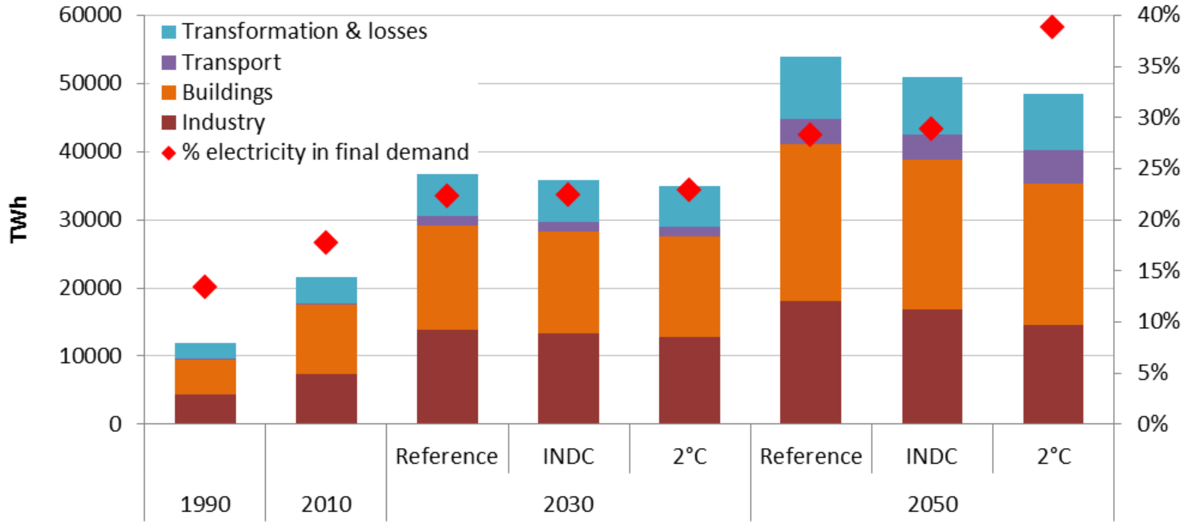
Electricity demand is to increase in all scenarios along with economic activity and rising standards of living around the world. In addition, electricity offers also climate mitigation options. Indeed it reaches almost 40% of final demand in 2050 vs. less than 30% in both the Reference scenario and the INDC scenario.

Roughly speaking, electricity demand would increase by about 10,000 TWh every ten years, starting from about 24,000 TWh in 2014, more than doubling by 2050 compared to 2014. The most rapidly expanding electricity demand sector is transport, due to the emergence of electro-mobility; the other demand sectors would also double their demand by 2050 with respect to 2014.

Due to enhanced energy efficiency, total electricity demand is slightly lower in the climate policy cases compared to the Reference scenario (5.5% lower for the INDC scenario in 2050, 11% for the 2°C scenario). The lower electricity use in these cases is due to higher efficiency in buildings combined with higher prices in all final demand sectors that slightly limit demand increase. This is partially compensated by an increase in the (road) transport sector where electrical vehicles (both plug-in and fully electrical) develop faster than in a context of climate policy implementation.

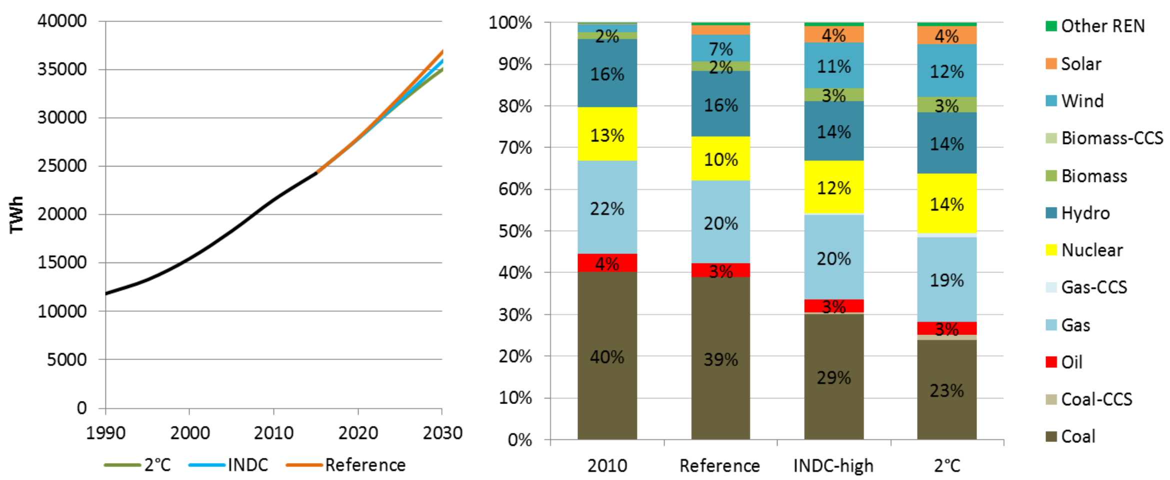
However, the weight of electricity in the final energy mix is higher in the INDC and 2°C scenarios than in the Reference scenario (Figure 47).

Figure 47: Electricity demand by sector (left) and electricity share in final demand (right), Reference, INDC and 2°C scenarios



In 2030 (Figure 48), the level of electricity production is still fairly similar across scenarios. However, the fuel shares between the INDC and Reference scenarios do differ, notably with power from coal contracting substantially and carbon-free power from nuclear and wind expanding, while leaving the share of gas unchanged. INDC policies would reduce the share of fossil fuels in 2030 from 62% to 52%. Going to the 2°C scenario implies a similar technological development, with, additionally, a slow emergence of CCS (2%) and a further expansion of biomass. Fossil fuels represent less than half (46%) of power production in 2030 in this case; they continue decreasing thereafter in both share and volume despite the expansion of CCS technologies.

Figure 48: Power production and production mix in 2030

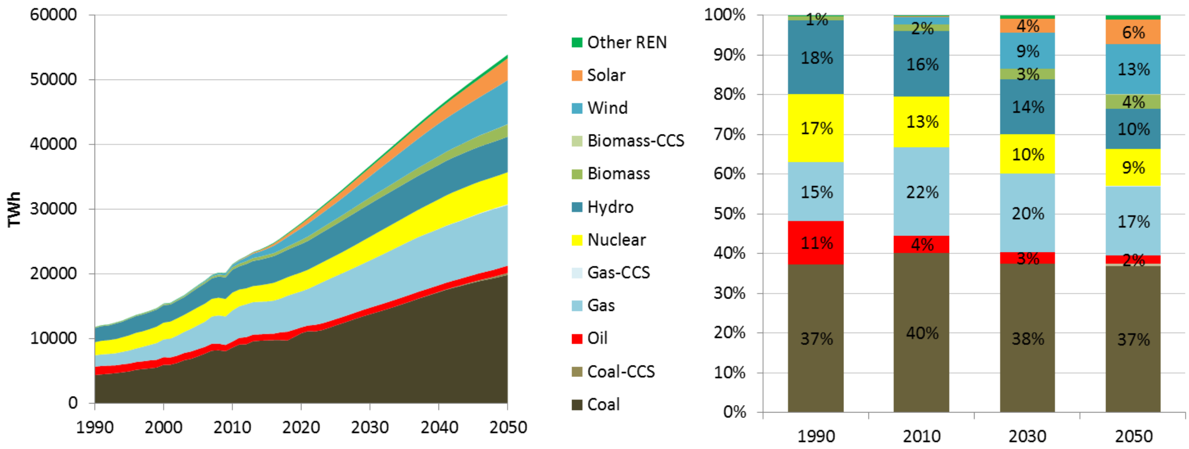


These trends in the power mix are reinforced over time beyond 2030. In the Reference scenario, while power production from all technologies is foreseen to increase, the share for coal would remain stable, hydro, gas and nuclear having decreasing shares, and wind and solar having increasing shares. Fossil fuels would still represent 57% of the power mix in 2050 (vs. 66% in 2014).

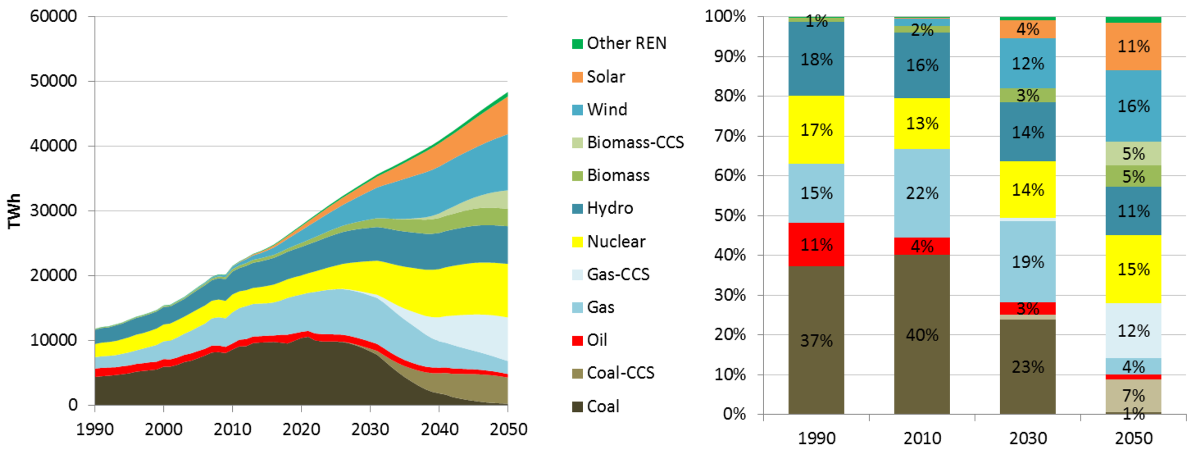
Since the power sector is the one offering the widest and cheapest decarbonisation opportunities, the image is dramatically different in the 2°C scenario. Non-fossil fuel technologies would rise to cover 71% of power production by 2050; fossil fuel production would be almost totally associated with CCS (20% of total).

Figure 49: Power production and production mix to 2050, Reference and 2°C scenarios

a) Reference scenario



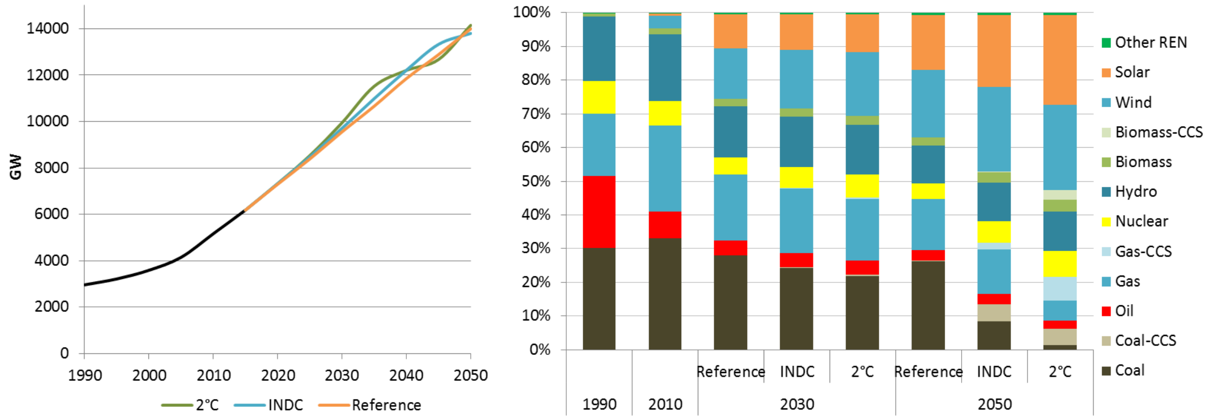
b) 2°C scenario



4.2.2 Capacities

Total installed power generation capacity is projected to grow around 2,000-2,500 GW every decade, increasing from about 6 TW globally in 2014 to over 9 TW in 2030 and 14 TW in 2050 (a more than twofold increase), very much in line with the evolution since 2000 in the three scenarios considered. Although electricity demand in the INDC and 2°C scenarios are lower than in the Reference, the total level of capacities installed is roughly similar across all scenarios because the renewables, which gain market share, have less running hours than dispatchable fossil fuel technologies. Renewables exceed 60% of the total installed capacity by 2050 in the INDC scenario, 70% in the 2°C scenario (vs. 26% in 2010 and 30% in 2014).

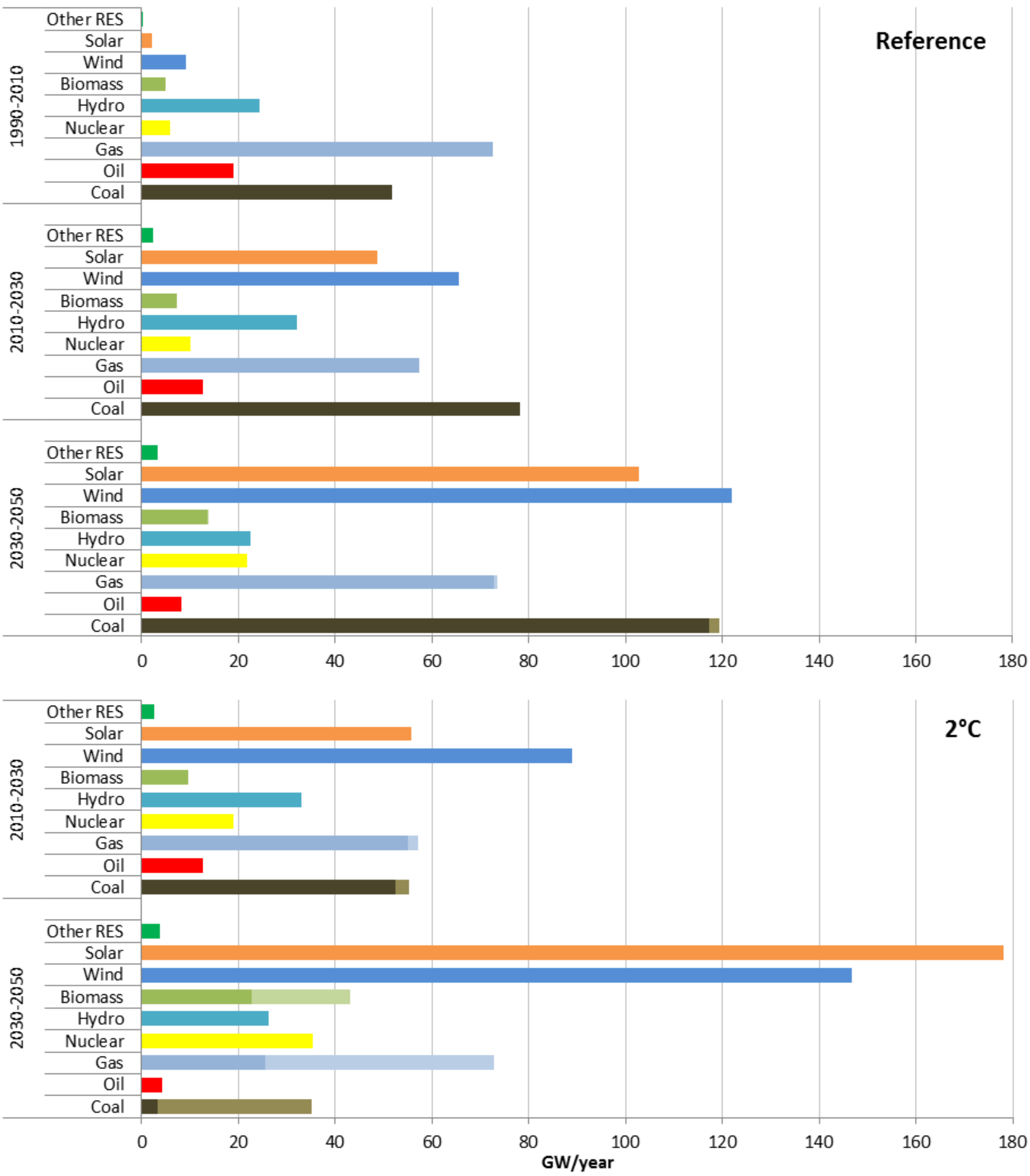
Figure 50: Installed power capacity, world (left), share of technologies (right)



New installations will need to be deployed quickly (and faster than before), to cover for the new demand and to substitute for decommissioned power plants. While total new installations averaged below 200 GW/year over 1990-2010, this rises to above 300 GW/year over 2010-2030 and nearly 500 GW/year over 2030-2050.

In the Reference scenario, there is still a non-negligible expansion of coal-based power in the future, gas and hydro would remain at their 1990-2010 paces and nuclear undergoes an increase to around 20 GW/year; installation rates for coal, wind and solar all exceed 100 GW/year in 2030-2050. In the 2°C scenario, the dynamics is different: the market size of coal-fired facilities is reduced by 40% after 2030 despite the deployment of coal with CCS; coal technologies without CCS stop being installed after 2030. CCS (combined across coal, gas and biomass) reaches 100 GW/year in 2030-2050 while solar and wind exceed each 140 GW/year.

Figure 51: World average new annual installations per technology, Reference and 2°C scenarios

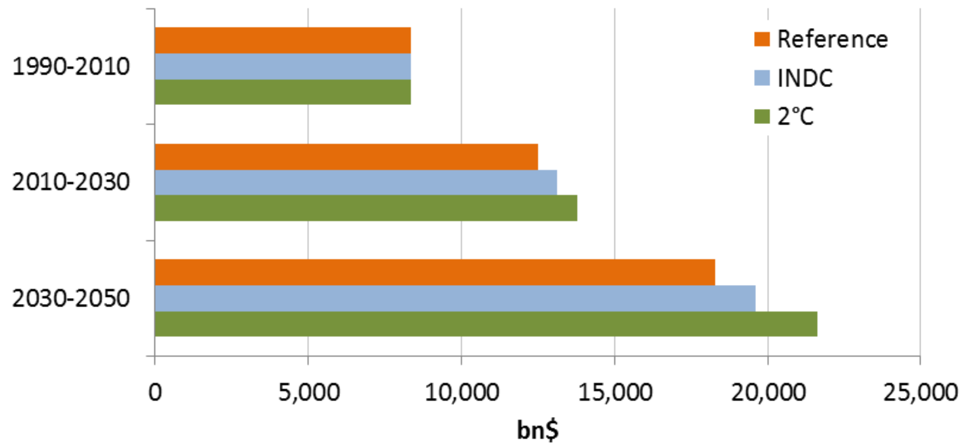


Note: coal, gas and biomass have technologies both without (dark) and with CCS (light).

4.2.3 **Investments**[47]

Global investments in new power capacities are projected to rise in all scenarios. Investments during the current decade are already expected to be 50% higher than in 2000-2010. Climate policies push towards technologies with higher capital costs and lower operating (fuel) costs; as a result, investments are higher in the INDC and 2°C scenarios; cumulated total investments over 2015-2050 are 7% and 15% higher, respectively. Over the 2015-2030 period, investments are expected to range from 9.8 to 11.2 tn$. As a result, investments in power production are a larger share of total investments in energy supply in the 2°C scenario compared to the Reference scenario, as shown in section 4.1.10.

Figure 52: World investments in power generation capacities

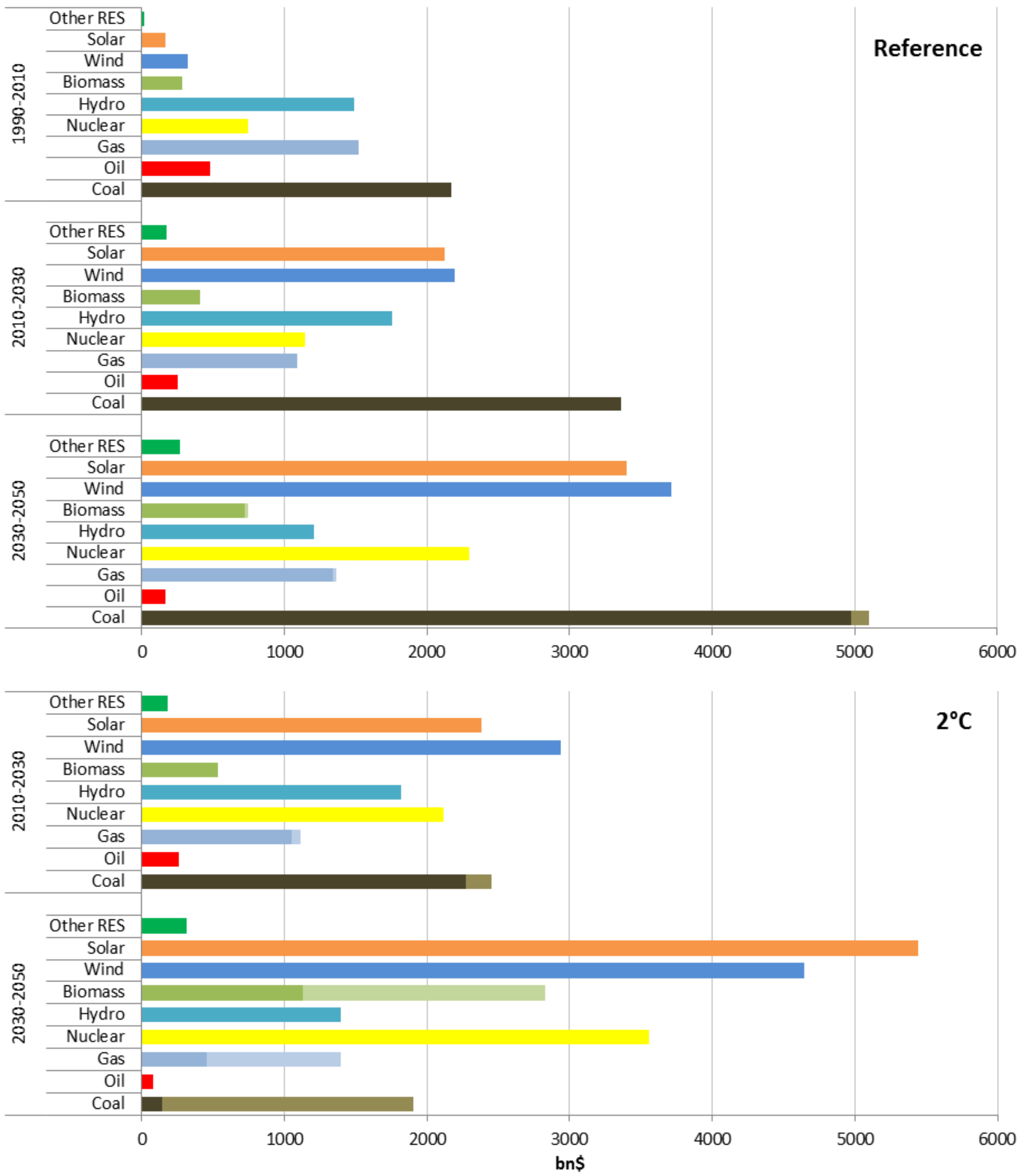


In all scenarios the deployment of renewables increases over time, this trend would be further enhanced in the framework of ambitious GHG mitigation policies: most investments go to solar and wind, followed by nuclear and CCS technologies (including coal, gas and biomass).

On the other hand the investments to coal would be much reduced when climate policy get implemented by more than half, despite the deployment of CCS, while it would attract the largest investments without climate policies (followed by wind and solar).

[47] All figures in this section are expressed in real USD of 2015

Figure 53: World investments in power generation capacities per technology, Reference and 2°C scenarios



Note: coal, gas and biomass have technologies both without (dark) and with CCS (light).

4.2.4 **Mitigation options**

The power sector is a crucial sector to achieve substantial GHG mitigation (see section 3.4 above for an overall view of mitigation options):

- It offers a very wide technology option portfolio and can accommodate at affordable cost decarbonisation for traditional technologies;
- In particular, it can integrate many renewable technologies.

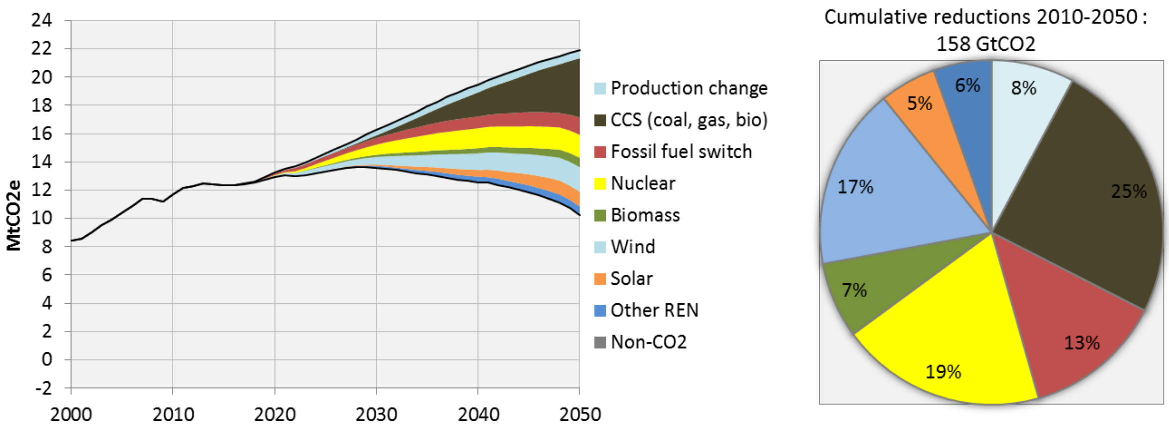
All regions diversify their power mix towards low-emission sources as a growing diversity of renewable energy sources gets exploited, according to each region's domestic potential and market conditions.

Therefore, the power sector alone would account for 40% of the reduction from the Reference to the INDC scenario in the medium term (2030), and also 40% of the further reductions from the INDC towards the 2°C scenario. See section 3.4.1 for more details.

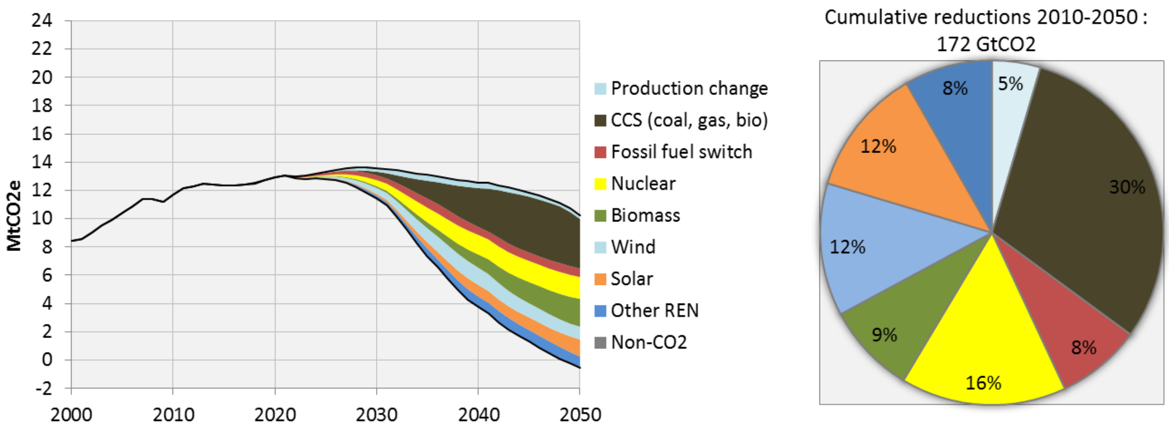
Whilst renewables undergo a significant expansion in the Reference scenario, they are further pushed by climate policies in the INDC and 2°C scenarios. In the INDC scenario renewables contribute to a third of the cumulative reductions from the power sector by 2050, ahead of CCS (a fourth, taking place beyond 2030), nuclear (a fifth) and switch from coal and oil to gas; further decarbonisation towards the 2°C scenario are achieved by renewables (41%), followed by CCS (30%), nuclear (16%) and further switch from coal and oil to gas.

Figure 54: World emissions mitigation options in the power sector (excl. LULUCF)

a) From Reference to INDC



b) From INDC to 2°C



Note: "Other REN" consists in hydro, geothermal and ocean power

From all these options, CCS is the only one not yet deployed at large scale nowadays, while appearing as a key option in the ambitious mitigation policies aiming at respecting the IPCC recommendations. The technology is subject to a number of uncertainties, with regards to cost, but also CO_2 transport and storage acceptability and sustainability. Pilot projects are being run in different regions: as of mid-2016 15 projects are in operation, 7 are under construction, and 18 additional are planned – most of the running projects are associated with enhanced oil recovery[48] (Global CCS Institute, 2015).

Would this technology not develop at large scale for technical and acceptability reasons, reaching ambitious mitigation objectives would entail even further energy efficiency as well as more renewables in the portfolio of mitigation options. The latter would likely come with more pressing questions on the sustainability of bioenergy production on the one hand and on the need to integrate even larger quantities of wind and solar into the electricity grid on the other hand.

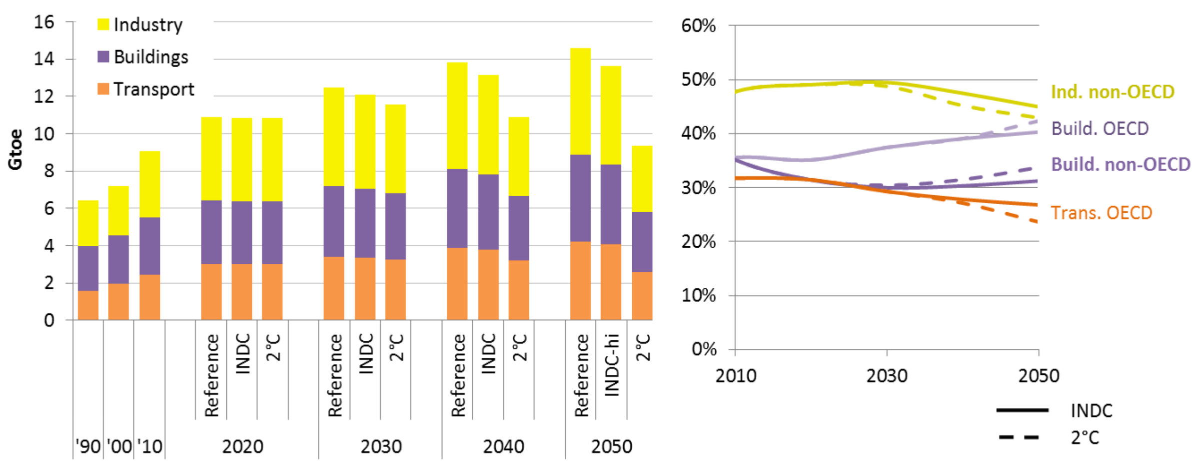
4.3 Final energy

4.3.1 Demand

With economic growth, rising living standards and increasing needs for mobility, final energy demand continues to grow in the future in all scenarios. After a decade with a high annual growth (2000-2010, 2.4%/year), energy efficiency improvements result in an decelerating growth of final energy demand in the future: 1.8%/year in the current decade for all scenarios; decreasing to 0.5%/year in 2040-2050 in the INDC scenario. Increasing energy efficiency efforts would even result in an overall final energy demand actually decreasing in the 2°C scenario after 2030.

Total final demand is projected to get close to 14 Gtoe in 2050 in the Reference and INDC scenarios; and decreases to 9.5 Gtoe in the 2°C scenario, the 2014 level. Non-energy use of energy fuels (for plastics and chemical feedstocks) increases slowly to 1.1 Gtoe in 2050 in the INDC scenario, compared to 0.8 Gtoe in 2014.

Figure 55: World final energy demand by sector (left), evolution of selected shares (right)



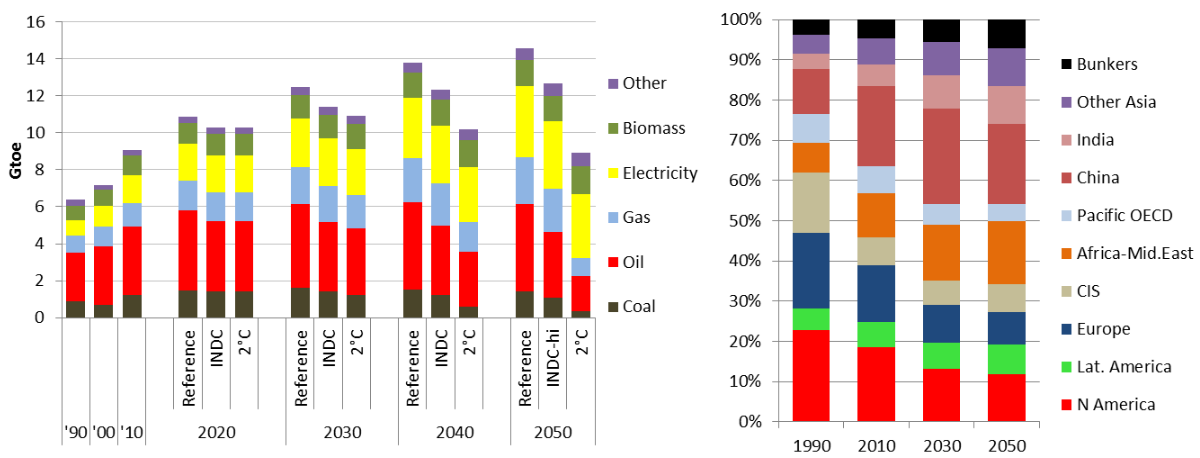
48 See:https://www.globalccsinstitute.com/projects/large-scale-ccs-projects#overview

The sectoral distribution of energy demand would remain fairly stable in the future and across all scenarios – at roughly 40% for industry (slightly increasing by 2030) and 30% each for buildings (slightly decreasing by 2030) and transport (slightly increasing over the whole period). In the 2°C scenario, sectoral shares in 2050 would be almost exactly equal to 2010: respectively 38%, 27% and 35%.

The different region would follow a somewhat different pattern. In OECD countries the transport final energy share decreases while the buildings one increases (both patterns are accentuated in the 2°C scenario). In non-OECD countries the industry share is decreasing from 2030 onwards, while the transport share increases steadily to almost a fourth of total demand by mid-century.

In terms of consumption per fuel, all scenarios suggest an acceleration of the historical electrification trend of final demand (share on total final demand up to 30%-40% depending on the scenario, vs. less than 20% in 2014) and, to a lesser extent, of biomass (around 15% of total), while coal reduces in volume as soon as climate policies are introduced. Oil and gas demand tend to maintain their shares by 2030, and then would reduce their contribution in the INDC and 2°C scenarios. The behaviour of oil is much linked to its role as a transport fuel, a sector characterised by growing needs of mobility, a fairly inelastic response to prices and low substitution possibilities especially for heavy vehicles and air transport (see section 4.1.4). Natural gas benefits first from its relatively lower carbon content compared to coal (and oil, in the industry sector) and thus acts as a transition energy vector, but then needs to reduce in the context of stringent climate policies in line with IPCC recommendations.

Figure 56: World final energy demand by fuel (left) and by region in the 2°C scenario (right)



In terms of the regional distribution of this final energy demand, the largest changes take place over 2010-2030, with the decrease of the shares of OECD countries and the increase for non-OECD countries, particularly China. Beyond 2030 the shares are more stable, with notable changes being a further increase of Africa-Middle East and changes within Asia (the share of China decreases as the shares of India and Other Asia increase). These trends are observed across all scenarios.

4.3.2 **Renewables**

The share of renewable energy in final gross demand[49] is projected to increase over time in all scenarios, including the Reference, for most regions (except where traditional biomass, a historically important energy source, is phased out in favour of cleaner and more efficient fuels, such as in India, South-East Asia or Sub-Saharan Africa).

Globally, in the INDC scenario the share of renewables grows at about three percentage point per decade, reaching 22% in 2030 and 28% in 2050 (vs. 18.5% in 2014); the 2°C exhibits a growth rate that is two to three times higher, reaching 24% in 2030 and then accelerating to 46% in 2050.

Table 16: Share of renewables in gross final demand, 2030, INDC scenario

	Total	Biomass	Hydro	Wind	Solar	Others
EU28	27%	16%	4%	5%	3%	1%
Australia	17%	10%	2%	4%	3%	0%
Canada	36%	11%	19%	5%	1%	0%
Japan	16%	7%	3%	3%	2%	0%
Korea (Rep.)	10%	5%	0%	3%	1%	0%
Mexico	20%	9%	3%	4%	3%	1%
USA	23%	13%	2%	6%	2%	0%
Rest of OECD	31%	9%	13%	4%	3%	1%
Russia	9%	4%	4%	0%	0%	0%
Rest of CIS	7%	4%	2%	1%	1%	0%
China	20%	9%	5%	4%	2%	0%
India	22%	16%	2%	2%	3%	0%
Indonesia	28%	25%	1%	1%	1%	1%
Rest of Asia	20%	15%	2%	1%	1%	1%
Argentina	15%	7%	5%	3%	0%	0%
Brazil	44%	22%	17%	4%	2%	0%
Rest of Latin America	27%	14%	9%	1%	2%	0%
North Africa	6%	2%	1%	2%	1%	0%
Sub-Saharan Af. (excl. SoA)	65%	61%	2%	1%	0%	0%
South Africa	20%	14%	1%	2%	2%	0%
Iran	1%	1%	1%	0%	0%	0%
Saudi Arabia	0%	0%	0%	0%	0%	0%
Rest of Middle-East	3%	0%	0%	0%	1%	0%
OECD	23%	12%	4%	5%	2%	0%
Non-OECD	21%	13%	4%	2%	2%	0%
World	22%	13%	4%	3%	2%	0%

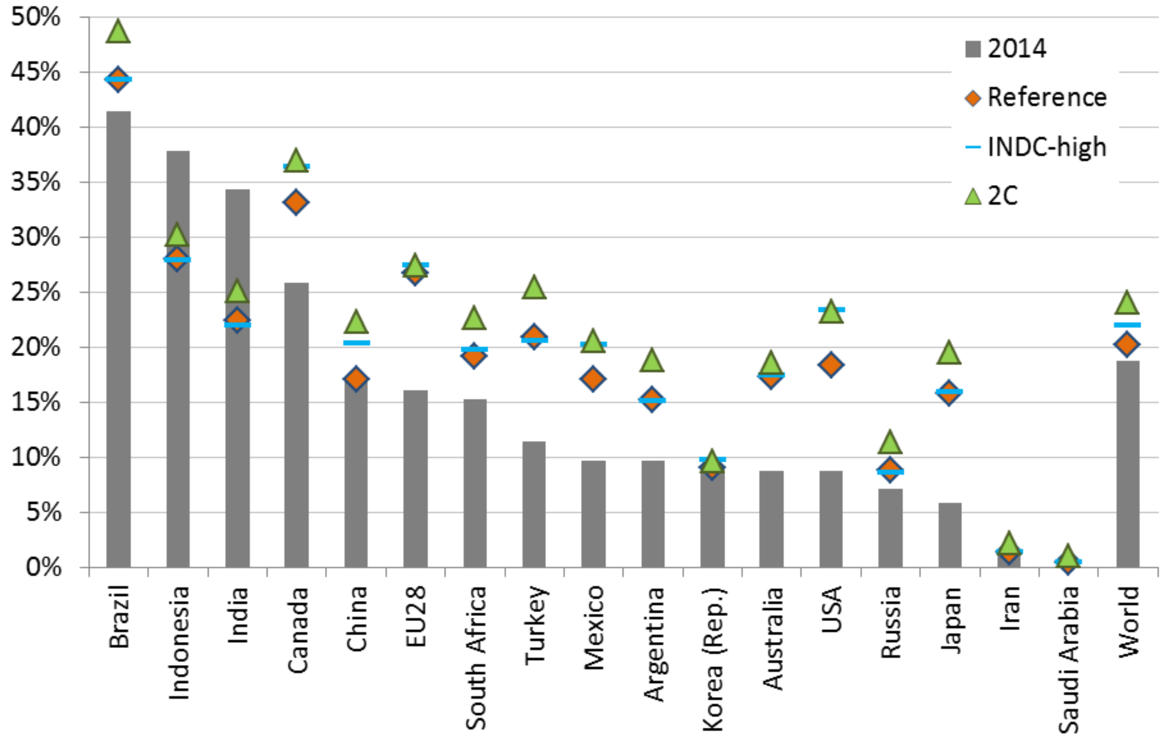
Note: The share in EU-28 follows the definition of the Directive 2009/28/EC (see EC (2009))

[49] Defined as the energy consumption of renewable origin as a share of final energy demand, including auto-consumption and transmission and distribution losses of the energy sector, and excluding non-energy uses of fuels

As renewables are deployed over time, the countries where the renewable share in the mix is most modified would be EU-28, USA, Japan and Turkey (increase of share in 2030 vs. 2014 in the Reference scenario). The implementation of INDC policies would bring the world in the half-way point towards the renewables share of the 2°C scenario; most impacted by the INDCs would be the USA, Canada, Mexico and China. Countries with low resource (South Korea) or low domestic energy prices (oil and gas exporters) see a more limited development.

About half of the increase across scenarios would come from additional direct biomass use, mostly in final demand sectors and especially in USA and Brazil, while the rest would be split among renewable electricity technologies.

Figure 57: Share of renewables in gross final demand, 2030, Reference, INDC and 2°C scenarios



Note: includes traditional biomass.

5 Variant scenarios

5.1 Low oil price variant

5.1.1 Rationale and definition

This section addresses a variant scenario analysing the potential impact of a low oil price future on long-term climate policies. The variant derives from the decrease of the global price of crude oil since the summer of 2014 that had not been seen since 2008, in the midst of the financial crisis when the price plummeted by almost 75% between July and December 2008. The steep fall in price then was followed by a steady recovery to high levels over 2009-2012, reaching around 120 $/bbl. The recent lowest value was reached in January 20th 2016 with 26 $/bbl (down from 108 $/bbl in June 20th 2014), with a slight recovery since to 49 $/bbl in June 6th 2016 (Figure 58).

Figure 58: Daily oil price, 2004-2015 (Brent, current $)

Source: US EIA[50], latest data point: 6th June 2016.

Most studies (for example: Baumeister and Kilian, 2016; Baffes et al 2015; Husain et al, 2015; Pflüger, 2015; Arezki and Blanchard, 2014) find that the oil price decline was driven by a combination of several factors, the most important being:

<u>1. Increased global oil production</u>: the development of US shale oil production increased global oil production. US production of crude oil increased by 72% from 2010 to 2015 (EIA 2016b), making this country the largest producer in the world surpassing Saudi Arabia and Russia. Likewise, higher-than-expected production in Iraq, Libya and Saudi Arabia may have affected oil prices since 2014. In particular, Saudi Arabia announced it was abandoning its role of "swing producer" for the oil market in November 2014, maintaining output 20% above 2010 levels.

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[50] http://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm

2. Moderate global oil consumption: lower-than-expected oil consumption may also have contributed to the drop in oil prices. Since mid-2014 economic growth has been weaker than expected in Europe and Asia, which, combined with policy measures aiming at spurring energy efficiency, led to a moderate demand evolution[51].

3. Crude oil inventories: the combined dynamics of supply and demand over the past two years translated into stocks changes unusually positive in 2014-2015 (almost 1 Mbl/d in 2014 and 2 Mbl/d in 2015, see IEA 2016a), signalling an abundantly supplied oil market.

4. US dollar exchange rate: oil is mainly traded in US $. This currency appreciated by 20-30% over the main currencies (Euro, Japanese Yen and Chinese Yuan) between 2014 and mid-2015 and made crude oil more expensive for the rest of the world, possibly affecting downwards oil demand.

Although the central reference case of this report incorporates a rebound of the oil price in the coming years due to a decreasing supply (mostly from OECD countries) and an increase of oil demand spurred by increased mobility of both goods and passengers (see section 0 and Figure 28), there is (obviously) still high uncertainty on the assessment of the future oil price.

As a consequence, this "low oil price" variant is examined to shed some light on the possible impacts on GHG mitigation policies by 2030 in the context of the UNFCCC 2015 Paris Agreement in the case of wider oil availability. Figure 59 shows the historical price until 2015, the average price over May 2016 (red dot), the central case and the low oil price variant. The latter will depend in particular on the capacity of the industry to sustain over time a reduction of exploration and production costs, especially for non-conventional liquids, while also adding new discoveries to cover for on-going production and to meet future demand. A long-term lasting low oil price will also imply a larger role for OPEC countries (where the cheapest resources are) in a context of tighter oil exports revenues for governments.

The impact on the policy cost, the energy balance and the GHG emissions is presented below. Complementary analysis on the effect of a lasting low oil price scenario can be found in Vrontisi et al. (2015) for Europe (economy) and in Kitous et al. (2016b) for oil exporting countries (political stability and economy).

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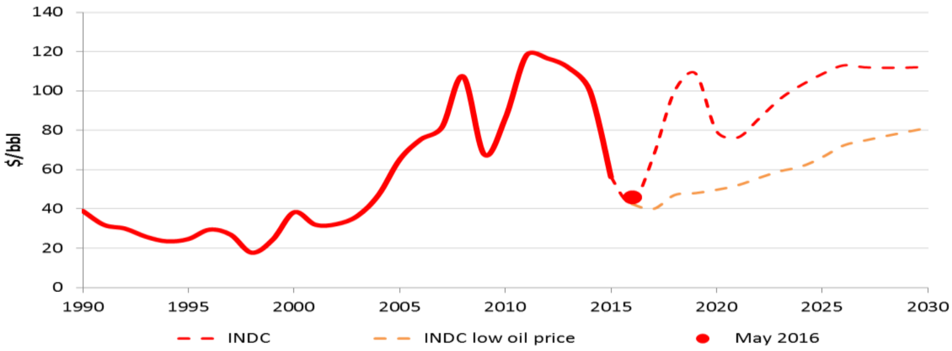
[51] Lower oil consumption can also result from a surge of cost-effective alternatives to conventional technologies, especially in the transportation sector where most oil is consumed. However, wide-scale substitution of oil by other fuels in vehicles has not yet materialised: in 2015 liquid biofuel represented around 2% of world liquid fuel consumption (IEA, 2016b), while electrical vehicles represented only 0.5% of total sales (US DOE (2016), OICA (2016)) and an even lower share of total vehicles in circulation.

Figure 59: Yearly oil price: INDC vs. INDC low oil price (Brent, $(2015))



Note: the graph shows the yearly oil price (Brent), the thick red line is history over 1990-2015, and the dot is the average price observed in May 2016[52].

5.1.2 Impact on the policy cost and the energy balance

The low oil price variant of the INDC scenario respects the national energy and GHG commitments of the central INDC case (see section 2.2).

Low oil price leads to higher oil consumption, which translates into higher CO_2 emissions in the transport sector. As a consequence, and in order to meet the 2030 GHG reduction commitments (INDCs), some countries have to implement higher carbon values than in the central case. Table 17 shows that this is the case for countries like the EU, USA, Australia, China, Mexico or Brazil. India still emits less than what appears in its INDC, and thus has no carbon value even with a low oil price.

Finally, in some cases the low oil price can lead to lower GHG emissions: this is the case for Canada, which faces lower oil production (and associated GHG emissions) in a low oil price world as low prices affect negatively its relatively more expensive and CO_2 intensive production[53]. As a consequence the carbon value required to reach in 2030 commitment appears lower than in the central case.

Table 17: Effect of the low oil price on the carbon value for INDC (2030)

	$(2015)/t$CO_2$	% difference with central INDC case
EU	68	35%
USA*	72	23%
CAN	31	-14%
AUS	28	5%
CHN	27	11%
IND	0	0%
MEX	57	50%
BRA*	5	138%

**: USA and BRA in 2025*

52 http://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm

53 For instance, in a context of lower oil price in 2016 (all scenarios), the oil production in Canada is expected to increase by only 1.5% in 2016 compared to 2015, while the compound yearly growth rate was 7% over 2010-2015 (NEB, 2016).

Table 18 provides the overall impact of the low oil price on the simplified world energy balance and the GHG emissions. It clearly shows the increased oil demand compared to the central case (+12%), mostly in non-OECD (+14%) and to a lesser extent in also OECD (+8%).

This is partially offset by a reduction in coal use due to the higher carbon value applied on all GHG emissions: -6% at world level and -17% for the OECD, which face most of the INDC-related emission reductions.

Energy-related CO_2 emissions stay the same in OECD, since these countries respect constraining emission commitments, but the sectoral distribution is different: a lower oil price entails higher emissions from transport and from buildings than in the central case (respectively +5% and +4%), which is compensated by lower emissions in the power sector (-6%) due to the higher carbon value than in the central case. In non-OECD, since a large share of emissions are not covered by mitigation policies, the CO_2 emissions increase in all sectors except the power sector, with total energy-related CO_2 being +4% higher than in the central case.

As a result, world energy-related CO_2 emissions and GHG emissions are respectively 3% and 2% higher than in the central case (by about 1 $GtCO_2e$), even though the INDC quantitative emission reduction objectives would still be met in the relevant countries.

Table 18: Effect of the low oil price on energy demand and CO_2 emissions (2030)

		INDC low oil price			% difference with central INDC case		
		World	OECD	Non-OECD	World	OECD	Non-OECD
Primary energy (Gtoe)	Total*	17.8	5.3	11.8	3%	1%	4%
	Oil*	5.6	1.5	3.3	12%	8%	14%
	Gas	4.2	1.3	2.9	4%	2%	5%
	Coal	3.9	0.5	3.3	-6%	-17%	-4%
	Others	4.2	1.9	2.3	-2%	-1%	-2%
Energy CO_2 ($GtCO_2$)	Total	38.6	9.0	27.3	3%	0%	4%
	Power	13.2	2.7	10.5	-1%	-6%	0%
	Transport	9.6	2.7	4.6	8%	5%	9%
	Industry	8.4	1.4	7.0	3%	0%	4%
	Buildings	3.6	1.4	2.2	6%	4%	8%
	Others	3.9	0.9	3.0	3%	-1%	4%
GHG emissions ($GtCO_2e$)	Total (excl. sinks)	55.3	11.4	41.6	2%	0%	2%

** World figures also include international bunkers*

In conclusion, a sustained oil price would result in INDC commitments to become more difficult to achieve in certain countries, while it would lead to higher GHG emissions at the global level in 2030, due to increased oil consumption in countries without constraint, making it a bit more difficult to meet 2°C objective.

5.2 Energy subsidies phase out

This section analyses in the context of the Paris Agreement the possible role of a phase-out of energy-related subsidies in terms of evolution of GHG emissions[54].

5.2.1 Definition

Energy subsidies are defined, within our modelling approach, according to the following:

$$Subsidy_{fuel,sector} = Max\left(0, Reference\ price_{fuel} - Sectoral\ price_{fuel,sector}\right) \times Energy\ consumption_{fuel,sector}$$

Fuel: oil, gas, coal

Sector: transport, industry, residential-services, other

This definition is similar to the price-gap approach of the IEA (2016b) or to the pre-tax subsidy definition used in a 2015 IMF working paper (see Coady D. et al. 2015). Reference prices per fuel are derived from: the import price for importing countries (when informed); the export price for exporting countries (when informed); the closest regional market price (when import price or export price is not informed). The cost of fuel distribution and the value-added tax are also added[55].

The subsidy ratio is defined as:

Sectoral price / Reference price

A ratio lower than 1 translates into a subsidy. The default assumption in the modelling is that, when lower than 1 historically, this ratio is kept constant over time[56]: subsidized sectoral prices are thus affected by changes in the international prices proportionally to their situation in the last data point (2012-2014 depending on the country, sector and fuel). In the subsidy phase-out variant scenario, the subsidy ratio progressively moves to 1 in 2030, at which point the sectoral prices are equal to their reference prices.

This additional taxation policy is applied on top of the energy and climate policies considered in the different scenarios presented in section 2.2 above: Reference scenario, INDC scenario, 2°C scenario.

5.2.2 Results

The results below give the evolution of the subsidy ratio, of energy demand and GHG emissions for the following regional aggregates: world, OECD countries, non-OECD

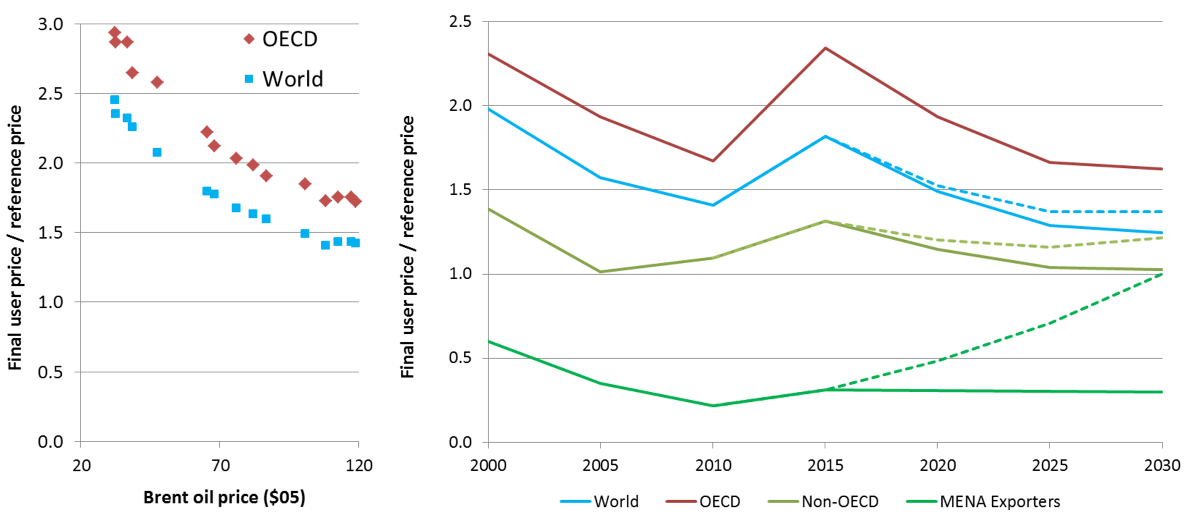
[54] This is a difference with the GECO 2015 report, where subsidies to fossil fuels were assumed to be progressively phased-out by 2050 in all scenarios: in the GECO2016 central scenarios they are assumed to be held constant (in ratio); their phase-out is explored in this section.
[55] See also section 2.2.1
[56] If there is no subsidy, i.e. when the domestic sectoral price is higher than the reference price, then the sectoral price follows the evolution of the reference price according to the country / sector / fuel taxation structure (partially in relative terms and partially in volume).

countries and the main oil and gas exporters from Middle-East and North-Africa (MENA)[57]: (these countries represented about 50% of the total crude net exports in 2014 – see BP (2015), Enerdata (2015)).

Figure 60 shows the price ratio for oil consumption, averaged across the different sectors (transport, industry and buildings) and at regional level. The left graph gives the historical evolution of the same ratio (for world and OECD) plotted as a function of oil price (Brent) over 2000-2014: it shows that the structure of energy taxes leads to a higher ratio at times of lower prices. The right graph shows the time evolution over 2000-2030 for the central case (without subsidy phase-out; i.e. the Reference scenario) and for the case with subsidy phase-out by 2030.

The end-use prices would stay well above international prices (value of 1) in OECD countries by 2030 (the ratio could even decrease over time since the oil price is increasing – see section 0), and on average slightly above 1 for non-OECD countries. However, these prices are lower than 1 for MENA oil exporters, and would remain so throughout all the period in the central case. The subsidy phase-out (the dotted lines) translates for this later group of countries into final user prices converging progressively towards the international prices by 2030 (adjusted by the assumption of a progressive introduction of value-added tax in some sectors[58]).

Figure 60: Oil subsidy ratio: vs. oil price over 2000-2014 (left), 2000-2030 (right)



Note: the graph shows the ratio between the final user price and the reference price for oil averaged over all final sectors: transport, industry, buildings, and countries. MENA stands for Middle-East and North Africa. 1 = reference price. Plain lines: no subsidy phase-out (here, Reference scenario). Dotted lines: subsidy phase-out case.

Table 19 shows the extent to which a phase-out of energy subsidies would have a downward effect on world energy demand compared to the central case (around -4%), mostly felt in non-OECD energy exporters (-20%), where subsidies are essentially to be found. Oil and gas consumption in 2030 would be lower by around 7% at world level, by 25% in the MENA exporters. This would translate into lower GHG emissions due to a

[57] Algeria, Iraq, Iran, Libya, Qatar, Kuwait, Oman, Saudi Arabia, United Arab Emirates
[58] The Gulf Cooperation Countries agreed in early 2016 to introduce some value added taxation of about 5% by 2018 – see http://www.reuters.com/article/gulf-tax-vat-idUSL8N14Y1Y520160114

decrease of energy-related CO_2 emissions (around -5% at word level, -6% on average for non-OECD, -20% for MENA exporters). The effect is virtually the same in the Reference scenario and in the INDC scenario, which is consistent with MENA exporters having little constraining climate policy.

Table 19: Energy subsidy phase-out on energy demand and GHG emissions (2030)

		Reference	INDC
Primary energy, total	World	-4%	-4%
	OECD	0%	0%
	Non-OECD	-5%	-5%
	of which MENA oil exporters	*-21%*	*-21%*
Primary energy, Oil & Gas	World	-7%	-7%
	OECD	1%	0%
	Non-OECD	-12%	-12%
	of which MENA oil exporters	*-25%*	*-25%*
CO_2 emissions (energy)	World	-5%	-5%
	OECD	0%	0%
	Non-OECD	-7%	-7%
	of which MENA oil exporters	*-20%*	*-21%*
GHG emissions (excl. sinks)	World	-4%	-4%
	OECD	0%	0%
	Non-OECD	-5%	-5%
	of which MENA oil exporters	*-17%*	*-17%*

Note: Comparison of a subsidy phase-out by 2030 with the central case (that considers a constant subsidy ratio over time)
Note: MENA: Middle East and North Africa

Phasing out energy subsidies at world-wide level by 2030 would thus contribute positively to reducing global GHG emissions at this time horizon. As shown in Table 20, this single policy measure would achieve emission reductions of energy CO_2 close to 47% (30% for total GHG emissions, respectively) of the world emission gap between the Reference scenario and the INDC scenario, and 25% (16%) between the Reference scenario and the 2°C case.

However, as expected, the contribution to emission reductions would greatly vary across countries: it is very important in oil and gas exporting countries (where it would amount to the expected CO_2 or GHG reductions of the 2°C scenario compared to the Reference scenario) and very little in OEDC countries, consistently with the level of energy subsidy in the different regions.

The phase-out of fossil fuel subsidy would not replace, as such, the formulated contributions to GHG reductions of energy importing countries (some displaying already ambitious climate objectives), but rather prove a useful policy tool for oil and gas exporters that are willing to embark on a 2°C trajectory. Additional benefits from such a policy are reallocating fossil fuel resources from domestic consumption to export markets and reducing pressure of subsidies on Government revenues.

Table 20: Implied contribution of subsidy phase-out to emission gap (world)

		Reference - INDC	Reference - 2°C
Energy CO_2	World	47%	25%
	OECD	1%	1%
	Non-OECD	79%	33%
	of which exporters	ns	91%
All GHGs (excl. sinks)	World	30%	16%
	OECD	1%	1%
	Non-OECD	45%	19%
	of which exporters	ns	68%

In conclusion, it seems that a phase-out of fossil fuel subsidies by 2030 would definitely lead to lower GHG emissions at the global level in 2030 by 2 $GtCO_2e$ in the INDC context, and move the world closer to the objective of remaining below 2°C in the long term.

6 Macroeconomic impacts

Climate-protecting policies will affect different sectors throughout the whole economy. This is illustrated by the sectoral contributions to greenhouse gas emission reductions in Section 3.4.1. In addition to the role of energy as primary production function in many economic sectors, the sectors are also interlinked via intermediate supply chains and energy is used alongside other inputs in the production process, such as labour. This section widens the study framework and focuses on the economy-wide abatement costs implied by climate change mitigation policies.

While this report focuses on the cost of mitigation policies, the JRC is also carrying out research related to detailed bottom-up evaluation of costs of climate change impacts and adaptation (see Ciscar et al. 2014).

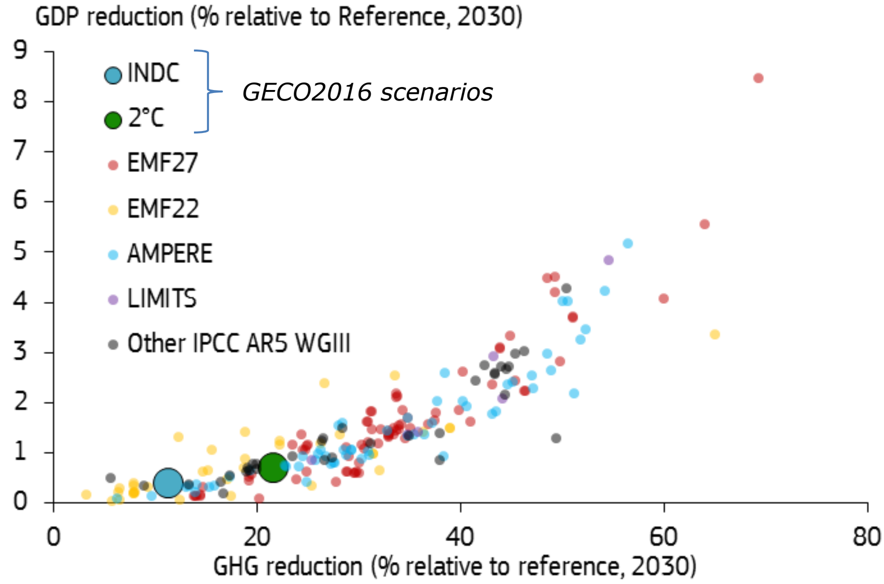
Policies envisaging a shift away from fossil fuels will entail also a transformation of the structure of production and consumption. As a result, mitigation policies will have an impact on macro-economic variables, such as Gross Domestic Production (GDP), terms of trade and aggregated demand of production sectors. This section presents an assessment of the macro-economic impact of the INDCs and of the 2°C scenario in comparison with the Reference, as laid out in Section 2.2. The results presented here derive from an analysis with the JRC-GEM-E3 model, for which the details and the explanation of the regional aggregation are provided in Annex 3. Economic impacts are summarized first in terms of changes in the global aggregate production level (global GDP). Next, this result is disaggregated by region and by component (consumption, trade, investments) and discusses the changes in employment by sector.

Two variants of the scenarios are considered. The first variant assumes that climate policies are implemented via grandfathered emission permits, except from the sectors covered by the EU Emission Trading System for which the implemented approach of auctioned permits is considered. Fiscal neutrality of the policies is prescribed by lump sum taxes or transfers. The alternative scenario includes carbon taxes. The revenue raised by these taxes is recycled (again in a budget-neutral way) by lowering existing distortionary taxes. In line with the UNFCCC's 'common but differentiated responsibilities', recycling schemes can be region-specific, which is illustrated in this alternative scenario. Both variants do not consider emission permit trade across regions. The main scenario inputs are the trajectory of GHG emissions and the shares of electricity generation technologies per region based on the analysis with respect to the Reference presented in previous sections (Section 3 and Section 4.2).

Figure 61 shows the impact of climate mitigation policies on the global aggregate of GDP as a percentage difference from the relevant Reference scenario in 2030. The GDP impact of the INDC (0.4%) and the 2°C (0.7%) scenarios are presented alongside the results (of the models with endogenous GDP) included in the IPCC's Fifth Assessment Report (IPCC 2014). While the emission reduction compared to the Reference in 2030 roughly doubles (from 11.2% in the INDC scenario to 21.6% in the 2°C scenario), the GDP impact does not increase by the same proportion. An important driver of this result is the set-up of the 2°C scenario, in which converging carbon values by 2030 (to two levels, one for high-income regions and one for low-income regions, as explained in Section 2.2.4) implies enhanced efficiency vis-à-vis the INDC scenario.

In general terms, the size of the abatement cost is relatively small: below 1% of global GDP. In terms of annual growth rates, this would mean an impact of less than 0.1% of annual growth as a global average (from nearly 3% per year in the Reference to 2.9% per year in the 2°C scenario over the 2020-2030 period). To frame this result, consider the following: the global aggregate level of production of the Reference in 2030 is reached in the 2°C scenario approximately four months later. Hence, the 2°C scenario would be definitively consistent with robust economic growth.

Figure 61: Impact on global aggregate GDP



Source: IPCC AR5 database for EMF27, EMF22, AMPERE, LIMITS, Other

A substantial degree of regional differentiation lies behind the global estimates presented above. Figure 62, Figure 63 and Table 21 present the highly detailed region-specific results of the INDC and the 2°C scenarios in terms of GDP changes compared to the Reference (% difference) in 2030. The visual representation in Figure 62 plots the greenhouse gas reductions against the impact on GDP and provides an intuitive initial overview of the macro-economic results. Unsurprisingly, a stronger shift away from the Reference emission trajectory implies more substantial economic changes, hence a larger impact on GDP. A number of additional insights are worthwhile mentioning.

The INDCs in a number of regions lead to emissions levels that are close to the levels of the Reference. Consequently, the GDP change for these regions is negligible. For Russia (RUS) and India (IND), GHG emissions in the INDC scenario are even slightly higher than in the Reference, implying an improvement of the GDP of these countries. Global demand for oil and gas, important export products for Russia, are hardly affected in the INDC scenario, as discussed in Section 4.1. For Central Asia and Caucasus (CASC), mitigation efforts entail a loss of competitiveness in the agricultural sector, driving down exports and GDP.

The 2°C scenario results confirm that lower levels of global fossil fuel consumption would affect fossil fuel-producing countries such as Russia (RUS), Saudi Arabia (SAU) and North Africa (NOAF). For a number of regions (New Zealand, USA, and EU), the mitigation action in the INDC is relatively ambitious, such that no additional effort is required to reach a 2°C trajectory. Consequently, the economic impact between the two scenarios is very similar. India is among the low-income countries for which carbon values converge to a lower level. As a result, India's competitiveness improves relative to other regions, leading to a positive impact on GDP.

Figure 62 is insightful to understand the GDP results, but expressing the GHG emission reductions as a difference with the Reference – including policy measures that are already in place – conceals the efforts covered by existing policies. This is particularly relevant for the EU, where the 20-20-20 targets imply substantial GHG reductions compared to historical levels of emissions. Therefore, Figure 63 plots the GDP impact (compared to Reference in 2030, as before) against GHG emission reductions compared to levels of 2010. The ambitious effort in the INDCs of high-income countries regions such as USA and EU becomes apparent. In addition, this representation illustrates that the 2°C scenario leaves scope for fast-growing low-income regions such as China (CHN), India (IND) and Sub-Saharan Africa (SSAF) to increase the levels of GHG emissions compared to 2010.

Figure 62: The extent of emission reduction from the Reference drives the GDP impact

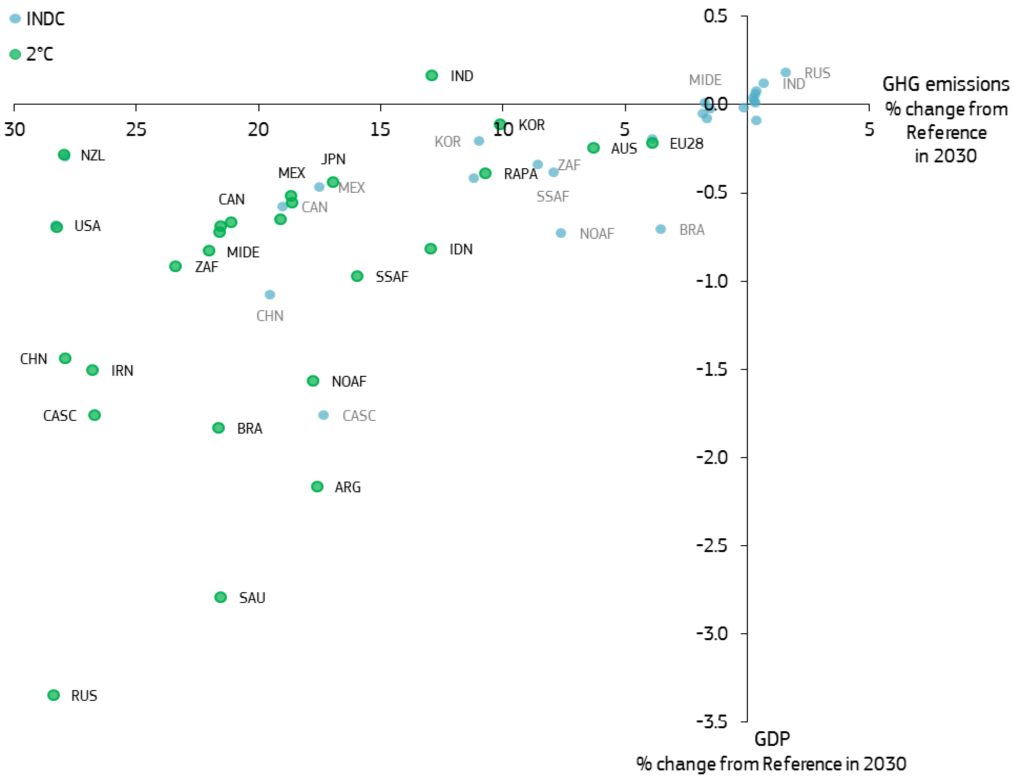
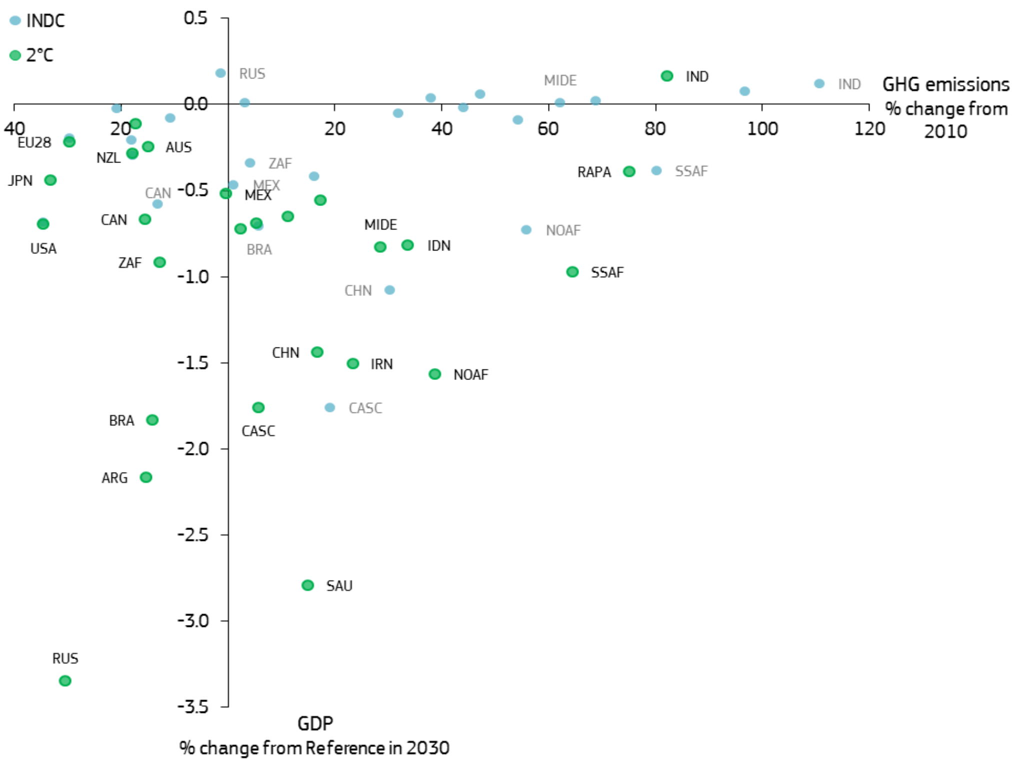


Figure 63: Emission reductions compared to 2010 levels and GDP impact in 2030



Raising revenues from carbon taxation is an opportunity to reduce existing distortions through the present tax system in many countries. Table 21 shows the GDP results by region for both scenarios and highlights how these results are affected by the implementation via carbon tax recycling.

Table 21: Impact of mitigation policies on GDP (2030, % change from Reference)

Difference (%) with Reference in 2030	INDC			2°C		
	GHG	*GDP*		*GHG*	*GDP*	
		Without tax recycling	With tax recycling		Without tax recycling	With tax recycling
World	-11.2	-0.4	-0.2	-21.6	-0.7	-0.4
EU28	-3.8	-0.2	0.0	-3.8	-0.2	0.0
USA	-28.3	-0.7	-0.6	-28.2	-0.7	-0.6
RUS*	1.6	0.2	0.7	-28.4	-3.3	-1.9
CAN	-19.0	-0.6	-0.5	-21.1	-0.7	-0.6
JPN	-1.5	0.0	0.0	-16.9	-0.4	-0.4
AUS	-1.6	-0.1	-0.1	-6.3	-0.2	-0.3
CHN*	-19.5	-1.1	-0.4	-27.9	-1.4	-0.6
IND*	0.7	0.1	0.0	-12.9	0.2	0.0
IDN*	0.4	-0.1	-0.1	-12.9	-0.8	-0.4
BRA*	-3.5	-0.7	0.4	-21.6	-1.8	0.0
KOR	-10.9	-0.2	-0.1	-10.1	-0.1	0.0
ANNI	-1.8	-0.1	0.0	-21.5	-0.7	-0.6
MEX*	-17.5	-0.5	-0.4	-18.6	-0.5	-0.4
ARG*	0.3	0.0	2.0	-17.6	-2.2	1.2
NOAF*	-7.6	-0.7	-0.4	-17.7	-1.6	-0.6
NZL	-27.9	-0.3	-0.3	-27.9	-0.3	-0.3
SAU*	0.3	0.1	0.3	-21.5	-2.8	-1.5
IRN*	0.3	0.0	0.1	-26.8	-1.5	-1.0
ZAF*	-8.5	-0.3	0.0	-23.4	-0.9	-0.4
MIDE*	-1.7	0.0	0.1	-22.0	-0.8	-0.7
SSAF*	-7.9	-0.4	-0.1	-15.9	-1.0	-0.5
CSAM*	-0.1	0.0	0.0	-18.6	-0.6	-0.3
CASC	-17.3	-1.8	-1.6	-26.7	-1.8	-1.6
SEAS*	0.3	0.0	0.1	-19.1	-0.7	-0.1
RAPA*	0.4	0.1	0.1	-10.7	-0.4	-0.4

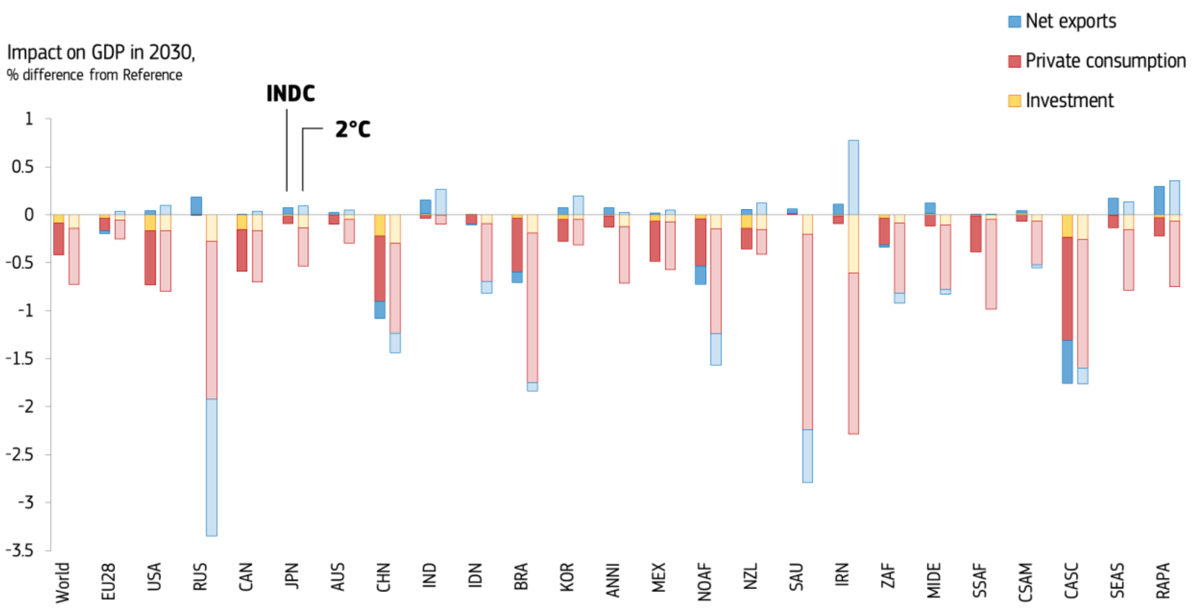
*Note: The tax recycling scenario considers the case where revenue raised from carbon taxes is recycled by lowering other distortionary taxes. In particular, labour taxes are reduced for high-income regions, while indirect taxes on investment and consumption are lowered for the regions with a * in the first column.*

Two different ways to recycle the revenues of carbon taxes are considered[59]. For high-income countries, where labour income taxes are typically an important source of government revenue, the additional funds raised from carbon taxes could be used to lower the tax on labour income. The second recycling scheme considers a lowering of the indirect taxes on consumption and investment (regions where this option is implemented are indicated by a * in Table 21). Framing climate policy in the more general context of a green fiscal reform of the tax system can indeed be advantageous, as illustrated by the results in Table 21. On a global level, the GDP impact is reduced from -0.4% to -0.2% in the INDC scenario, and from -0.7% to -0.4% in the 2°C scenario. For Brazil (INDC) and Argentina (2°C), positive GDP results are reconciled with lower GHG emissions, indicating the potential for a 'double dividend'. India (IND) is a particular case where part of the gains in competitiveness in the scenario without recycling is now offset by more efficient implementation in other regions. In general, the results indicate that an implementation tailored to the specifics of different regions can be beneficial and efficiency-enhancing.

To better understand the driving factors behind the GDP results, Figure 64 presents a decomposition of the total GDP impact into private consumption, investment and trade for both the INDC and the 2°C scenario (for the case without tax recycling). The figure is constructed in such a way that the sum of the three components matches the percentage change in GDP as reported in Table 21.

The changes in net exports (exports minus imports) reflect changes in relative competitiveness of regions and countries. The INDC scenario illustrates improvements in terms of trade of Russia (RUS), India (IND) and a number of other regions. This is due to the varying levels of ambition reflected in the INDCs.

Figure 64: Decomposition of the GDP effects in the INDC (left bars) and 2°C (right bars) scenarios, % difference from Reference in 2030



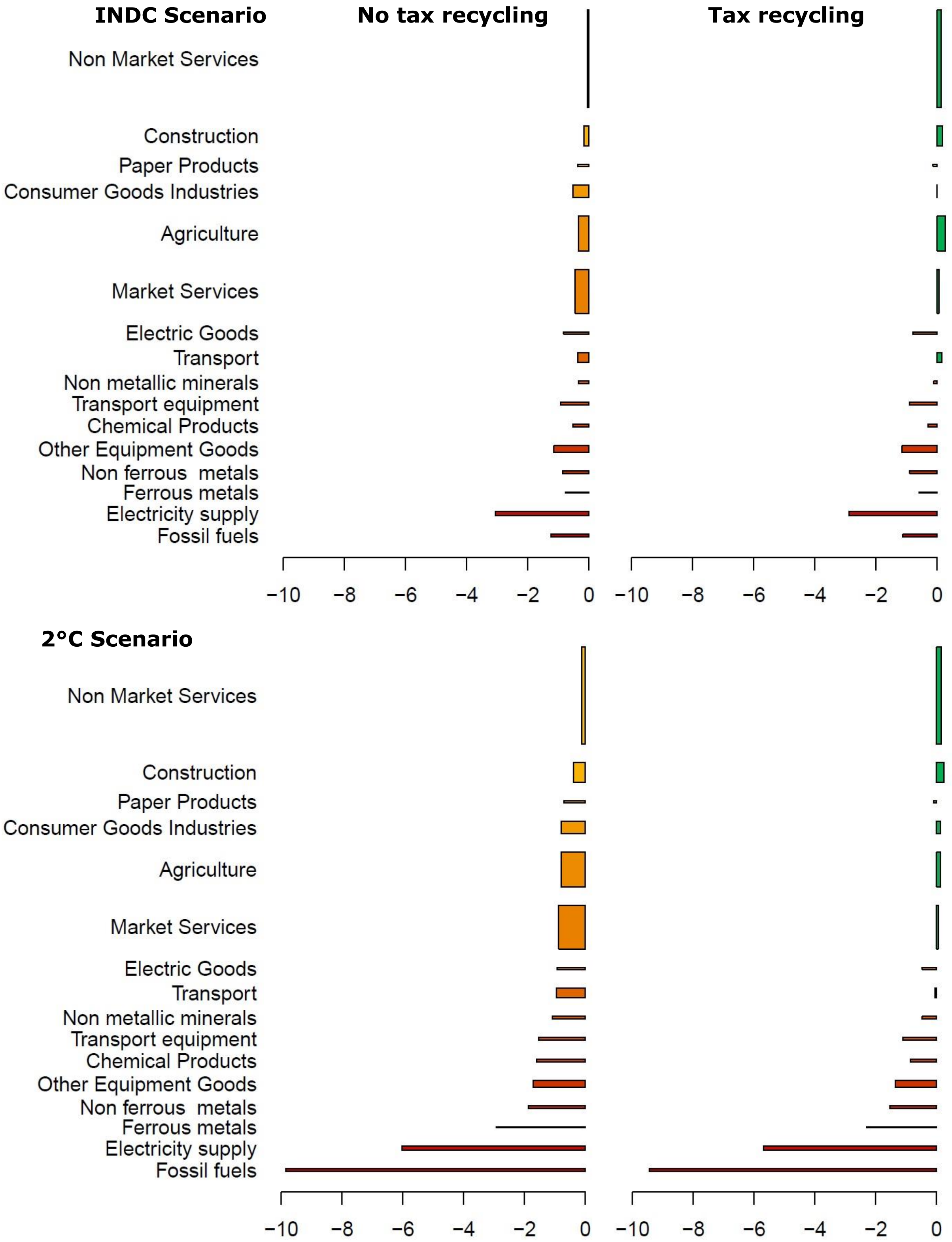
[59] Excluding cases where carbon tax revenues were negative after general equilibrium interactions.

Aggregate consumption is an important variable to consider, as it is linked more closely to the concept of economic welfare. Since consumption is one of the major contributors to GDP, it is no surprise that changes in consumption are an important driver of the overall GDP impacts. In the case without revenue recycling schemes shown here, the changes in consumption level are negative in all regions in both scenarios.

The third component of GDP is investment. In the current modelling set-up, investment needs are closely linked to the evolution of GDP: higher levels of production raise the demand to expand the existing stock of capital. As a consequence, investment is reduced for most regions in both scenarios. However, a number of caveats apply. The necessary investments to improve energy efficiency of households' durables, such as cars and heating systems, are not represented explicitly in this version of the model. In addition, a bottom-up representation of specific capital vintages in the energy, the electricity generation and the transport sectors are not included. More details on investments related to energy supply and transformation and the power sector can be found in Sections 4.1.10 and 4.2.3 respectively.

Figure 65 presents the impact on employment by sector on a global level. Overall, the scenarios that consider carbon tax revenue recycling by lowering existing taxes (right-hand side) illustrate that reducing GHG emissions can be close to neutral in terms of employment: -0.01% and -0.17% in the INDC and 2°C scenarios respectively, compared to the Reference in 2030. Without complementary measures to stimulate other sectors of the economy (left-hand side of Figure 65), the results indicate a negative employment impact in all sectors on a global average. However, Figure 65 illustrates that a number of important sectors for employment (services, agriculture; the height of the bars is scaled to represent employment by sector in the Reference in 2030, such that the surface of the bars represents the change in the absolute number of jobs) are not the sectors among those most affected. Energy efficiency leads to a reduction of employment in the energy sectors (fossil fuels and electricity). In the 2°C scenario, a shift away from fossil fuels is also reflected in employment results. The results for the scenarios where carbon tax revenue recycling is considered clearly illustrate a transition of jobs away from fossil fuel and energy-intensive sectors into low-carbon, service-oriented sectors, illustrating the transformation in global economic structure implied by climate change mitigation policies.

Figure 65: Global employment impact by sector, % difference from the Reference in 2030



Note: The height of the bars is scaled to employment by sector in the Reference in 2030. The width of the bars show the percentage change in employment compared to the Reference in 2030 (horizontal axis), such that the bar surface represents the change in employment compared to the Reference in absolute numbers.

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List of abbreviations and definitions

Acronyms & Abbreviations

AR5: Fifth Assessment Report of the IPCC

BAU: Business As Usual

BECCS: Bio-Energy combined with Carbon Capture and Sequestration

BGR: German Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe)

BTL: Biomass-To-Liquids

CCS: Carbon Capture and Sequestration

COM: Communication from the European Commission

COP: Conference Of the Parties

CTL: Coal-To-Liquids

DOE: US Department Of Energy

EC: European Commission

EFTA: European Free Trade Association

EIA: US Energy Information Administration

GDP: Gross Domestic Product

GECO: Global Energy & Climate Outlook

GHG: Greenhouse Gases

GTAP: Global Trade Analysis Project

GTL: Gas-To-Liquids

IEA: International Energy Agency

IIASA: International Institute for Applied Statistical Analysis

IMF: International Monetary Fund

INDC: Intended Nationally Determined Contribution

IPCC: Intergovernmental Panel on Climate Change

JRC: European Commission Joint Research Centre

LNG: Liquefied Natural Gas

LULUCF: Land Use, Land Use Change and Forestry

MER: Market Exchange Rate

NDC: Nationally Determined Contribution

NEB: Canada National Energy Board

OECD: Organisation of Economic Co-operation and Development

OICA: Organisation Internationale des Constructeurs d'Automobiles

OMR: IEA Oil Monthly Report

PPP: Purchasing Power Parity

RCP: Representative Concentration Pathway

REN: Renewable Energy

UN: United Nations

UNFCCC: United Nations Framework Convention on Climate Change

USGS: US Geological Survey

WG I, II, III: Working Group I, II, III of the IPCC

WMO: World Meteorological Organization

Country and regional codes

Africa - Middle-East: MENA, South Africa and SSAF

ANNI: Rest of Europe (Europe except EU28) and Turkey

ARG: Argentina

AUS: Australia

BRA: Brazil

CASC: Central Asia and Caucasus; see Rest of CIS

CAN: Canada

CIS: Commonwealth of Independent States

CHN: China

CSAM: Rest of Central and South America (Chile, Rest of Latin America)

EFTA: Iceland, Liechtenstein, Norway, Switzerland

EU28: European Union

Europe: EU28, EFTA, Other Balkans (Albania, Bosnia-Herzegovina, Kosovo, Macedonia, Montenegro, Serbia)

IDN: Indonesia

IND: India

IRN: Iran

JPN: Japan

KOR: South Korea

Latin America: Argentina, Brazil, Chile, Mexico, Rest of Latin America

LDC: Least Developed Countries (UN definition, mostly countries from Sub-Saharan Africa and South Asia)

MENA: Middle-East North Africa (Algeria, Egypt, Iran, Libya, Morocco, Turkey, Tunisia, Saudi Arabia, Rest of Middle-East)

MEX: Mexico

MIDE: see Rest of Middle-East

NOAF: North Africa (Algeria, Egypt, Libya, Morocco, Tunisia)

North America: Canada, USA

NZL: New Zealand

Pacific OECD: Australia, Japan, Korea (Rep.), New Zealand

OECD: OECD countries (as of 2010)

Other Asia: Rest of Asia, excluding Indonesia

RAPA: Rest of Asia and Pacific (Afghanistan, Bangladesh, Bhutan, Korea (PR), Macau, Maldives, Mongolia, Nepal, Pakistan, Sri Lanka)

Rest of Asia: Indonesia, Malaysia, Thailand, Vietnam, Rest South Asia (Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka), Rest South-East Asia (Brunei, Cambodia, Hong-Kong, Lao PDR, Macau, Mongolia, Myanmar, Korea (PR), Philippines, Singapore, Taiwan), Rest Pacific (Fiji Islands, Kiribati, Papua New Guinea, Samoa (Western), Solomon Islands, Tonga, Vanuatu)

Rest of CIS: Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyz Rep., Moldova, Tajikistan, Turkmenistan, Ukraine, Uzbekistan

Rest of Latin America: Central America (Bahamas, Barbados, Belize, Bermuda, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, NL Antilles and Aruba, Panama, St Lucia, St Vincent and Grenadines, Trinidad and Tobago), Rest South America (Bolivia, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela)

Rest of Middle-East: Bahrain, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Syria, United Arab Emirates, Yemen

Rest of OECD: Chile, Iceland, New Zealand, Norway, Switzerland, Turkey

RUS: Russian Federation

SAU: Saudi Arabia

SEAS: South-East Asia (Brunei, Cambodia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Taiwan, Thailand, Vietnam)

SSAF: Sub-Saharan Africa (Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Congo DR, Cote d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe)

UAE: United Arab Emirates

USA: United States of America

ZAF: South Africa

Units

Energy

EJ	Exajoule	1000 000 000 000 000 000 J
toe	tonne of oil equivalent	
ktoe	thousand tonnes of oil equivalent	1000 toe
Mtoe	million tonnes of oil equivalent	1000 000 toe
Gtoe	giga tonnes of oil equivalent	1000 000 000 toe
Mbl/d	million barrels per day	1000 000 bl/d
Tbl	tera barrels	1000 000 000 000 bl

Electricity

GW	gigawatts	1000 000 000 W
TWh	terawatt-hours	1000 000 000 000 Wh

Prices

$/bbl $ per barrel of oil

$/boe $ per barrel of oil equivalent

Emissions

$MtCO_2e$	million tonnes of CO_2	1000 000 tCO_2
$GtCO_2e$	giga tonnes of CO_2	1000 000 000 tCO_2

Monetary units

k$	thousand dollars	1000 $
M$	million $	1000 000 $
bn$	billion $	1000 000 000 $
tn$	trillion $	1000 000 000 000 $

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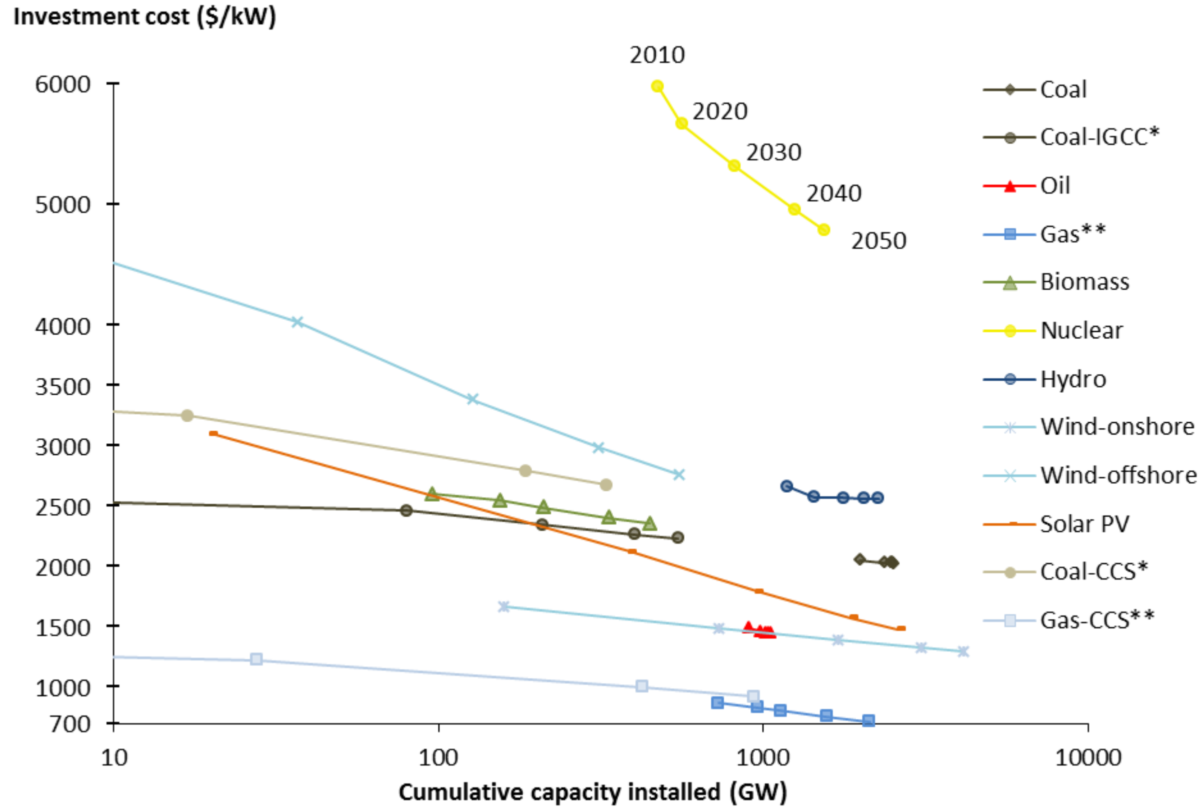
Annex 1 Power production techno-economic assumptions

Power generation technologies are represented with a full techno-economic description, with fixed investment costs, operation and maintenance costs, efficiencies and fuel costs. Investment costs are calculated by learning curve functions, linking cumulated installed capacities with unit investment cost. The resulting investment costs over time and installed capacities are endogenous and specific to each scenario.

Figure 66: Learning curves for power production technologies in the 2°C scenario



Note: Starred technologies (and ** for coal and gas, respectively) benefit from learning of technologies both without and with CCS.*

Figure 66 shows investment costs for selected technologies and how they evolve with cumulated installed capacities. In the case of technologies without and with CCS, both options technologies benefit from learning in the other, i.e. learning happens with the cumulative capacities summed over both options.

Table 22 provides the investment costs for selected power generation technologies in the GECO2016 scenarios.

Table 22: Overnight investment costs for selected power production technologies in the 2°C scenario ($/kW)

Technology		2010	2020	2030	2040	2050	Learning rate
Coal	Conventional thermal turbine	2100	2000	2000	2000	2000	2.0%
Coal-IGCC*	Integrated coal gaseification	2900	2500	2300	2300	2200	3.5%
Oil	Conventional thermal turbine	1500	1500	1500	1400	1400	11.2%
Gas**	Combined cycle gas turbine (CCGT)	900	800	800	800	700	12.4%
Biomass	Conventional thermal turbine	2600	2500	2500	2400	2400	5.0%
Nuclear	Pressurised water reactor (Generation III/III+)	6000	5700	5300	4900	4800	10.9%
Hydro	Large hydro	2700	2600	2600	2600	2600	0.6%
Wind-onshore	(Average onshore)	1700	1500	1400	1300	1300	5.3%
Wind-offshore	(Average offshore)	5100	4000	3400	3000	2800	9.2%
Solar PV	Distributed photovoltaic	3100	2100	1800	1600	1500	12.3%
Coal-CCS*	IGCC with CCS	n.a.	4100	3200	2800	2700	4.4%
Gas-CCS**	CCGT with CCS	n.a.	1600	1200	1000	900	5.5%

Note: The learning of starred technologies (and ** for coal and gas, respectively) benefit from learning of technologies without CCS and of the learning of the relevant CO_2 capture technology.*

CCS technologies include a CO_2 capture rate of 90% for coal and gas, and 75% for biomass.

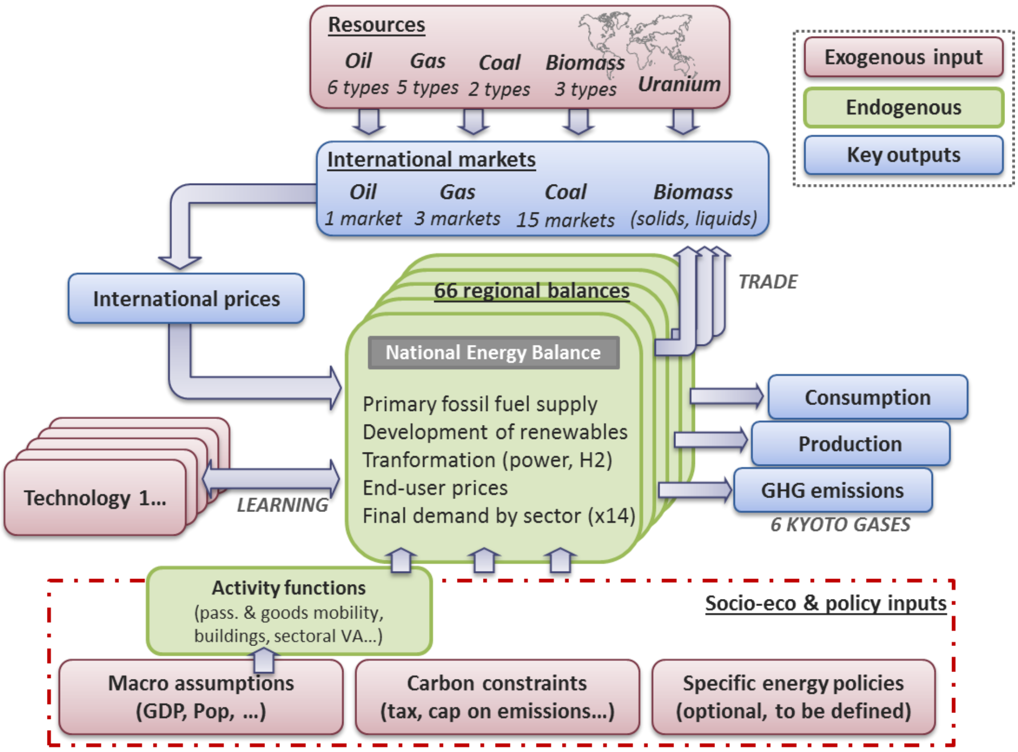
Annex 2 JRC-POLES description

Model

JRC-POLES is a world energy-economy partial equilibrium simulation model of the energy sector, with complete modelling from upstream production through to final user demand. The JRC-POLES model follows a year-by-year recursive modelling, with endogenous international energy prices and lagged adjustments of supply and demand by world region, which allows for describing full development pathways to 2050. The model provides full energy and emission balances for 66 countries or regions worldwide (including detailed OECD and G20 countries), 14 fuel supply branches and 15 final demand sectors.

This exercise used the EC JRC-POLES 2016 version. Differences with other exercises done with the JRC-POLES model by EC JRC, or with exercises by other entities using the POLES model, can come from different i/ model version, ii/ historical data sets, iii/ parameterisation, iv/ policies considered.

Figure 67: JRC-POLES model general scheme



Final demand

The final demand evolves with activity drivers, energy prices and technological progress. The following sectors are represented:

- industry: chemistry (energy uses and non-energy uses are differentiated), non-metallic minerals, steel, other industry;

- buildings: residential, services (specific electricity uses are differentiated, different types of buildings are considered);

- transport (goods and passengers are differentiated): road (motorcycles, cars, light and heavy trucks – different engine types are considered), rail, inland water, international maritime, air domestic and international;

- agriculture.

Power system

The power system describes capacity planning of new plants and operation of existing plants for 40 technologies.

The planning considers the existing structure of the power mix (vintage per technology type), the expected evolution of the load demand, the production cost of new technologies, and resource potential for renewables.

The operation matches electricity demand considering the installed capacities, the variable production costs per technology type, the resource availability for renewables.

The electricity demand curve is built from the sectoral distribution over typical days.

Electricity price by sector depend on the evolution of the power mix, of the load curve and of the energy taxes.

Other sectors

The model also describes other energy transformations sectors: liquid biofuel (BTL), coal-to-liquid (CTL), gas-to-liquid (GTL), hydrogen (H_2).

Oil supply

Oil discoveries, reserves and production are simulated in 88 individual countries and for 6 types of fuel: conventional crude & NGLs (inland and shallow water), tar sands, extra heavy oil, oil shale (kerogen), deepwater and arctic oil.

The market is structured along the market power of the different countries:

- non-OPEC production produces depending on remaining reserves, oil price and production cost;

- OPEC production adjusts to the evolution of demand and non-OPEC production;

- Gulf production can develop a spare capacity to adjust for short term variations, it adjusts to the evolution of demand and non-Gulf production.

International oil price depend on the evolution the oil stocks on the short term, and on the longer run on the production cost and on spare capacity in the Gulf. Price to consumer considers the evolution of taxation, including the impact of a carbon value.

Gas supply

Gas discoveries, reserves and production are simulated in 88 individual countries or regions for 4 types of gas: conventional gas (inland and shallow water), shale gas, deepwater and arctic gas. They supply 15 regional markets, made up of the national gas demand of the 66 JRC-POLES countries and regions. 37 of the producers are considered as key producers with a capacity to export on international markets through trading routes. Gas transport is done through inland pipeline, offshore pipelines or LNG.

Gas price is simulated for 3 regional markets: Europe, America, Asia. It depends on the transport cost, the regional R/P ratio, the evolution of oil price and the development of LNG (integration of the different regional markets). Price to consumer considers the evolution of taxation, including the impact of a carbon value.

Coal supply

Coal production is simulated in 81 individual countries or regions. Some countries (USA, Australia, China, India) have two or more production regions to better represent transportation costs which can represent a significant share of the coal delivery cost. They supply 15 regional markets, made up of the national coal demand of the 66 JRC-POLES countries and regions. 26 of the producers are considered as key producers with a capacity to export on international markets through trading routes.

Coal delivery price for each route depends on the transport cost (international and inland), the mining cost, and other operation costs. An average delivery price is calculated for each of the 15 consuming markets. The model also calculates an average international price for 3 "continental" markets: Europe, Asia, America. Price to consumer considers the evolution of taxation, including the impact of a carbon value.

Biomass supply

The model differentiates 3 types of primary biomass: energy crops, short rotation crop (cellulosic) and wood (cellulosic). They are described for each of the 66 country through a potential and a production cost curve – in the case of SRC and wood this is derived from look-up tables provided by the specialist model GLOBIOM-G4M (Global Biosphere Management Model*)*. Biomass can be traded, either in solid form or as liquid biofuel.

Wind, solar and other renewables

These renewables are associated to potentials per country, which can be more detailed (in the case of wind and solar, where supply curves are used) or less (hydro, geothermal, ocean where only a potential figure is used).

GHG emissions

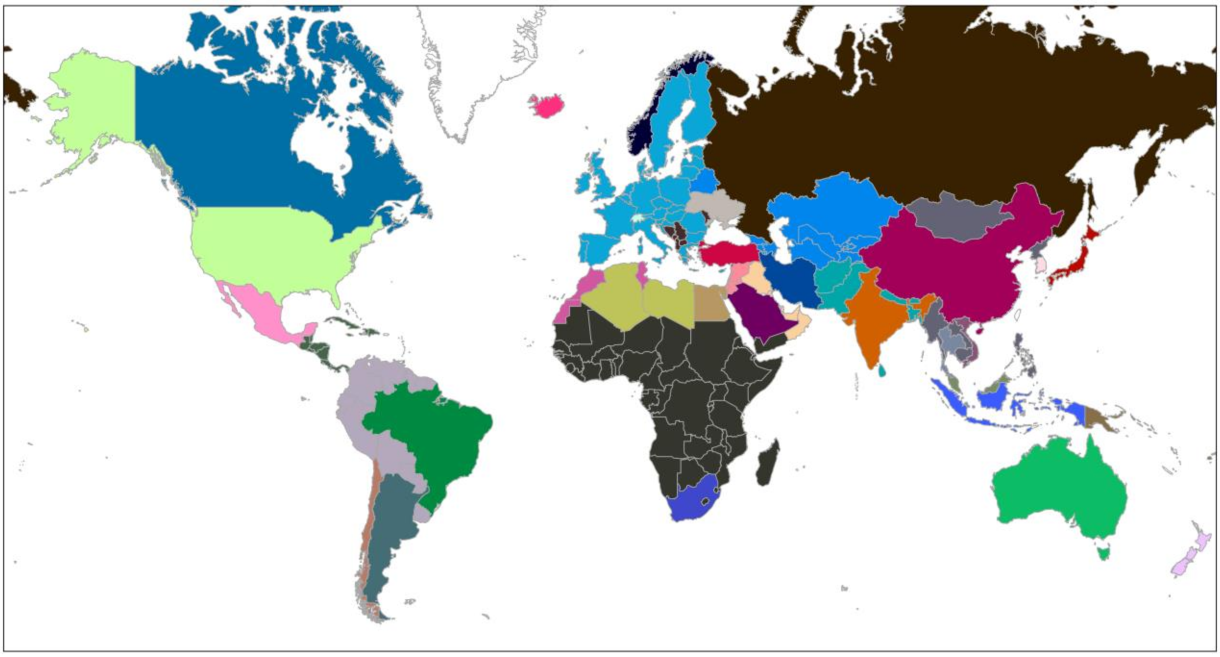
CO_2 emissions from fossil fuel combustion are derived directly from the JRC-POLES energy balance that is influenced by mitigation policies (carbon value, support policies to technologies, energy efficiency targets). Other GHGs from energy and industry are simulated using activity drivers identified in the JRC-POLES model (e.g. sectoral value added, mobility per type of vehicles, fuel production, fuel consumption..) and abatement cost curves. GHG from agriculture and LULUCF are derived from GLOBIOM-G4M lookup tables.

Countries and regions

Table 23: JRC-POLES model regional detail

Europe	CIS	America	Africa	Middle East	Asia	Pacific
EU28	Russia	Argentina	Egypt	Iran	China	Australia
Iceland	Ukraine	Brazil	Algeria & Libya	Saudi Arabia	India	Japan
Norway	Other CIS	Canada		Turkey	Indonesia	Korea (Rep.)
Switzerland		Chile	Morocco & Tunisia	Mediterranean Middle-East	Malaysia	New Zealand
Other Balkans		Mexico			Thailand	
		USA	South Africa	Rest Gulf	Vietnam	Rest Pacific
		Rest Central America	Rest Sub-Saharan Africa		Rest South Asia	
		Rest South America			Rest South-East Asia	

Figure 68: JRC-POLES model regional detail map



Data sources

Table 24: JRC-POLES model historical data and projections

Series		Historical data	GECO Projections
Population		UN (2015)	UN (2015, medium fertility)
GDP, growth		World Bank (2015)	EC (2015), IMF (2016), OECD (2013, see also Dellink et al. 2014)
Other activity drivers	Value added	World Bank (2015)	JRC-POLES model
	Mobility, vehicles, households, tons of steel..	Sectoral databases	
Energy resources	Oil, gas, coal	BGR (2014), USGS (2013), WEC (2013a), sectoral databases	
	Uranium	OECD (2014)	
	Biomass	EU: Green-X model[1] Non-EU: GLOBIOM model[2]	
	Hydro	Enerdata (2015)	
	Wind, solar	NREL (2013), Pietzcker (2014)	
Energy balances	Reserves, production	BP (2015), Enerdata (2015), IEA (2015)	
	Demand by sector and fuel, transformation (including. power), losses	Enerdata (2015), IEA (2015)	
Energy prices	International prices, prices to consumer	EIA (2016), Enerdata (2015), IEA (2015)	JRC-POLES model
GHG emissions	Energy CO_2	Derived from JRC-POLES energy balances	JRC-POLES model
	Other GHG Annex 1	UNFCCC (2015)	JRC-POLES model, GLOBIOM[2]
	Other GHG Non-Annex 1 (excl. LULUCF)	EDGAR (EC JRC 2015b)	JRC-POLES model, GLOBIOM[2]
	LULUCF Non-Annex 1	FAO (2015)	JRC-POLES model, GLOBIOM[2]
Technology costs		JRC-POLES learning curves based on literature, including but not only: EC JRC (2014), IEA Technology Roadmaps, WEC (2013b), TECHPOL database[3]	

Notes:
1: University of Vienna: http://www.green-x.at/
2: IIASA: http://www.globiom.org/
3: developed in several European research projects: SAPIENT, SAPIENTIA, CASCADE MINTS - see for instance: http://cordis.europa.eu/result/rcn/47819_en.html

Annex 3 JRC-GEM-E3 description

The GEM-E3 model, a Computable General Equilibrium (CGE) model, is used to assess the direct and indirect impacts of mitigation efforts until the year 2030. The GEM-E3 model is a multi-sector, multi-region model that includes the interactions between the energy system, the economy and the environment. It is built on sound microeconomic foundations and integrates multiple data sources such as trade statistics, input-output data and information on emissions of greenhouse gasses. Furthermore, existing tax structures and unemployment mechanisms are incorporated. The version of the model used here is global (25 regions, see Table 25) and covers all industry sectors, disaggregated into 31 sectors, of which 10 electricity generating technology sectors.

In a general equilibrium framework, results regarding impacts of imposed policies are presented comparatively with the Reference projections of the economy, thus in terms of percentage differences from the Reference scenario. The GEM-E3 Reference is constructed on the basis of a variety of data sources. First, the future path of GDP is based on projections done by the OECD (see Dellink et al. 2014) for all regions in the world. Second, population projections are taken from the UN (2015). Third, the input-output tables and the data on bilateral trade flows are derived from the GTAP 8 database. Fourth, the emission levels of greenhouse gasses (totals and by sector) and the shares of electricity generation technologies are harmonised with the Baseline in the POLES model. For the EU, the Baseline is consistent with the 2013 reference of the PRIMES model. Importantly, for the EU this Baseline already includes substantial policy measures. In particular, Europe complies with the "20-20-20 Package" and is in line with the "EU Energy, Transport and GHG emission trends to 2050; update 2013" (EC, 2013). For the other regions, policy measures that are already put in place are included, in line with section 2.2. Additional data sources include labour statistics from ILO and energy statistics from IEA.

The GEM-E3 model is a recursive dynamic CGE model representing multiple regions, sectors and agents. The interactions between three types of agents are included: households, firms and governments. Household behaviour derives from the maximisation of a Stone-Geary (Linear Expenditure System) utility function. Unemployment is modelled via a wage curve mechanism. Firms maximise profits subject to sector-specific nested constant elasticity of substitution production technologies. The behaviour of governments is exogenous, and government budget balance relative to GDP is assumed to be at the level of the Reference in all scenarios.

Table 25: Regional aggregation in the JRC-GEM-E3 model

Region	*Code*
European Union	EU28
USA	USA
Russia	RUS
Canada	CAN
Japan	JPN
Australia	AUS
China	CHN
India	IND
Indonesia	IDN
Brazil	BRA
Republic of Korea	KOR
Rest of Europe (Switzerland, Norway, Albania, Iceland, Bosnia, Serbia, Turkey...)	ANNI
Mexico	MEX
Argentina	ARG
North Africa	NOAF
New Zealand	NZL
Saudi Arabia	SAU
Iran	IRN
South Africa	ZAF
Rest of Middle East	MIDE
Sub-Sahara Africa	SSAF
Rest of Central and South America (incl. Caribbean and North-Atlantic Islands)	CSAM
Central Asia and Caucasus (incl. Belarus, Ukraine, Kazakhstan, Azerbaijan,...)	CASC
South-East Asia	SEAS
Rest of Asia and Pacific	RAPA

Source: GEM-E3 model

Annex 4 Detailed policies

The following tables provide a full list of the policies considered in the GECO2016 scenarios (see also 2.2.2 for the Reference scenario and 2.2.3 for the INDC scenarios for a discussion on how these policies were implemented).

The objectives of all these policies were reached, except in the following cases:

- 2020 emissions:
  - Norway, Switzerland (emissions result from the same carbon price as for EU28 ETS sectors, reflecting the single EU ETS market)
- 2020 energy:
  - EU28 (renewables in transport: policy under reconsideration)
  - China (policy reached in the INDC scenarios)
  - Malaysia (power capacities reached; share in total power capacities half reached)
  - Ukraine (half reached while 2020 emissions target exceeded)
- 2025-2030 emissions:
  - Iceland, Norway, Switzerland (emissions result from the same carbon price as for EU28 ETS sectors, reflecting the single EU ETS market)
  - Morocco & Tunisia (conditional INDC policies very constraining in terms of the effort necessary to reach the target; the policy effort was capped by using the highest carbon value applied in any other country / region by 2030)
- 2025-2030 energy:
  - Turkey (nuclear capacities: slower development than planned)
  - South Africa (CCS from coal-to-liquids: half reached)
  - Several targets for countries not modelled individually were considered but not necessarily reached (Ecuador, Papua New Guinea, Bangladesh, Jordan, Algeria, Cameroon)
- 2025-2030 other:
  - Several targets expressed for the LULUCF sector not related to emissions were considered but not modelled (Brazil, Chile, Ecuador, Japan, Cambodia, China, India, Vietnam)

An Excel version of these tables along with further detail is available in the GECO website, see: www.ec.europa.eu/jrc/geco.

Table 26: GHG policies in and around 2020 in the Reference scenario

UN Party	GHG coverage	Sectoral coverage	Metric	Base year	Target year	Objective	Source
Europe							
EU28	All GHGs	All excl LULUCF	Emissions	1990	2020	-20%	EU 2020 Climate and Energy Package (European Commission, 2008)
EU28	All GHGs	ETS sectors	Emissions	2005	2020	-21%	EU 2020 Climate and Energy Package (European Commission, 2008)
Norway	All GHGs	All	Emissions	1990	2020	-30%	National Communication 6 (UNFCCC, 2014)
Switzerland	All GHGs	All	Emissions	1990	2020	-20%	National Communication 6 (UNFCCC, 2014)
North America							
Canada	All GHGs	All excl LULUCF	Emissions	n.s.	2020	727 MtCO2e	Canada's Emission Trends (Ministry of Environment and Climate Change, 2014)
USA	All GHGs	All	Intensity of GDP	2005	2020	-17%	Climate Action Report (US Department of State, 2014) / National Communication 6 (UNFCCC, 2014)
Central & South America							
Brazil	All GHGs	All	Emissions	2020 (BAU)	2020	-36.1% to -38.9%	Copenhagen Accord (UNFCCC, 2009); National Communication 2 (UNFCCC, 2010)
Chile	All GHGs	All	Emissions	2020 (BAU)	2020	-20%	Copenhagen Accord (UNFCCC, 2009)
Pacific							

Australia	All GHGs	All	Emissions	2000	2020	-5%	National Communication 6 (UNFCCC, 2013)
Japan	All GHGs	All	Emissions	2005	2020	-3.8%	Ministry of the Environment (COP19, 2013)
New Zealand	All GHGs	All	Emissions	1990	2020	-5% (conditional: -10% to -20%)	Copenhagen Accord (UNFCCC, 2009); National Communication 6 (UNFCCC, 2013)
South Korea	All GHGs	All excl LULUCF	Emissions	2020 (BAU)	2020	-30%	Copenhagen Accord (UNFCCC, 2009); National Communication 3 (UNFCCC, 2012)
Asia							
China	CO2	All excl LULUCF	Intensity of GDP	2005	2020	-40% to -45%	Copenhagen Accord (UNFCCC, 2009)
India	GHG	All excl agriculture	Intensity of GDP	2005	2020	-20% to -25%	Copenhagen Accord (UNFCCC, 2009)
Indonesia	CO2	Energy	Emissions	2020 (BAU)	2020	-26%	Copenhagen Accord (UNFCCC, 2009); National Communication 2 (UNFCCC, 2012)
Malaysia	All GHGs	All	Intensity of GDP	2005	2020	-40%	National Communication 2 (UNFCCC, 2011)
Thailand	All GHGs	Energy, transport	Emissions	2020 (BAU)	2020	-7%	Copenhagen Accord (UNFCCC, 2009); Development trajectory (ADBI, 2012)
CIS							
Russia	All GHGs	All	Emissions	1990	2020	-15% to -25%	Copenhagen Accord (UNFCCC, 2009)
Ukraine	All GHGs	All	Emissions	1990	2020	-20%	Copenhagen Accord (UNFCCC, 2009)
Africa							
South Africa	All GHGs	All	Emissions	2020 (BAU)	2020	-34%	Copenhagen Accord (UNFCCC, 2009); National Communication 2 (UNFCCC, 2011)

Table 27: Energy policies in and around 2020 in the Reference scenario

UN Party	Technology	Metric	Target year	Objective	Source
Europe					
EU28	Renewables	Share in gross final demand	2020	20%	European Commission , DG Energy
EU28	Renewable fuels	Share in transport demand	2020	10%	European Commission , DG Energy
EU28	Private vehicles emissions	Emissions, in g/km	2021	95	European Commission , DG Energy
EU28	Energy demand	%reduction vs. BAU	2020	-20% (primary: 1.5 Gtoe, final: 1.1 Gtoe)	European Commission , DG Energy
Switzerland	Renewables	Share in primary demand	2020	24%	Energy Strategy 2050
North America					
Canada	Private vehicles emissions	Emissions, in g/km	2025	88	Canadian Environmental Protection Act
Mexico	Non-fossil + cogeneration	Share in power capacities	2018	34.6%	National Development Plan 2014-2018
Mexico		Capacity targets	2018	Nuclear: 1.4 GW Renewables: 23.3 GW	National Development Plan 2014-2018
Mexico	Non-fossil	Share in power production	2024	35%	Energy Transition Law 2015
USA	Wind, Solar, Geothermal	Power production	2020 vs. 2012	Doubling	White House
USA	Private vehicles emissions	Consumption, miles/gal	2020	54.5	US EPA
Central & South America					
Argentina	Renewables	Share in power production	2017	8%	Renewables law, 2015

Brazil		Capacity targets	2024	Biomass: 18 GW Hydro: 117 GW + small hydro 8 GW Nuclear: 3 GW Solar: 7 GW Wind: 24 GW	Decenal Energy Expansion Plan (2024)
Chile	Non-conventional renewables	Share in power capacities	2020	20%	National Communication 2 (UNFCCC, 2011)
Pacific					
Australia	Renewables	Share in power production	2020	23.5%	Australian Government, Department of Environment
Japan		Capacity targets	2020	Biomass: 5.5 GW Solar: 28 GW Wind: 6 GW	Ministry of Economics, Trade and Industry
New Zealand	Renewables	Share in power production	2025	90%	New Zealand Energy Efficiency and Conservation Strategy 2011-2016
S.Korea	Renewables	Share in primary demand	2020	5%	
Asia					
China	Non-fossil	Share in primary demand	2020	15%	WRI
China		Capacity targets	2020	Hydro: 350 GW Nuclear : 58 GW Solar: 100 GW Wind: 200 GW	Energy Development Strategy Action Plan (2014-2020)
India		Capacity targets Additional vs. 2010	2022	Biomass: +10 GW Solar: +100 GW Wind: +60 GW	India's Union Budget 2015-2016
Indonesia	Renewables	Share in power production	2019	19%	Energy and Mineral Resources Ministry

Malaysia	Renewables	Share in power capacities	2020	10%	National Renewable Energy Policy and Action Plan (2010)
Malaysia		Capacity targets	2020	Biomass: 0.8 GW Hydro (small): 0.5 GW Solar PV: 0.2 GW	National Renewable Energy Policy and Action Plan (2010)
Thailand	Renewables	Share in primary demand	2022	20%	National Communication 2 (UNFCCC, 2011)
Vietnam	Renewables	Share in primary demand	2020	5%	National Energy Development Strategy 2020 (2013)
Vietnam	Renewables	Share in power production	2020	4.5%	Power Development Plan 2011-2020 (2013)
CIS					
Ukraine	Renewables	Share in final consumption	2020	11%	National Action Plan for Renewable Energy (2014)
Ukraine	Renewables	Capacity targets	2020	Biomass: 1 GW Hydro: 5.4 GW Solar: 2.3 GW Wind: 2.3 GW	National Action Plan for Renewable Energy (2014)
Middle East					
Turkey	Renewables	Share in gross final energy consumption	2023	20.5%	National Renewable Energy Action Plan (2014)
Turkey		Capacity targets	2023	Hydro: 34 GW Solar: 5 GW Wind: 20 GW	National Renewable Energy Action Plan (2014)
Turkey	Renewables	Share in power production	2023	30%	Energy Strategy Plan 2010-2014
Africa					
Egypt	Renewables	Share in power production	2020	20%	Egypt Regional Center for Renewable Energy and Efficency

South Africa	Capacity targets	2030	Solar: 9.4 GW Wind: 8.5 GW

Table 28: GHG policies in 2025-2030 in the INDC scenarios

UN Party	GHG coverage	Sectoral coverage	Metric	Base year	Target year	INDC uncond'l	INDC cond'l	BAU emissions at Target year (Mt)
Europe								
Albania	CO2	Energy, industrial processes	Emissions	2030 (BAU)	2030	-11.5%	-11.5%	5.9
EU28	All GHGs	All sectors	Emissions	1990	2030	-40%	-40%	
EU28	All GHGs	ETS sectors	Emissions	2005	2030	-43%	-43%	
Iceland	All GHGs	All sectors	Emissions	1990	2030	-40%	-40%	
Macedonia (FYROM)	CO2	FF combustion	Emissions	2030 (BAU)	2030	-30%	-36%	17.7
Norway	All GHGs	All sectors (LULUCF net-net)	Emissions	1990	2030	-40%	-40%	
Serbia	All GHGs	All sectors	Emissions	1990	2030	-9.8%	-9.8%	
Switzerland	All GHGs	All sectors	Emissions	1990	2030	-50%	-50%	
North America								
Canada	All GHGs	All sectors (LULUCF net-net)	Emissions	2005	2030	-30%	-30%	
Mexico	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-22%	-36%	973
USA	All GHGs	All sectors (LULUCF net-net)	Emissions	2005	2025	-26%	-28%	
Central & South America								
Argentina	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-15%	-30%	670
Brazil	All GHGs	All sectors	Emissions	2005	2025	-37%	-37%	

Chile	All GHGs	All sectors	Intensity of GDP	2007	2030	-30%	-45%	
Colombia	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-20%	-30%	335
Costa Rica	All GHGs	All sectors	Emissions	2012	2030	-25%	-25%	
Dominican Republic	CO2, CH4, N2O	All sectors	Emissions	2010	2030		-25%	
Ecuador	CO2, CH4, N2O	Energy	Emissions	2025 (BAU)	2025	-20.4%	-45.8%	n/a
Grenada	CO2, CH4	Electricity, Transport, Waste, Forestry	Emissions	2010	2025	-30%	-30%	
Peru	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030	-20%	-30%	298
Venezuela	CO2	Energy	Emissions	2030 (BAU)	2030	-20%	-20%	340
Pacific								
Australia	All GHGs	All sectors	Emissions	2005	2030	-26%	-28%	
Japan	All GHGs	All sectors excl sinks	Emissions	2013	2030	-26%	-26%	
Korea (Republic)	All GHGs	All sectors excl LULUCF	Emissions	2030 (BAU)	2030	-37%	-37%	851
Marshall Islands	CO2, CH4, N2O	All sectors	Emissions	2010	2025	-32%	-32%	
New Zealand	All GHGs	All sectors (LULUCF net-net)	Emissions	2005	2030	-30%	-30%	
Asia								
Afghanistan	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030		-13.6%	48.9
Bangladesh	All GHGs	Power, transport and industry	Emissions	2030 (BAU)	2030	-5%	-15%	234
Cambodia	CO2, CH4, N2O	Energy	Emissions	2030 (BAU)	2030		-27%	11.6
China	CO2	Energy	Intensity of GDP	2005	2030	-60%	-65%	
India	All GHGs	All sectors	Intensity of GDP	2005	2030	-33%	-35%	
Indonesia	All GHGs	All sectors	Emissions	2030	2030	-29%	-41%	2881

				(BAU)				
Malaysia	CO2, CH4, N2O	All sectors	Intensity of GDP	2005	2030	35%	-45%	
Philippines	All GHGs	All sectors	Emissions	2030 (BAU)	2030		-70%	n/a
Singapore	All GHGs	All sectors	Intensity of GDP	2005	2030	-36%	-36%	
Thailand	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-20%	-25%	555
Vietnam	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-8%	-25%	787
CIS								
Azerbaijan	All GHGs	Energy, agriculture, waste, LULUCF	Emissions	1990	2030	-35%	-35%	
Belarus	All GHGs	All sectors excl LULUCF	Emissions	1990	2030	-28%	-28%	
Kazakhstan	All GHGs	All sectors	Emissions	1990	2030	-15%	-25%	
Moldova	All GHGs	All sectors	Emissions	1990	2030	-64%	-67%	
Russian Federation	All GHGs	All sectors	Emissions	1990	2030	-25%	-30%	
Tajikistan	CO2, CH4, N2O	All sectors	Emissions	1990	2030	-10%	-35%	
Ukraine	All GHGs	All sectors excl LULUCF	Emissions	1990	2030	-40%	-40%	
Middle East								
Iran	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-4%	-12%	n/a
Iraq	CO2, CH4, N2O		Emissions	2035 (BAU)	2035	-13%	-15%	305
Israel	All GHGs	All sectors excl LULUCF	Emissions	2030 (BAU)	2030	-22.6%	-22.6%	106
Lebanon	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030	-15%	-30%	43.6
Saudi Arabia	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-130 MtCO2e	-130 MtCO2e	n/a
Turkey	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-21%	-21%	1175

Africa								
Algeria	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030	-7%	-22%	n/a
Burkina Faso	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030	-6.6%	-18.2%	118
Cameroon	CO2, CH4, N2O	Energy, agriculture, forestry, waste (no LULUCF)	Emissions	2035 (BAU)	2035		-32%	104
Central African Republic	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030	-3.5%	-5%	110
Congo (Dem. Rep.)	CO2, CH4, N2O	Energy, agriculture, forestry (no LULUCF)	Emissions	2030 (BAU)	2030		-17%	430
Côte d'Ivoire	All GHGs	All sectors excl LULUCF	Emissions	2030 (BAU)	2030	-28%	-36%	34
Equatorial Guinea	CO2, CH4, N2O	All sectors	Emissions	2010	2030	-20%	-20%	
Ethiopia	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030		-64%	400
Gambia	All GHGs	All sectors excl LULUCF	Emissions	2010	2030	-45.4%	-45.4%	
Ghana	All GHGs	All sectors	Emissions	2030 (BAU)	2030	-15%	-45%	74
Guinea	All GHGs	Energy, agriculture	Emissions	2030 (BAU)	2030		-13%	53
Kenya	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030	30%	-30%	143
Madagascar	CO2, CH4, N2O	All sectors (net of sinks)	Emissions	2030 (BAU)	2030	-14%	-14%	214
Morocco	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030	-13%	-32%	170
Niger	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030	-3.5%	-34.6%	96
Nigeria	CO2, CH4, N2O	All sectors	Emissions	2030 (BAU)	2030	-20%	-45%	850
Sao Tome and Principe	CO2, CH4, NOx	All sectors	Emissions	2030 (BAU)	2030		-24%	240
South Africa	All GHGs	All sectors	Emissions		2030	2020-	at 398-	n/a

						2035: plateau	614 MtCO2e	
Tanzania	All GHGs	All sectors (gross emissions)	Emissions	2030 (BAU)	2030	-10%	-20%	146
Tunisia	All GHGs	All sectors	Intensity of GDP	2010	2030	-13%	-41%	
Zambia	CO_2, CH_4, N_2O	Energy, Agriculture, Waste, LULUCF	Emissions	2030 (BAU)	2010	-25%	-47%	80

Table 29: GHG policies in 2025-2030 in the INDC scenarios

UN Party	Technology / Sector	Metric	Target year	Objective
Europe				
EU28	Renewables	Share in gross final demand	2030	27%
Central & South America				
Brazil	Renewables	Share in of liquid biofuels	2030	18%
Brazil	Renewables	Share in primary energy	2030	45%
Brazil	Renewables excl. hydro	Share in primary energy	2030	28-33%
Brazil	Renewables excl. hydro	Share in power production	2030	23%
Brazil	LULUCF	Restoring and reforesting forests	2030	12 million hectares
Brazil	LULUCF	Restoring degraded pasturelands	2030	Additional 15 million hectares
Brazil	LULUCF	Enhancing of integrated cropland-livestock-forestry systems (ICLFS)	2030	5 million hectares
Chile	LULUCF	Recover and sustainably manage forest + reforest	2030	100,000 hectares + 100,000 hectares
Ecuador	LULUCF	Restore forest by 2017 and increase until 2025	2025	500,000 hectares + 100,000 hectares/year
Ecuador	Hydro	Capacity	2025	2.2 GW (conditional: 4.3 GW)
Pacific				
Japan	LULUCF	Continuation of equivalent of KP LULUCF accounting	2030	Expected to contribute 2.6% of the 26% target

Japan	Nuclear	Share in power production	2030	20-22%
Japan	Renewables	Share in power production	2030	22-24%
Papua New Guinea	Renewables	Share in power production	2030	100%
Asia				
Bangladesh	Energy intensity		2030	Reduce relative to 2013
Bangladesh	Renewables	Capacity	2030	Wind: 400 MW Solar: 100 MW
Bangladesh	Landfill gas	% used for electricity production	2030	70%
Cambodia	LULUCF	Increase forest cover	2030	Up to 60 %
China	Non-fossil fuels	Share in primary energy	2030	20%
China	LULUCF	Increase the forest stock volume on the 2005 level	2030	Around 4.5 billion cubic meters
India	Non-fossil fuels	Share in new power capacity	2030	40%
India	Renewables	Capacity	2022	Wind: 60 GW Solar: 100 GW
India	LULUCF	Create an additional carbon sink through additional forest and tree cover	2030	2.5 to 3 bn tCO2eq
Indonesia	Renewables	Share in primary energy	2025	23%
Vietnam	LULUCF	Forest cover increase	2030	+45%
Middle East				
Jordan	Renewables	Share in primary energy	2025	11%
Turkey	Renewables	Capacity	2030	Wind: 16 GW Solar: 10 GW
Turkey	Hydro		2030	Tapping the full hydroelectric potential
Turkey	Nuclear	Capacity	2030	Commissioning of a nuclear power plant
Turkey	Electricity grid	Reduction of losses	2030	to 15%
Africa				
Algeria	Renewables	Share in power production	2030	27%
Cameroon	Renewables	Share in power production	2035	25%

South Africa	Non-fossil fuels	Share in power production	2050	Decarbonised electricity by 2050 (US$349bn 2010-2050)
South Africa	Coal-to-liquids	CO2 captured and stored	2050	23 Mt CO2
South Africa	Electric transport	Investment	2050	US$513 bn 2010-2050
South Africa	Plug-in vehciles	Share in vehicles	2030	20%

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