IDDRI

STUDY

N°05/15 OCTOBER 2015 | CLIMATE

Beyond the Numbers: Understanding the Transformation Induced by INDCs

A Report of the MILES Project Consortium

www.iddri.org

Institut du développement durable
et des relations internationales
27, rue Saint-Guillaume
75337 Paris cedex 07 France

SciencesPo

This report has been prepared by the MILES project Consortium under contract to DG CLIMA (No. 21.0104/2014/684427/SER/CLIMA.A.4)

This project is funded by the European Union.

Disclaimer: This report was written by a group of independent experts who have not been nominated by their governments. The contents of this publication are the sole responsibility of IDDRI and can in no way be taken to reflect the views of the European Union or any government and organisation.

Contributing authors	**Institution**	**Role**	**Logo**
Thomas Spencer Roberta Pierfederici Henri Waisman Michel Colombier	Institut du développement durable et des relations internationales (IDDRI), France	Coordinating lead authors	
Christoph Bertram Elmar Kriegler Gunnar Luderer Florian Humpenöder Alexander Popp Ottmar Edenhofer	Potsdam-Institut für Klimafolgenforschung (PIK), Germany	Chapter 4	
Michel Den Elzen Detlef van Vuuren Heleen van Soest	Netherlands Environmental Assessment Agency (PBL), Netherlands	Chapter 4	
Leonidas Paroussos Panagiotis Fragkos	Energy - Economy - Environment Modelling Laboratory (E3M Lab), Greece	Chapter 2.2 Case study 1	
Mikiko Kainuma Toshihiko Masui Ken Oshiro (MHIR).	National Institute for Environmental Studies (NIES), Japan	Chapter 2.3 Case study 6	
Keigo Akimoto, Bianka Shoai Tehrani, Fuminori Sano, Junichiro Oda	Research Institute of Innovative Technology for the Earth (RITE), Japan	Chapter 2.3 Case Study 2	
Leon Clarke Gokul Iyer Jae Edmonds	Pacific Northwest National Laboratory (PNNL), United States	Chapter 2.4	
TENG Fei	Tsinghua University, China	Chapter 2.5	
FU Sha	Renmin University and National Centre for Climate Change Strategy and International Cooperation, China	Chapter 2.5 Case Study 5	
Jiang Kejun	Energy Research Institute of NRDC (ERI)	Chapter 2.5	
Alexandre C. Köberle, Alexandre Szklo, André F. P. Lucena, Joana Portugal-Pereira, Pedro Rochedo and Roberto Schaeffer	Energy Planning Program, Center for Energy and Environmental Economics, Graduated School of Engineering, Universidade Federal do Rio de Janeiro, (COPPE/UFRJ), Brazil	Chapter 2.6 Case Study 3	
Aayushi Awasthy Manish Kumar Shrivastava Ritu Mathur	The Energy and Resources Institute (TERI), India	Chapter 2.7 Case study 7 Case study 8	

Beyond the Numbers: Understanding the Transformation Induced by INDCs

A Report of the MILES Project Consortium

Spencer, T., Pierfederici, R., et al. (2015). Beyond the numbers: understanding the transformation induced by INDCs, Study N°05/15, IDDRI - MILES Project Consortium, Paris, France, 80p.

☆☆☆

The author would like to thank Pierre Barthelemy, Ivan Pharabod, Alain Chevallier, Lena Spinazze and Delphine Donger for their careful reading and suggestions.

☆☆☆

This research was funded by the French Government as part of the "Investissements d'avenir" programme under the reference ANR-10-LABX-01.

☆☆☆

For more information about this document, please contact:
Thomas Spencer - thomas.spencer@iddri.org

ISSN 2258-7071

Table des figures

EXECUTIVE SUMMARY

What is Innovative and Complementary About this Report?

As part of the negotiations towards a new climate agreement to be sealed in Paris in December 2015, countries have been requested to submit new 'intended nationally determined contributions' (INDCs), in particular new greenhouse gas (GHG) emissions targets for the period beyond 2020. As of October 19, the 123 INDCs, covering 150 countries, submitted to the UNFCCC represent ca. 85.8% of global GHG emissions in 2012.[1]

At the Lima Conference of the Parties (COP20) in 2014, the Secretariat of the UNFCCC was tasked with producing a synthesis report on the "aggregate effect" INDCs. This UNFCCC synthesis report will analyse the impact of INDCs on global emissions, in the light of the goal of limiting warming to 2°C or 1.5°C. Other analysis, in particular the annual UNEP Gap Report, will perform similar assessments. These reports represent the cutting edge in terms of understanding the aggregate effect of INDCs on global emissions, in the light of the 2°C goal.

This report aims to do something different and complementary. It is the outcome of an international research project involving 15 leading research teams from 11 countries (see authors' list). In 2015, the objective of the project has been to produce a detailed analysis of INDCs in terms of three innovative aspects:

- Understanding **the transformation of the energy sector that would result from implementing the INDCs, in particular at the national level for major economies but also at the global level.** The focus here has been on the implications of INDCs and instead of to 2025 to 2030, while taking into account the importance of embedding this understanding in the long-term perspective of the transformation required to 2050. The project has developed detailed analysis on what it would take to implement the INDCs, in terms of the roll-out of renewable energy, improvement of energy efficiency, and the deployment of other low-carbon solutions. The project is based on the participation of leading national experts, who have each analysed their country's INDC, as well as on leading global modelling teams who have assessed INDCs in aggregate.
- Understanding **options to stay on track with 2°C at the global level,** in the light of the level of transformation in the global energy system implied by INDCs by 2030.
- Understanding the **co-benefits and trade-offs** of INDCs, in particular related to local air-pollution, energy-security, investment requirements, and risks of lock-in into high emitting infrastructure.

In order to perform this analysis, the report has adopted an innovative methodology:

- Detailed, sector-specific, national-level INDC scenarios are developed, which show concretely what would be required to reach INDCs (*national INDC scenarios*). These national INDC scenarios have been produced by the respective research teams for five countries and one region: the USA, China, Brazil, Japan, India[2] and the EU. Together these represent 60% of global

---

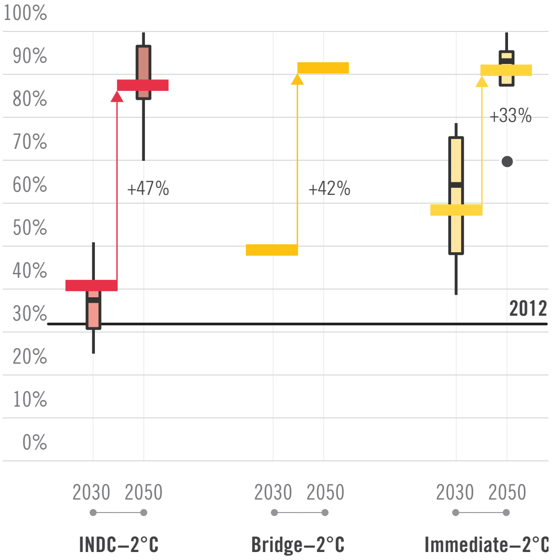
[1] Source: WRI, CAIT Climate Data Explorer, Paris Contributions Map. Available online at: http://cait.wri.org/indc/.

[2] The India assessment is based on the previously published TERI study "Energy Security Outlook" (2015), adjusted for the headline targets of the Indian INDC.

Figure A. Reduction in carbon intensity of electricity in USA, EU, China, India, Brazil and Japan

Source: MILES project analysis (see country chapters in this report)

Figure B. Low-emission electricity share



Source: REMIND model calculations and IPCC scenario database (box plots)

Note to Figure B: INDC-2°C assumes INDC implementation to 2030, and then a shift to a 2°C trajectory; Bridge-2°C assumes stronger policy action from 2020 and towards a 2°C trajectory ; immediate-2°C assumes an immediate global implementation of a 2°C goal after 2015

emissions from fossil fuel combustion, and 74% of global GDP in 2012. **These countries are very different, and the transitions that will be induced by INDCs will vary between countries.** Nonetheless, it is possible to see some common trends or patterns.

- In order to assess the global implications of INDCs, a global-level INDC scenario was developed integrating the headline emissions or policy targets of INDCs published by October 2 within a global modelling framework (*global INDC scenario*). This details transformations in the global energy sector implied by INDCs. Secondly, a global INDC-2°C scenario was developed, which implements INDCs until 2030, and then shifts to a 2°C scenario from 2030. This scenario is used to explore the implications of INDCs for the 2°C objective. Thirdly, a 2°C- bridge scenario was developed, allowing for a more continuous transition from the INDCs to 2°C. In this scenario, policies and targets are strengthened by 2020 for 2030 and beyond, and investors respond early to this strengthened policy commitment.

INDCs Significantly Accelerate the Energy Transition in Major Economies

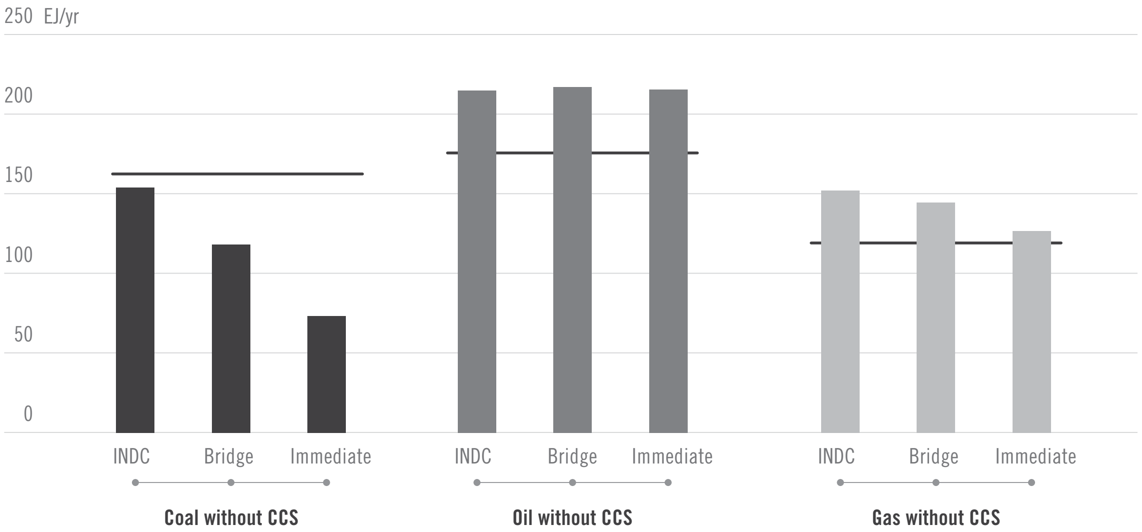
Energy resource endowments, energy supply systems and the economic drivers and the structure of energy demand differ markedly between major economies. However some robust features of the impact of INDCs on national energy transformations in Brazil, China, the European Union, India, Japan and USA, as well at the global level, can be identified.

- **Key finding:** ***the INDCs will* accelerate and consolidate *a significant transition in the electricity sector and in energy efficiency in the next 15 years, driving innovation and reduced costs.***

The INDCs imply a significant transition in the electricity sector. In aggregate from 2010 to 2030 the carbon intensity of electricity production declines by 40% in the five countries and one region assessed (Figure A). In these national INDC scenarios, renewable energy becomes the dominant source of electricity, reaching 36% in the electricity mix. At the global level, the deployment of low-carbon electricity production under the global INDC scenario is 41% in 2030, an increase of roughly 10 percentage points from 2012 levels, but still below what is seen in 2030 in 2°C scenarios (Figure B). Global investments in low-carbon electricity account for 78% of cumulative investment from 2020-2030 in electricity supply, in the global INDC scenario, up from 67% in 2012.

Similar positive trends are seen regarding energy efficiency in the end-use sectors: transport, buildings and industry. Transport in particular

Figure C. Risks of lock-in through the deployment of unabated fossil fuels in 2030



Source : REMIND model calculations and IEA

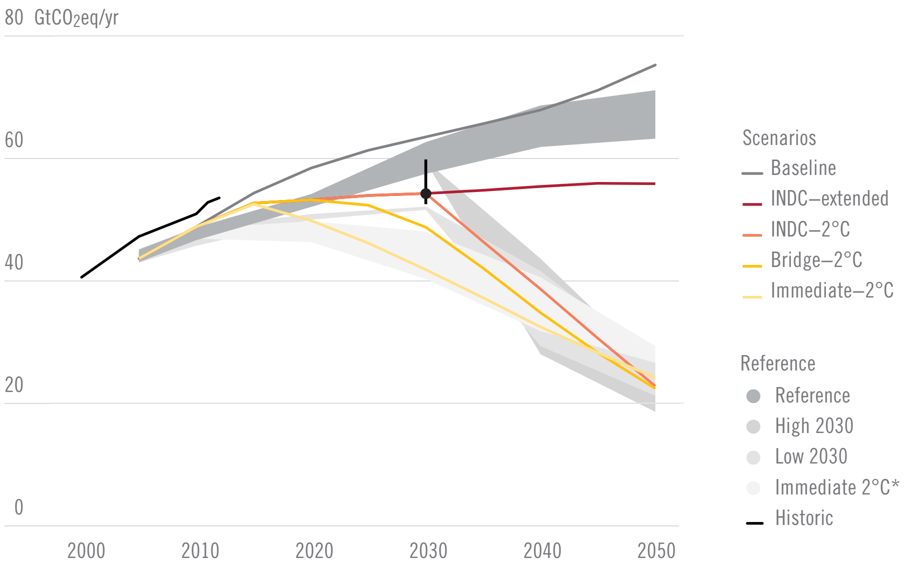
would see significant improvements in energy intensity, falling in aggregate by 30% between 2010 and 2030 in the in the five countries and one region assessed individually. In Japan and the European Union for example, the energy intensity of GDP drops a further 33% and 34% between 2010 and 2030, while it drops 48% in China over the same time period. In the USA, energy intensity of GDP drops 26% between 2010 and 2025.

- **Key finding**: *some crucial low-carbon solutions, like CCS, electric vehicles, advanced biofuels, sustainable urban planning, appear unlikely to be developed under the INDCs at the scale and speed required for a 2°C scenario, given the implied lock-in of carbon-intensive infrastructure in 2030 under the INDC scenario. Post-Paris policy efforts also need to focus on stimulating technology innovation, deployment and diffusion in order to drive down costs in such sectors where insufficient progress is being seen. This highlights also the importance of developing short-term targets in the light of long-term climate constraints, building on the development of national deep decarbonisation pathways to 2050.* **The Paris agreement should foster the development of national deep decarbonisation pathways by 2018.**

The INDC scenarios demonstrate little penetration of alternative technologies in the transport sector by 2030 (with the exception of Brazil and biofuels). However, 2°C scenarios suggest that alternative transport technologies, in particular electric vehicles in many scenarios, will need to be rolled out massively from 2030, with the share of electricity in transport energy consumption reaching a significant share of global transport energy demand by 2050 (about one sixth to one fifth). **To achieve this level in 2050, innovation in and deployment of alternative vehicles must start early**, with a growth rate of the alternative passenger vehicle industry of around 35-40%/year already between 2015 and 2030. It seems unlikely that INDC scenarios would support this rate of technology deployment. The national and global INDC scenarios likewise demonstrate little deployment of CCS, with a share of CCS in electricity generation of about 3% in 2030 for the USA, China, Japan and the EU, although **given the scale of fossil fuel infrastructure in 2030 under the INDC scenario it seems that CCS will need to be a crucial technology for mitigation post-2030**. The level of penetration of CCS seen in INDC scenarios raises questions of whether the technology would be deployable at scale from 2030.

The report also investigates the **risk of lock-in into high-carbon infrastructure**. In the global INDC scenario, deployment of unabated fossil fuel is significantly higher than what would be seen in a 2 degrees scenario. By 2030, unabated coal deployment is more than twice as high in the global INDC scenario developed for this paper than in the immediate 2°C scenario (Figure C). At the same time, as noted above, the technology that could render this unabated fossil fuel capacity coherent with a 2°C scenario does not seem to be developed sufficiently under the INDCs. The INDC scenario thus implies a significant bet on CCS after 2030,

Figure D. Greenhouse gas emissions in the scenarios of this study, compared with literature



Greenhouse gas emissions in the scenarios of this study (solid lines), compared with the 2030 range and best estimate from the country-level analysis of conditional INDCs of PBL (www.pbl.nl/indc, vertical black line and dot), and the inter-quartile ranges of the FullTech-450-OPT (Immediate 2°C), FullTech-450-LST (Low 2030) and FullTech-450-HST (High 2030) scenarios of the AMPERE study, as well as the reference policy scenarios of the AMPERE and LIMITS studies. While section 4.3 discusses the INDC-2°C scenario, section 4.4 explores the possible effect of an early announcement of 2°C compatible policies (Bridge-2°C). Total greenhouse gas emissions were calculated based on global warming potentials from IPCC's second assessment report (SAR).*

Source: REMIND model calculations, EDGAR (JRC/PBL, historical emissions),
PBL INDC Tool calculations (www.pbl.nl/indc INDC range and best estimate) and IPCC AR5 scenario database

** with action starting after 2010*

without providing assurances that research, development and deployment of this technology would be sufficient to rapidly assure its commercial availability.

It seems like there is insufficient policy focus to disincentivize fossil fuel use, in particular via carbon pricing and emissions performance standards. Without such policies, low carbon support policies face an uphill battle to replace fossil fuel infrastructure.

Building the Bridge from INDCs to 2°C

The number of INDCs submitted and their level of ambition constitute a significant improvement over previous policy commitments. They have initiated a broad and interlinked policy process at national and international level, giving an entry point to put the world on track to 2°C. However, by themselves INDCs as currently submitted are not yet in line with 2°C. Therefore, the report develops a 'bridge scenario', in which action is strengthened and accelerated by 2020.

- **Key finding:** ***INDCs imply an acceleration of climate action and a deviation from previous trends and policy commitments. However, they would necessitate very stringent and rapid mitigation measures post-2030 if the 2°C target is to be met. This would imply at the global level significantly higher costs and risks to feasibility compared to a scenario of earlier, stronger action. A dynamic approach to climate policy-making, under the Paris agreement, with further rounds of strengthened policy commitments, is critical to keep the 2°C target in reach. This policy strengthening would need to happen rapidly after 2015.***

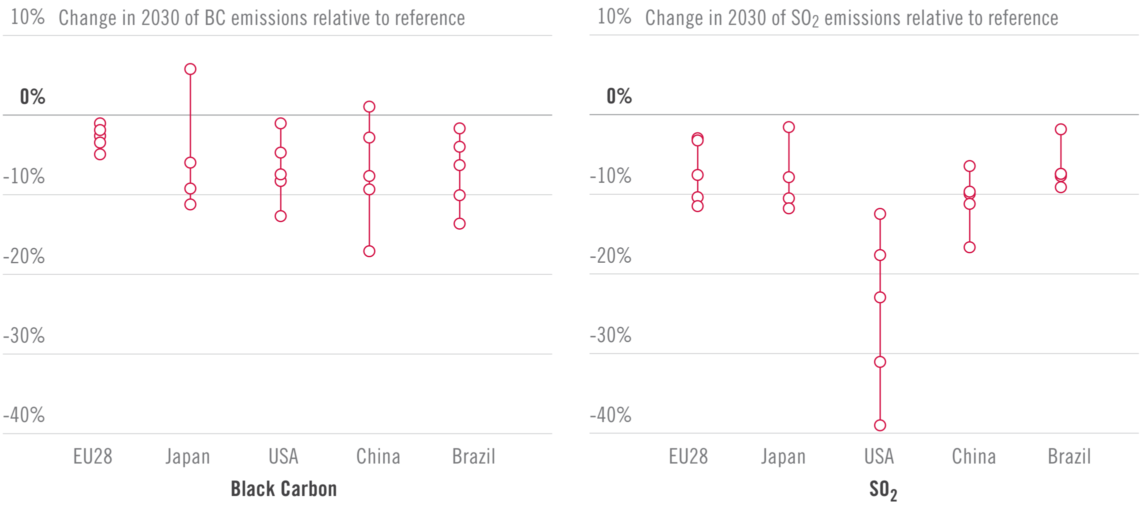
INDCs lead to a significant reduction of emissions compared to projections based on existing policies and commitments (Figure D). Nonetheless the global INDC scenario in this report showing emissions of 54 $GtCO_2eq$[3] in 2030 is above the emissions range of cost-effective scenarios consistent with the 2°C goal as estimated by the IPCC's Fifth Assessment Report (30-50 Gt CO_2e in 2030). **With this level of emissions in 2030, emissions reductions would need to be extremely rapid, more than 4% per year, if the 2°C objective is to be met.**

The bridge scenario represents a situation in which by 2020 targets and policies for 2030 are strengthened, and ideally new ambitious targets

---

[3] Source: REMIND model and PBL INDC Tool.

Figure E. Assessment of local air pollution co-benefits of INDCs



Source: IIASA calculations

Each dot represents the estimate based on a different model ○

proposed for the period after 2030. Due to this strengthening of policy commitments by 2020, energy sector and other actors perceive the long-term commitment to attain the 2°C goal as credible, and therefore restructure their investments in the energy sector early on and reduce emissions below the level of what would be required by current INDCs in order to avoid abrupt and rapid reductions after 2030. The report shows that this can lower global emissions in 2030 substantially to around 49 Gt-CO_2eq/yr, close to the upper bound of the range of cost-effective 2°C scenarios in AR5, amounting to an overachievement of current INDCs by more than 5 GtCO_2eq/yr in 2030. In the bridge scenario, cumulative low-carbon electricity investment exceeds that in the INDC scenario by roughly half between 2020-2030, while reducing investments into new freely emitting fossil-fuel power capacity by a third compared to today's level and the INDC scenario. The bridge scenario can play a major role in avoiding a carbon investment bubble and stranded assets in the energy sector.

If the provisions for such continuous strengthening of policy commitments in the Paris Agreement are perceived credible and backed up by strengthening national policies, it can have an **immediate and amplifying effect** on the transformation process by shifting expectation of businesses and altering investment decisions. Addressing the pre-2020 ambition gap through stronger national policies and international cooperative initiatives is also crucial. **This analysis shows the crucial importance of a system of dynamic revision and a credible long-term goal in the Paris agreement.**

Socio-Economic Implications in the Context of Multi-Objective Development Strategies and INDCs

Governments inevitably have multiple objectives: reducing environmental damage, promoting growth and jobs, innovation and competitiveness, energy security, etc. They must assess the interaction between these objectives in defining climate policy. In this report, we have considered co-benefits and trade-offs through a quantified assessment of national model results and country case-studies.

- Key finding: *INDCs can lead to significant co-benefits to climate mitigation in the countries studied, in terms of percentage reductions in energy import dependency and local air pollution. Such co-benefits can be a significant driver to develop ambitious national climate policies.*

For energy importers, INDCs can lead to significant improvements in **energy security**. The report estimates reductions in energy imports in the order of 2-12% in China, 9-17% in Japan and up to 9% in the EU in 2030, compared to a reference scenario with existing policies but no further climate action. In the Japan case study, import dependency is reduced from 94% today to 75% under the INDC scenario in 2030 (taking nuclear electricity as a domestic energy source), reducing import bills by 23% from 283 billion USD to 219 billion USD.

Implementing INDCs also implies significant co-benefits in terms of reducing **local air pollution**.

In China, the report estimates a reduction of black carbon and sulphur dioxide in the order of 5-10% and about 10% respectively (mid-range of the estimates) in 2030, compared to a Reference Scenario of existing policies and no further climate action (Figure E).

Key Conclusions and Recommendations

This report has assessed the aggregate and real-economy effect of INDCs. Doing so can provide a more detailed national and sectoral picture of progress being made, and areas where further policy efforts are required. There are three key conclusions from the analysis:

- In the analysis of this report, INDCs **accelerate and consolidate** action on climate change in key major economies and at the global level. A significant transition appears in the electricity sector, with the dynamic of technology deployment approaching what is required for 2°C. The whole process towards the Paris negotiations has established a dynamic on which future policy and business strategies can build.
- There appears to be **uneven progress** on addressing the drivers of GHG emissions, when we consider what actions are projected to underpin the implementation of INDCs. Future climate cooperation and national policy must consider how to address specific barriers to certain crucial solutions, such as accelerating innovation and deployment of post-2030 mitigation options and limiting carbon lock-in.
- The INDCs are **an entry point** to put the world on a trajectory towards 2°C but as currently submitted may not be enough to keep the 2°C goal in reach. Post-2030, the required rate transformation of necessary reductions is very high and potentially costly. In order to address this, the Paris Agreement should establish a clear mechanism to allow the regular, predictable and timely revision of national contributions and the global framework. New contributions should be based on a vision for the deep decarbonisation of national energy systems. **The Paris agreement should foster the development of national deep decarbonisation pathways by 2018.**

1. INTRODUCTION

Countries have committed to signing a new global agreement on climate change in Paris by the end of 2015. The bricks of this agreement are the so-called 'intended nationally determined contributions' (INDCs), which contain countries' proposed undertakings on mitigation and, for some, adaptation. Regarding mitigation, these INDCs contain a range of different emissions targets, expressed in different forms and against different years. They are often accompanied by descriptions of more precise aspirations regarding aspects of the transition to a low-carbon economy, such as goals for renewable energy, non-fossil fuel energy, or specific regulatory policies.

Given this diversity, understanding the implications of INDCs for the transition to a low-carbon economy in line with the 2°C or 1.5°C objective is challenging. It is also challenging for another reason. More than the precise emissions level in a given year, the potential of INDCs to limit warming to 2°C is determined by their capacity to unleash concrete transformations, particularly in the global energy sector, which would allow the deep decarbonisation of the global economy by 2050. These transformations are technological, infrastructural, economic and financial, and social and political. Multiple transition pathways are possible, but only some are coherent with long-term deep decarbonisation. Moreover, the transition pathway developed towards a certain year, such as 2030, conditions profoundly both what can and what must be done thereafter in order to reach long-term climate goals.

The objective of this report is to analyse the energy sector transformations that would be required to reach INDCs, and understand what these transformations imply for the goal of limiting warming to 2°C. This report is the result of an international research project encompassing 15 leading research teams from 11 countries (see authors' list). It is structured as follows:

- Section 2 provides a national level assessment of INDCs for five countries and one region – the EU, the US, China, India, Brazil and Japan – which together account for 60% of global emissions from fossil fuel combustion, and 74% of global GDP in 2012. This analysis focuses on the years 2025 and 2030, while taking into account the need for a long-term trajectory to 2050.
- Section 3 provides analysis of the co-benefits and trade-offs of INDCs, with a particular focus on their implication in major economies for local air pollution and energy security, notably energy import dependency.
- Section 4 provides a global assessment of the impacts of INDCs in the energy sector, in the light of the 2°C goal. It explores the post-2030 energy sector transformations and emissions trajectory that would be required to hold warming to below 2°C, given the implementation of INDCs. It also develops a 'bridge' scenario, in which policy action is strengthened by 2020 in order to smooth the transition from INDCs to a 2°C trajectory.

Throughout this paper, a number of case studies deepen the analysis presented in the main body of the report. These are not essential to the understanding of the report as a whole, but contain in themselves a wealth of interesting analysis. Readers are invited to browse them or focus on the main report as they prefer.

2. UNDERSTANDING THE EFFECTS OF INDCS AT THE NATIONAL LEVEL

2.1. Introduction and Methodology

The objective of this chapter is to build a better understanding of the implications of INDCs at the national level, in terms of the transformations that they imply in the real economy. The analysis of this chapter focuses on the 6 countries/regions with research teams contributing to the MILES project – the United States, the European Union, Japan, China, India and Brazil. Together, these countries made up 60% of global GHG emissions excluding land-use in 2012, or 56% of global GHGs including land-use. Countries represented in the MILES project made up 74% of global GDP at market exchange rates in 2012. The analysis in this chapter focuses particularly on the energy sector. GHG emissions from the energy sector represent 80% of emissions in the countries represented in the MILES project in 2012.[4]

The methodology in this chapter gives a detailed vision for the potential transformation induced by the INDC in the energy sectors of the countries assessed. There are several reasons for trying to understand the potential transformations induced by the INDCs with this high level of granularity:

- It can help to increase the national and international credibility of the INDCs, by understanding what transformations and policies would be required to implement them.
- It can provide useful information to the public and private sectors at the national and international level, in terms of the strategies being pursued, the potential future growth of low-carbon technologies, energy markets, and so on.
- It can provide further understanding of the opportunities, barriers and level of ambition for the INDCs.
- It can provide complementary analysis to attempts to aggregate the effects of INDCs relative to 2°C, for example by comparing technology deployment in the INDC scenarios and 2°C scenarios.

The assessments in this chapter are provided on a country by country basis, as the focus is on the implications of the INDCs at the national level. The objective is not to compare across countries: significant differences in the development and resource endowments of each country render cross-country comparison difficult. Rather the objective is to provide as detailed an understanding as possible of the INDC at the national level.

In order to understand the methodology of the analysis here, it is important to provide the distinction between *INDCs* and *INDC scenarios*. INDCs provide the headline target(s) for emissions and in some cases other related targets such as a non-fossil fuel share in the energy mix. INDC scenarios involve the development of detailed, internally coherent scenarios which explore the INDCs' implications for the energy sector. In order to develop these INDC scenarios, each national research team has used the modelling and analytic tools available to them. Each country research team has also benefited from its proximity to the policy process and public debate in their country. The INDC scenarios therefore include both the headline targets of INDCs, but also the underlying policy vision to achieve the INDC, to the extent of each country research team's knowledge.

The results have been presented using a consistent data template, ensuring the usability and transparency of results. In addition to the data

---

[4] All data from this paragraph based on CAIT. Available at: http://cait.wri.org/

submissions, each country research team has developed or is developing under the MILES project a detailed report on the implications of their country's INDC.

INDC scenarios should therefore not be taken as predictions, still less as government policy, but rather as credible, detailed and internally coherent explorations of pathways towards achieving the headline ambitions announced in the INDCs.

The following subsections present the analysis for each country represented in the MILES project. An effort has been made to present similar information in each subsection, although this needs to be balanced with flexibility to present the unique circumstances of each country.

2.2. The European Union

Analysis of effect of the INDC scenario in the energy sector

The European Union (EU) submitted its INDC on the 6th of March 2015.[5] Under its INDC, the European Union and its Member States are committed to a binding target of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990. This covers the following greenhouse gases (GHGs): CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3. All emitting sectors are covered, and international credits will not be used. The EU had also previously adopted an objective to reduce emissions by 80-95% by 2050 compared to 1990, based on the reductions assessed to be consistent with the 2°C target by the IPCC AR4 report for developed countries as a group.[6] The EU's INDC is therefore intended by European policy makers to be a credible mid-term milestone towards this 2050 objective. The EU's INDC is based on the policy targets and orientations adopted by the European Council of heads of state in October 2014, under the so-called EU 2030 Climate and Energy Framework.[7] These are presented in Table 1.

Case Study 1: shift in investment requirements for INDC implementation in the EU

The implementation of the European INDC (that envisages at least 40% reduction in domestic GHG emissions in the period 1990-2030) implies significant changes in investment requirements for the EU energy system both in demand and supply sectors.

Investment expenditures[1] for the energy system increase already in the Reference scenario from 638 bn. €' 10 in 2010 to 826 bn. € in 2020 and to 873 bn. € in 2030, i.e. a growth of 37% during 2010-2030. The main reasons for the increase are:

- Replacement of ageing energy infrastructure (power plants, passenger cars, electricity grids, gas pipelines, petroleum refineries)
- Extension and enhancement of network infrastructures
- Additional investments in the framework of already agreed policies as part of the 2020 Energy and Climate Package (mainly directed towards energy efficiency improvements in energy demand sectors and accelerated deployment of renewables)

The EU INDC implies a further increase in energy related upfront investments by 10% from Reference levels in 2030, while the benefits of these investments in terms of reduced fuel spending are more tangible in the longer term. Capital expenditures increase following the accelerated penetration of renewable energy sources, advanced energy efficient technologies, equipment and infrastructure (e.g. insulation investments to improve thermal integrity of the European building stock, RES for power generation, advanced efficient appliances, improvement in grids, hybrid vehicles).

The 2030 Energy and Climate policy framework and the European INDC can facilitate effective market coordination between different energy/economy system actors in the decarbonisation process (technology providers, individual consumers, infrastructure developers, policy-makers). Investments in energy efficiency and low/zero carbon technologies can be triggered by specific policy instruments like the ETS (clear price signal), while specific energy efficiency and renewable policies can provide further incentives for extensive restructuring of the EU energy system. Even with ETS reform, a tightening of the ETS cap and increased carbon prices, it is unlikely that carbon pricing alone can trigger sufficient investments in the energy system towards carbon abatement especially in the buildings and transport sectors. Complementary policies are required in order to overcome market and non-market barriers and to achieve the required investments for the cost-effective implementation of the EU INDC, especially in the period after 2020.

Sectoral investment trends:

In 2010, the transport sector accounted for about 85% of the overall energy system investments due to high expenditure requirements for vehicles purchases (especially for passenger cars), vessels and railways. The Reference scenario shows an increase in investments in all energy sectors by 2030, with transport and power supply accounting for about 90% of the overall increase

---

[1] Annualized and discounted

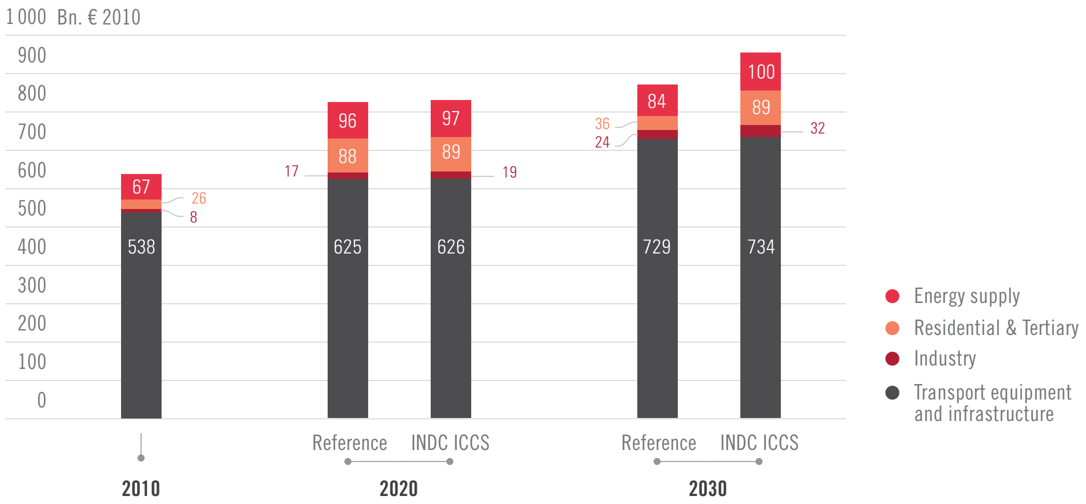
---

[5] Submission by Latvia and the European Commission on behalf ff the European Union and its member states, Riga 6 March 2015. Available at: http://www4.unfccc.int/submissions/INDC/Published%20Documents/Latvia/1/LV-03-06-EU%20INDC.pdf

[6] Council of the European Union (2009), "Presidency Conclusions". Available at http://www4.unfccc.int/submissions/INDC/Published%20Documents/Latvia/1/LV-03-06-EU%20INDC.pdf

[7] European Council, 23 and 24th of October 2014, Conclusions. Available online at: http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf

Figure. Energy system investments, European Union



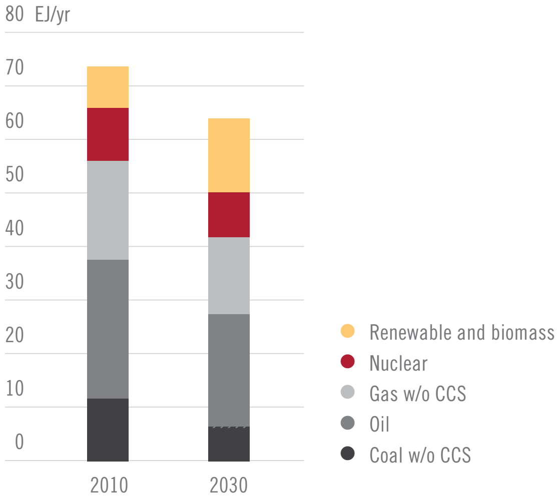
Source: ICCS, PRIMES model

between 2010 and 2030.

Based on PRIMES results (see figure above), the implementation of the EU INDC requires higher investments relative to the Reference scenario especially in the residential/commercial and in the energy supply (power generation) sectors, which account for 65% (54 bn. €) and 19% (16 bn. €) respectively of the overall increase in 2030. In the INDC context, the most important policy challenges that the EU faces are the large-scale deployment of intermittent Renewable technologies for electricity production (which must be complemented with additional investments for grid enhancement, storage, balance and flexible generation) and massive energy efficiency investments in buildings (retrofits, deep renovation of households, investments for energy using equipment and direct energy efficiency investment for improving thermal integrity of households). On the other hand, electrification of the transport sector which is considered as a critical ingredient of the transition to a low-carbon economy will mainly take place in the period after 2030 and thus the increase in transport-related investments is relatively modest, while the share of transport in overall energy system investments declines from 84% in the Reference to 77% in the ICCS INDC scenario in 2030.

In order to understand the investment challenges at macroeconomic level, we must compare energy investment figures with overall EU GDP. In 2010, total energy system investments accounted for 5.2% of European GDP. The Reference scenario implies a stabilisation of energy investments as a percentage of GDP for the period 2010-2030. On the other hand, the EU ICCS INDC scenario leads to an increase of overall energy investment expenditures which in 2030 represent 5.7% of the EU GDP. Transport investments account for the bulk of overall energy investments and represent 4.4% of EU GDP in 2030 (in both scenarios). The implementation of the EU INDC leads to particularly high investment challenges for the residential/commercial sector, as investment expenditure have to increase by about 2.5 times (from 0.2% of EU GDP in Reference to 0.5% in the EU ICCS INDC scenario). Investment in the energy supply sector (including power plants) increase from 0.5% of the EU GDP in Reference to 0.6% in EU ICCS INDC scenario in 2030, as a result of accelerated deployment of capital-intensive low-carbon technologies and additional investments for grid expansion and enhancement in order to complement massive penetration of variable renewables (storage, back-up capacity, intelligent grids, flexible generation).

Figure 1. Primary energy, European Union



Source: ICCS, PRIMES model

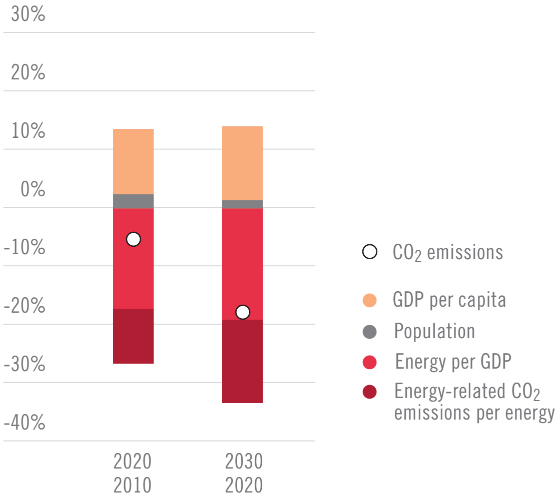
Table 1: targets and policy orientations adopted under the EU 2030 Climate and Energy Framework

		2030 target
Greenhouse gases	All sectors	At least -40% from 1990 levels
	Sectors covered by the European Emissions Trading Scheme	-43% from 2005 levels
	Sectors not covered by the European Emissions Trading Scheme	-30% from 2005 levels
Renewable energy	Renewable energy share in gross final energy consumption	27% at European level
Energy efficiency	Absolute reduction in primary energy demand compared to a BAU case	-27% (indicative)

Source: Authors

The analysis in this section is based on the scenarios developed by Energy-Economy-Environment Modelling Laboratory (E3MLab) at the National Technical University of Athens, using the PRIMES energy system model and the GEM-E3[8] macroeconomic model. These models are often used by the European Commission for Impact Assessments and related analysis of EU energy and climate policies. The ICCS INDC scenario presented here assumes a 40% reduction in EU GHGs emissions by 2030 compared to 1990, while in the long term it assumes the achievement of an 80% GHG emissions reduction by 2050 (in line with the "Roadmap for moving to a competitive low carbon economy in 2050"). The headline macroeconomic drivers in the ICCS INDC scenario are reproduced in Table 2.

Figure 2. High-level drivers of emissions changes, EU



Source: ICCS, PRIMES model

Table 2: headline drivers in the EU ICCS INDC scenario

	2010	2020	2030
GDP (billion US$2005)	13901	16098	18834
Population (million)	504	517	525

Source: ICCS, PRIMES and GEM-E3 models

Figure 1 presents the evolution of EU primary energy demand[9] by energy source between 2010 and 2030 in the ICCS INDC scenario. A 13% reduction of primary energy demand is achieved, with demand falling to 64.3 EJ in 2030. The largest reduction is in coal demand, which falls by 45%. Primary energy from renewables and biomass, on the other hand, grows by 80%. Figure 2 represents the high-level drivers of decarbonisation in the EU in terms of the so-called Kaya identity, which describes changes in CO2 energy-related emissions as the product of four factors:

- 1. Change in population
- 2. Change in GDP/capita
- 3. Change in final energy consumption / GDP (energy intensity)
- 4. Change in carbon emissions / unit of final energy (carbon intensity)

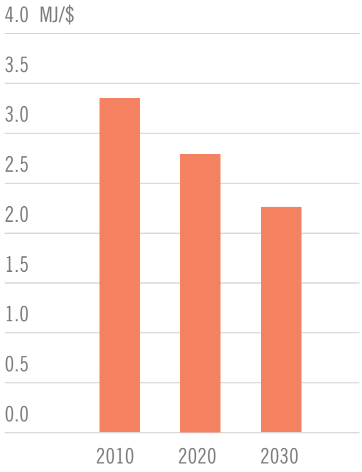
Compared to the period 2010-2020, the decarbonisation of European energy system accelerates dramatically in the decade 2020-2030, as a result

---

[8] www.gem-e3.net

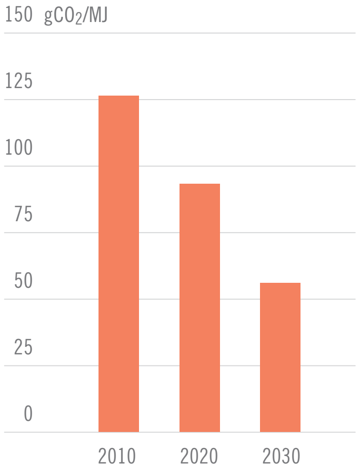
[9] Defined as total primary energy consumption (PRIMES results are consistent with the EUROSTAT and IEA conventions that use the physical energy content method for calculating primary energy equivalent of alternative energy forms and fuels).

Figure 3. Energy intensity of GDP, European Union



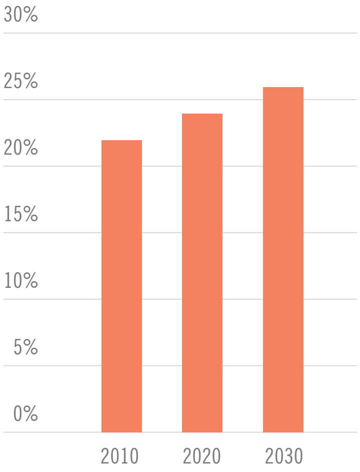
Source: ICCS, PRIMES model

Figure 4. Carbon intensity of electricity production, EU



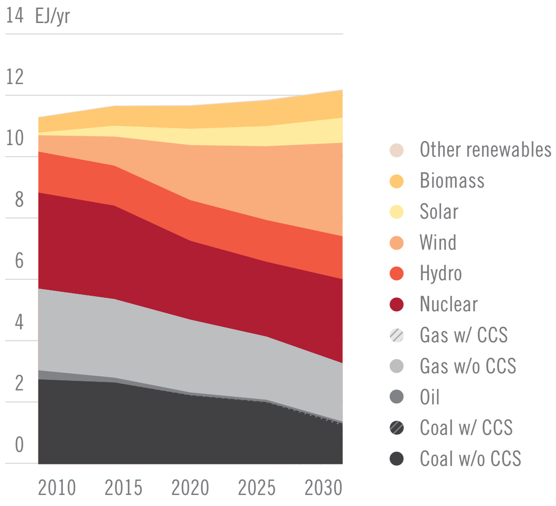
Source: ICCS, PRIMES model

Figure 5. Electrification of final energy demand, EU



Source: ICCS, PRIMES model

Figure 6. Electricity supply, European Union



Source: ICCS, PRIMES model

of further renewables growth to substitute for fossil fuels in both electricity generation (mainly wind turbines and solar PV) and in final energy consumption (biofuels in transport, biomass and solar thermal heating in buildings), and a slight increase of nuclear electricity. Improvements in energy intensity provide the bulk of emissions reductions, underscoring the importance of strong energy efficiency policies in all energy demand and supply sectors, including more ambitious standards, regulations for heating and electrical appliances, higher renovation rates in buildings, stringent implementation of the Efficiency-related directives, purchase of more efficient energy equipment and vehicles by energy consumers. This improvement in energy efficiency represents a major challenge of implementing the EU INDC.

Figures 3-5 present the so-called three pillars of decarbonisation: improvements in energy intensity, decarbonisation of electricity, and the shift from fossil fuels to electricity in final energy (for example, the shift from internal combustion engine to plug-in hybrid and full electric vehicles).[10] In the INDC scenario the EU's energy intensity improves by 33% between 2010 and 2030 (Figure 3), or 2.1% per year compared to 1.5% over the last 10 years. An even more significant improvement is required in the carbon intensity of electricity supply, which reduces by 56% between 2010 and 2030, reaching 50.9 tCO2/TJ and entailing very significant changes in the EU's electricity generation mix.

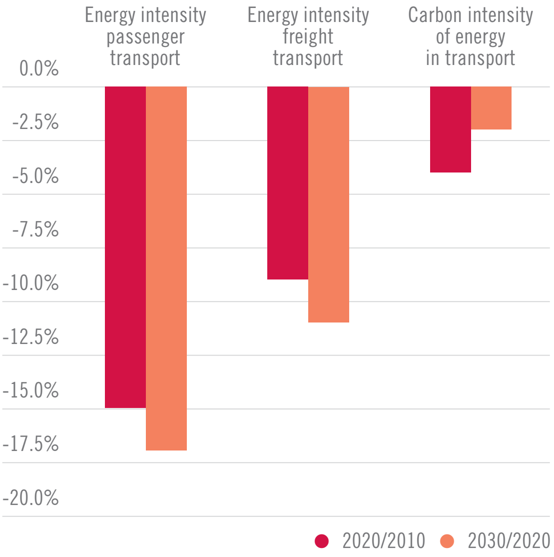
Figure 6 presents this changing electricity mix between 2010 and 2030 under the ICCS INDC scenario. As can be seen, the share of renewables grows very significantly, making up 50.7% of the EU electricity mix by 2030. This entails a compound annual growth rate for wind of 9.1% and 12% for solar in the period 2010 to 2030. The share of nuclear falls by 5 percentage points between 2010 and 2030; by 2030 a small amount of CCS is modelled to be coming online.

Figure 7 and Figure 8 present the major drivers of decarbonisation in two significant end-use sectors:

---

[10] The concept of the three pillars of decarbonisation is further developed in the report of the Deep Decarbonization Project. Cf. IDDRI and SDSN, "Pathways to Deep Decarbonization – 2014 Report". Available online at: www.unsdsn.org/wp-content/uploads/2014/09/DDPP_Digit.pdf

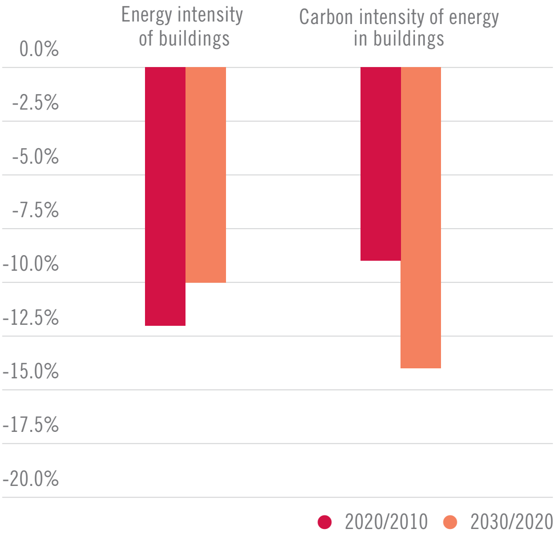
Figure 7. Energy and carbon intensity in the transport sector, European Union



Energy intensity in passenger and freight transport is calculated as TJ/pkm and TJ/tkm respectively.

Source: ICCS, PRIMES model

Figure 8. Energy and carbon intensity in the buildings sector, European Union



Energy intensity of buildings is calculated as TJ/capita.

Source: ICCS, PRIMES model

transport and buildings.[11] It can be seen that the carbon intensity improvement of energy consumption in the transport sector is slight, and indeed slows down in the decade from 2020-30, compared to 2010-20. This is because of slower penetration of biofuels due to concerns regarding the life-cycle emissions impacts of biofuels, the displacement of food production, as well as the lack of an explicit target for biofuels deployment after 2020. Increased electrification of transport through modal switch and growing deployment of plug-in hybrid and electric vehicles is not able to fully compensate this slow-down in the penetration of biofuels. Electricity contributes 3% to final energy consumption in transport in 2030, and biofuels 8%; oil falls from 95% in 2010 to 88% of final energy consumption in transport in 2030. Further, important improvements in energy intensity are observed (Figure 7). These offset significant increases in the demand for transport services as economic activity, trade and standards of living increase: passenger kilometres per capita are projected to grow by 18% between 2010 and 2030, and tonne kilometres grow by 37%. Overall, transport emissions are reduced by 11% between 2010 and 2030 mainly as a result of significant improvements in energy efficiency.

The buildings sector, on the other hand, reduces emissions by 36% between 2010 and 2030. The drivers of this are shown in Figure 8. Significant improvements in energy intensity drive an 18% reduction in total buildings final energy demand between 2010 and 2030. In order to achieve this, large-scale deep retrofits of the buildings stock are required. Energy supply in the buildings sector also decarbonizes, as electricity displaces fossil fuels and specific electricity consumption increases (i.e. new uses for electricity such as information technology). Electricity's share in final energy demand in the buildings sector increases from 33% in 2010 to 43% in 2030.

Emissions Outcomes and Conclusions

The section above presented the main energy sector transformations induced by the EU ICCS INDC scenario. Table 3 shows the results in the emissions reductions for the energy sector. It should be noted that scenario results for all GHGs and emitter sectors were not reported for the EU under the MILES project, due to the focus on the energy sector.

The analysis above shows the importance of the decarbonisation of electricity supply in Europe, through notably the massive penetration of renewables. This poses a policy challenge in terms of appropriate incentive schemes (such as feed-in-tariffs and subsidies), appropriate electricity market design, provision of the required storage and flexible generation to balance and support a rapidly growing share of variable renewables, and grid enhancement, reinforcement and interconnection

---

[11] The carbon intensity is measured in terms of direct emissions from transport and building, excluding indirect emissions from electricity generation.

see case study number 1 below. Two other challenges can be highlighted related to the improvement of energy efficiency in the buildings and transport sectors, both of which must significantly contribute to the reduction of energy-related GHG emissions. Vehicle performance standards, currently in place to 2020, will need to be extended to the freight transport sector and tightened for the period after 2020. Ambitious retrofit programs of the building stock will need to be developed and financed.

Table 3: emissions reductions achieved in the EU ICCS INDC scenario (Mt CO_2 from fossil fuel combustion and industry)

	2010	2030
Electricity	1295	621
Buildings	647	416
Industry	756	676
Transport	1051	936
Other	266	187
Total	4015	2836

Source: ICCS, PRIMES model

The analysis suggests that the EU's INDC represents a significant acceleration of the decarbonisation of the EU economy, notably in the electricity supply, transport and buildings sectors. It also points to some of the challenges beyond 2030. Electrification of road transport, although at a low level in 2030, would have to be scaled up dramatically (in combination with provision of the required recharging infrastructure) thereafter to reduce transport-related emissions. Likewise, CCS which is a very small in the ICCS INDC scenario in 2030, will have to be deployed at scale to further reduce both power generation emissions and start to make a dent on industrial emissions.

2.3. Japan

Analysis of effect of the INDC scenario in the energy sector

Japan presented its INDC to the UNFCCC on the 17th of July 2015.[12] Japan's INDC is to reduce GHG emissions by 26% by 2030 compared to 2013 levels, equivalent to a 25.4% reduction against 2005 levels. This would equate to emissions levels of about 1.042 Gt CO_2eq in 2030. All sectors and all GHGs (CO2, CH4, N2O, HFCs, PFCs, SF6, and NF3) are covered by Japan's INDC (Table 4). A detailed estimation of sectoral reductions is given alongside the INDC (Table 5), as well as an estimation of the level of final energy consumption in 2030 and electricity generation mix in 2030. In this regard, the Japanese INDC provides a high level of transparency regarding the strategy required to achieve its INDC.

Table 4: Description of the Japanese INDC

Commitment	GHG emissions reduction of 26%by 2030 compared to 2013 (25.4% compared to 2005)
Greenhouse Gases	Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)
Calculation	Net emissions (including LULUCF)
Aggregation Across Gases	CO_2-equivalent using 100-year global warming potential (GWP) values taken from IPCC AR4.
Sectors	Energy, Industrial processes and product use, Agriculture, LULUCF, Waste
Reference Year	FY 2013 and FY 2005
Target Year	FY 2030

Source: http://www4.unfccc.int/submissions/INDC/Published%20Documents/Japan/1/20150717_Japan's%20INDC.pdf

Table 5: Estimated emissions of energy-originated CO_2 in each sector in the Japanese INDC (Mt CO2)

	Estimated emissions of each sector in FY 2030	FY 2013
Energy originated CO_2	927	1235
Industry	401	429
Commercial and other	168	279
Residential	122	201
Transport	163	225
Energy conversion	73	101

Source : http://www4.unfccc.int/submissions/INDC/Published%20Documents/Japan/1/20150717_Japan's%20INDC.pdf

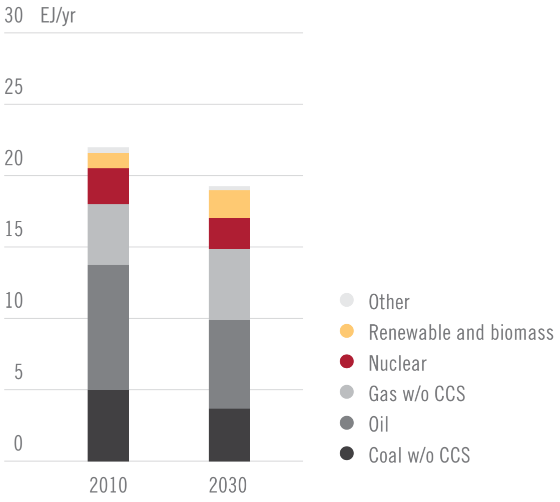
After the nuclear accident at the Tokyo Electric Power Company's Fukushima Dai-ichi Nuclear Power Station, the Japanese nuclear fleet was entirely stopped for safety reasons. The share of nuclear in gross electricity generation fell from 25.8% in 2010 to 1.3% in 2013. After the Fukushima accident, in July 2015 the Japanese Government finalized a «Long-term Energy Supply and Demand Outlook", which formed the basis of the Japanese INDC.

Within the context of the MILES project, two research teams from Japan provided INDC scenarios: the Research Institute of Innovative Technology for the Earth (RITE) and the National Institute for Environmental Studies (NIES). These scenarios are broadly speaking comparable, and both achieve the INDC target of a reduction of 26% against 2013 levels, or 25.4% against 2005 levels. Unless otherwise

---

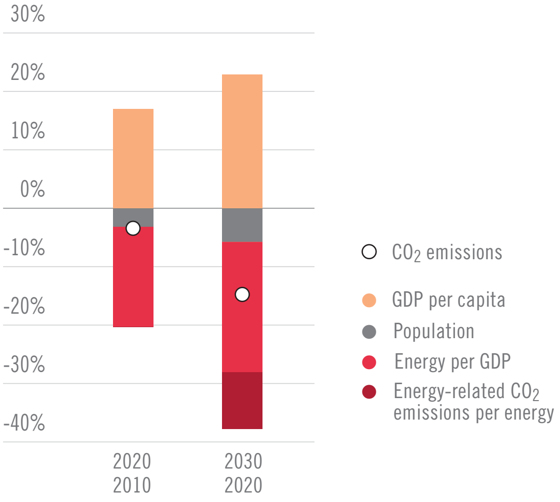
[12] Government of Japan (2015), Submission of Japan's Intended Nationally Determined Contribution (INDC). Available online at: http://www4.unfccc.int/submissions/INDC/Published%20Documents/Japan/1/20150717_Japan's%20INDC.pdf

Figure 9. Primary energy, Japan



Source: NIES AIM/Enduse [Japan] model

Figure 10. High-level drivers of emissions changes, JP



Source: NIES AIM/Enduse [Japan] model

indicated, in this subsection the figures are taken from the INDC scenario provided by NIES, while the discussion in the text builds on both scenarios and points to interesting differences between the two. The headline macroeconomic drivers in the two INDC scenarios are reproduced in Table 6.

Table 6: headline drivers in the NIES and RITE Japanese INDC scenarios

	2010	2020	2030
GDP (billion US$2005) NIES GDP (billion US$2005) RITE	4619 4648	5322 5343	6406 6429
Population (million) NIES and RITE	128	124	117

Source: NIES AIM/Enduse[Japan] model and RITE DNE21+ model

The cornerstone of the NIES INDC scenario is a significant improvement in energy intensity[13], which poses a big challenge in a country that is already as efficient as Japan. Figure 9 provides an overview of primary energy supply between 2010 and 2030, which falls by 12.4% reaching 19.3 EJ/yr in 2030. The sectoral division of these improvements and the challenge that this entails is discussed further below. Figure 10 shows the four high-level drivers of decarbonisation in the NIES INDC scenario. Improvements to energy intensity provide the bulk of emissions reductions in the decades 2010 to 2020 and 2020 to 2030. In the first decade, decarbonisation of the Japanese energy supply is marginal, due to the 2 percentage point drop in nuclear as a share of primary energy and the time-lag required to ramp up renewable energy. By contrast, in the decade 2020 to 2030 the decarbonisation of the Japanese energy supply accelerates, as renewables ramp up and nuclear reaches its pre-Fukushima level in Japanese primary energy supply (11%). A similar pattern is seen in the RITE INDC scenario for Japan, in which decarbonisation of the energy supply contributes just 1% to the decline of Japanese emissions in the decade 2010-2020, before jumping to 11% in the decade 2020-2030.

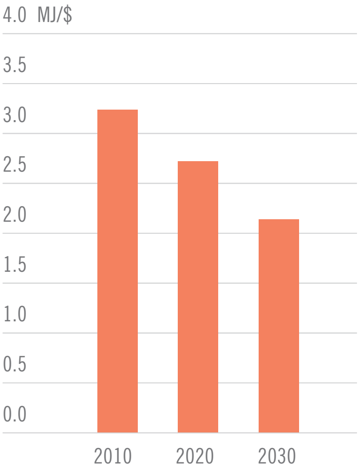
Figures 11-13 display the impacts of the NIES INDC scenario across the three pillars of decarbonisation. It was noted above that a reduction in energy demand provides a crucial driver of emissions reductions in the INDC scenario. Energy intensity of the GDP falls by 34% between 2010 and 2030, leading to an intensity level of 2.2 MJ/M$ GDP. Final energy consumption falls by 8.4% between 2010 and 2030 in absolute terms, to a level of 13.7 EJ in 2030. This is close to the level projected by the Japanese government in the information accompanying its INDC submission, namely a reduction of 9.7% in absolute terms between 2013 and 2030. In the electricity sector, after rising slightly between 2010-2020 due to Fukushima, the carbon intensity of the Japanese electricity mix decreases by 28% reaching 79.4 tCO2/TJ in 2030. A similar level is reached in the RITE INDC scenario, namely 74.6 tCO2/TJ. Electrification of final energy demand also climbs significantly, reaching just under 26% of total final energy consumption in the NIES INDC scenario and 27.45% of final energy demand in the RITE INDC scenario.

Figure 14 displays the electricity mix for Japan in 2010, and in 2030 in the NIES and RITE INDC scenarios respectively. The NIES INDC scenario

---

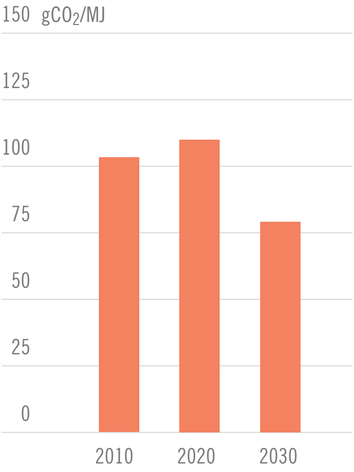
[13] Energy intensity is defined as final energy consumption/GDP.

Figure 11. Energy intensity of GDP, Japan



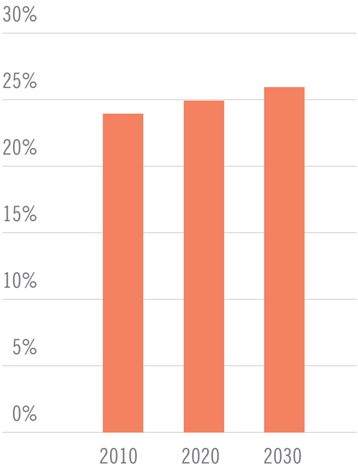
Source: NIES AIM/Enduse [Japan] model

Figure 12. Carbon intensity of electricity production, Japan*



Source: NIES AIM/Enduse [Japan] model

Figure 13. Electrification of final energy demand, Japan



Source: NIES AIM/Enduse [Japan] model

** It should be noted that there are no official energy-related targets for 2020. Therefore the 2020 carbon intensity of electricity depends of the assumptions on the electricity mix, especially on the schedule for restarting nuclear power plants. In this modelling scenario, nuclear power is restarted but still stays at a low level in 2020, accounting for the temporary rise in carbon intensity by 2020. Nonetheless, the main point holds true, namely that the challenge for Japan is to manage the challenges associated with its nuclear fleet, and drive down the carbon intensity of its electricity supply. This had led to a spike in carbon intensity of electricity in Japan.*

sees a slight absolute decline in electricity demand between 2010 and 2030, in the order of -3.7%; whereas the RITE INDC scenario essentially sees a stabilisation of electricity demand. In the context of economic growth and increasing electrification of final energy, this highlights the importance of electrical efficiency measures in end-use sectors.

Currently, the impact of Fukushima can be seen in the spike of coal and gas generation and to a lesser extent oil. Coal has jumped from 26.8% in 2010 of the Japanese electricity mix to 33.7% in 2014, while gas has jumped from 26.9% in 2010 to 39.6% in 2014.

In 2030, the NIES and RITE INDC scenarios reflect a broadly similar mix, with some differences. A key commonality is the strong increase of renewables, which rise from 9% of the electricity mix in 2010 to 20.3% in the NIES INDC scenario and 24% in the RITE INDC scenario. The total level of the production of nuclear is very close in 2030 in both scenarios, namely 231.6 TWh in the NIES INDC scenario and 222.6 TWh in the RITE INDC scenario. By contrast, the NIES scenario relies slightly more on natural gas (38.6%) than coal (17%), whereas the RITE scenario relies slightly more on coal (22.7% unabated coal and 26% if coal with CCS is included) and less on gas (27%). Japan is a country almost completely lacking in domestic fossil fuel resources, and therefore a key issue in the design of the energy and electricity mix is energy security. This is addressed further in case study number 6 below. One key conclusions emerging from the analysis summarized in Figure 14 is that there are multiple credible pathways to a transition in the Japanese electricity mix, which can contribute to implementing the Japanese INDC.

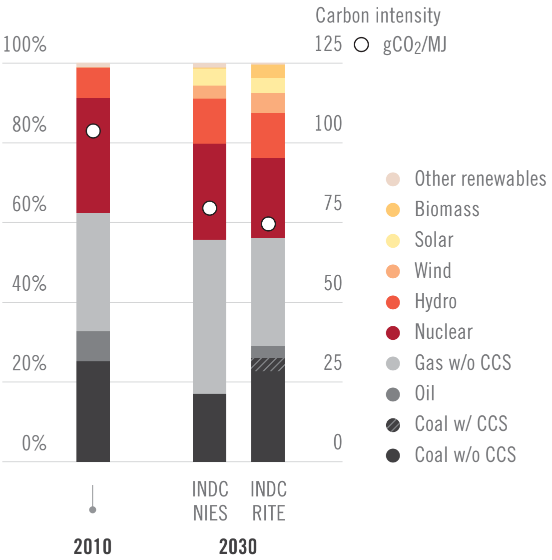
Figure 15 and Figure 16 show the improvements of energy and carbon intensity in the transport and buildings sectors under the NIES INDC scenario. It can be seen that the buildings sector must make significant improvements in energy intensity of 12% between 2010 and 2020 and a further 6% in 2020 to 2030 (a total of 18% between 2010 and 2030), through the purchase of efficient equipment. Likewise the carbon intensity of energy supply in the buildings sector improves by 14% between 2010 and 2030, thanks notably to a shift away from oil and further towards electricity and natural gas. The share of electricity in final energy consumption of the buildings sector increases to 53% by 2030. In the transport sector, continuous declines in energy intensity are achieved between 2010 and 2030, -27% for passenger transport and -7% in freight transport. The carbon intensity of transport fuel declines only by 2%, reflecting limited electrification and biofuel penetration.

Emissions Outcomes and Conclusions

Table 7 presents the emissions reductions achieved in the NIES INDC scenario for energy-related emissions. It can be seen that a significant reduction is achieved in the electricity, buildings and transport sectors.

The data represented in this Table are derived

Figure 14. Electricity supply, Japan

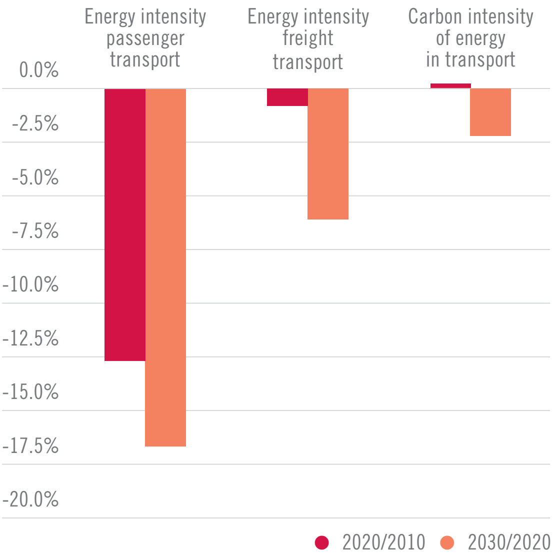


Source: NIES AIM/Enduse [Japan] model and RITE DNE21+ model

from the NIES INDC scenario, and not from the Japanese Government's INDC document, which provides detailed breakdowns by sector of how the INDC could be achieved.[14] The differences in the results presented here and those of the Japanese Government's INDC scenario are partly an outcome of the modelling framework used in the NIES INDC scenario. The NIES INDC scenario relies more on low-emissions electricity than end-use efficiency, as a result of cost-minimization by the AIM/Enduse model. In the NIES INDC scenario, the share of fossil fuels in power generation in 2030 is around 56%, the same share as in the Japanese Government's INDC document; but in the NIES INDC scenario, gas rather than coal makes up a greater share of residual fossil fuels. Moreover, the NIES INDC scenario controls all Kyoto-gas in 2030 in order to reach the 2030 INDC target, but the share of different GHGs depends on the model's optimization of reductions between sectors and gases. In this case, the reduction depends more on CO2 rather than non-CO2 gases. Hence, there is a difference in CO2 emissions between the NIES INDC scenario and the INDC document submitted by the Japanese government, although the NIES scenario reaches the total GHG emissions target as specified in the INDC document.

However, the central points developed here remain valid. The NIES INDC scenario underscore

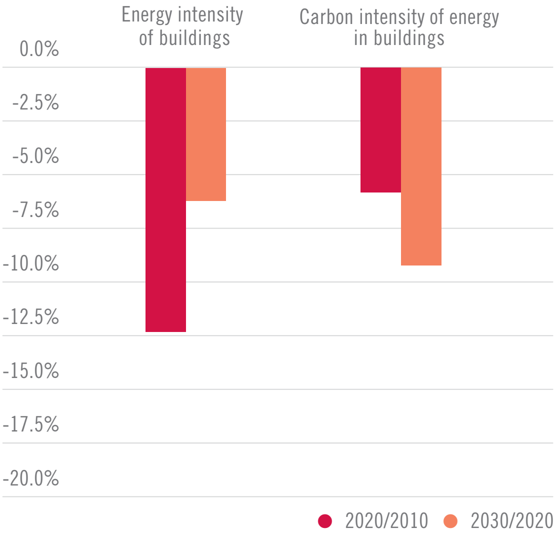
Figure 15. Energy and carbon intensity in the transport sector, Japan



Energy intensity in passenger and freight transport is calculated as TJ/pkm and TJ/tkm respectively.

Source: NIES AIM/Enduse [Japan] model

Figure 16. Energy and carbon intensity in the buildings sector, Japan



Energy intensity of buildings is calculated as TJ/capita

Source: NIES AIM/Enduse [Japan] model

some key transformational challenges facing Japan, in particular the significant improvement of end-use efficiency in buildings and transport, and the rollout of renewables in electricity while managing the challenges of the nuclear fleet. The NIES and RITE INDC scenarios demonstrate that the Japanese INDC appears feasible as long

---

[14] Government of Japan (2015), Submission of Japan's Intended Nationally Determined Contribution (INDC). Available online at: http://www4.unfccc.int/submissions/INDC/Published%20Documents/Japan/1/20150717_Japan's%20INDC.pdf

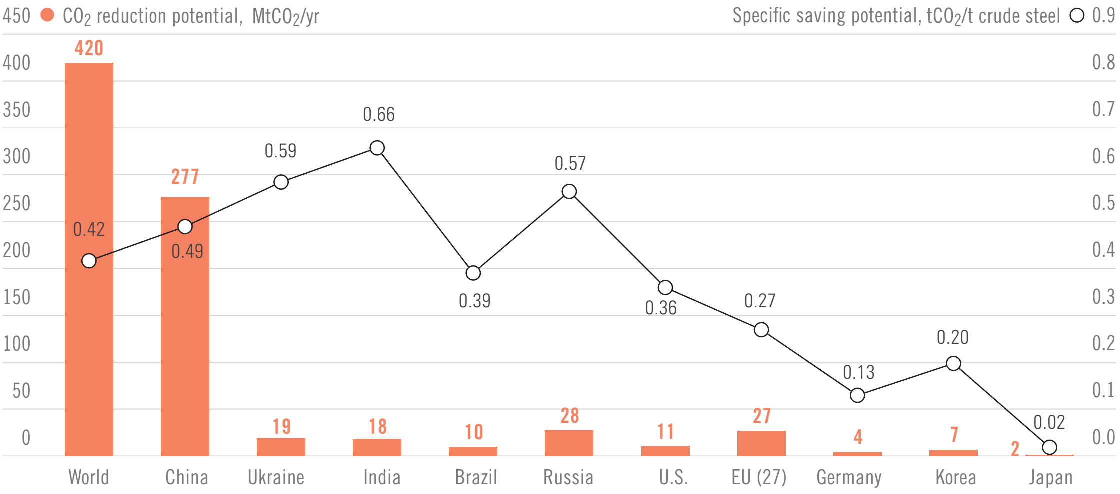
Case Study 2: Challenges and opportunities for emissions reductions in the industrial sectors

The above analysis of the Japanese INDC illustrated the importance of improved end-use efficiency in achieving emissions reductions. This will require pushing forward the technology frontier, by developing technologies that can then be diffused globally. A particular challenge relates to the reduction of emissions in the industry sectors, some of which are energy intensive, exposed to international competition and technologically difficult to decarbonize. The objective of this case study is to illustrate the potential of reducing emissions in the industry sectors globally, and describe some of the conditions for tapping this potential.

One area where short-term gains could be made is in improving the efficiency in iron and steel and cement industries. There are still large discrepancies in the efficiency of those sectors among countries, and room for substantial improvements in many of them (Oda et al., 2012). The estimated potentials of global emissions reductions in 2010 are about 420 million tCO2/year in the iron and steel sector, when best available technologies in 2010 are adopted throughout the world (Oda et al., 2013). In addition, the global potential of emissions reductions in 2020 in the cement sector are about 180 million tCO2/year when best available technologies in 2005 are adopted (Akimoto, 2012). The figure below shows global emissions reduction potential for crude steel.

Sector-based efforts for emission reductions with global cooperation are thus very important to achieve the emission reduction potentials. This in turn requires further sector-specific efforts in cooperation, to diffuse best-available technologies and mitigate the competitiveness concerns that may arise from applying stringent constraints to emissions-intensive, trade exposed industries (Spencer et al., 2015).

Figure. CO_2 reduction potential for crude steel (2010)



Source: Oda et al. 2013

as a significant restructuring of the Japanese energy system is achieved. The estimated marginal abatement costs for the INDC in 2030 are about 180 US$/t-CO2, and 260 US$/t-CO2 by NIES and RITE scenarios, respectively. A number of challenges emerge from this analysis. Firstly, the INDC requires ambitious energy efficiency and even conservation policies to reduce energy and in particular electricity demand. To implement this level of efficiency Japan will have to further push the technology frontier for efficient equipment, and explore options to conserve energy through structural measures. Secondly, energy security and affordability will continue to be important issues for Japan, as it emerges from the Fukushima crisis (see case study 4). Thirdly, the NIES and RITE INDC scenarios sees a huge growth in renewables in Japan, which will further drive global markets but also poses a challenge given the geographical constraints that Japan faces to exploiting renewables.

Table 7: energy related emissions 2010 – 2030, Japan under the NIES INDC Scenario (Mt CO2)

	2010	2030
Electricity	373	274
Buildings	153	108
Industry	346	315
Transport	225	193
Other	27	26
Total	1124	916

Source: NIES AIM/Enduse[Japan] model

2.4. United States

Analysis of the effect of the INDC scenario in the energy sector

On March 31, 2015, the United States submitted its Intended Nationally Determined Contribution (INDC) to the Framework Convention on Climate Change. The heart of that submission is an undertaking on the part of the United States "*to achieve an economy-wide target of reducing its greenhouse gas emissions by 26%-28% below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%.*"[15] The scope and coverage of the United States' contribution is summarized in **Table 8**. The United States' contribution is framed exclusively in terms of greenhouse gas emissions. It does not, for example, include technology standards or emissions intensity goals. It also eschews the use of international emissions trading mechanisms.

Table 8: Scope and Coverage of the United States INDC

Commitment	26-28% reduction in greenhouse gas emissions relative to 2005 in 2025.
Greenhouse Gases	Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)
Calculation	Net emissions (including land-use change)
Aggregation Across Gases	CO_2-equivalent using 100-year global warming potential (GWP) values taken from IPCC AR4.
Sectors	All IPCC sectors
Reference Year	2005
Target Year	2025 (no intermediate year commitments)

Source: http://www4.unfccc.int/submissions/INDC/Published%20Documents/United%20States%20of%20America/1/U.S.%20Cover%20Note%20INDC%20and%20Accompanying%20Information.pdf

The United States expects to be able to implement its INDC by using existing legislative authority, e.g. the Clean Air Act (42 U.S.C. §7401 et seq.), the Energy Policy Act (42 U.S.C. §13201 et seq.), and the Energy Independence and Security Act (42 U.S.C. §17001et seq.). Those instruments are applied to reducing emissions in four general categories as outlined in **Table 9**.

The analysis in this section is based on scenarios developed using a U.S.-focused version the Global Change Assessment Model (GCAM-USA). GCAM is a regionally disaggregated, technologically detailed model of human and physical Earth systems (Calvin, et al., 2011). GCAM models the simultaneous interactions of 31 geopolitical regions outside of the U.S. The version used for this study (GCAM-USA), then breaks the energy and economy components of the U.S. into 50 states and the District of Colombia. GCAM simulates the behavior of economic agents allocating scarce resources. GCAM has energy, agriculture, land use, macro-economy and climate modules coupled in a comprehensive computational framework. It runs on a 5-year time step from 1990. In this analysis we focus on the United States region in the larger global context. Two key drivers for the analysis, United States' population and GDP are presented in **Table 10**.

Table 9: Mechanisms and Instruments to achieve the United States INDC

Target Emissions	Instrument
Reduce power plant emissions	Clean Air Act: regulations to cut carbon pollution from new and existing power plants.
Reduce transportation emissions	Clean Air Act: fuel economy standards for light-duty vehicles (2012-2025 model years), heavy-duty vehicles (2014-2018 model years with the intention to adopt standards for heavy duty vehicles in 2016 for model years 2021-2027);
Reduce building sector and related emissions	Energy Policy Act and the Energy Independence and Security Act: Energy conservation standards for 29 categories of appliances and equipment as well as a building code determination for commercial buildings.
Reduce non-CO_2 emissions	Clean Air Act: use specific alternatives to high GWP HFCs in certain applications through the Significant New Alternatives Policy program; Reduce methane emissions from landfills and oil and gas production.

Table 10: United States Population and GDP Drivers

Year	2015	2020	2025
GDP (Billions US$2005)	15,450	17,535	19,871
Population (Millions)	321	334	346

Source: PNNL, GCAM-USA

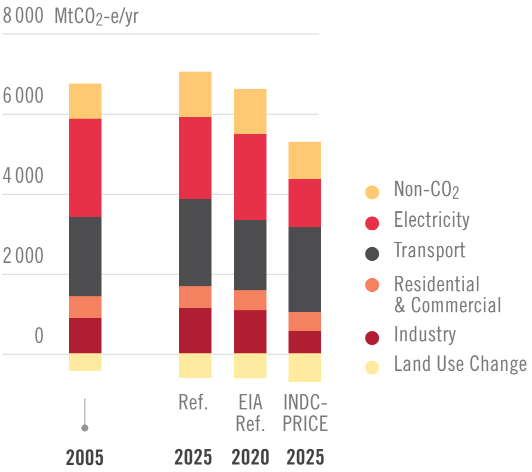
In this analysis, we use GCAM-USA to run three scenarios. The first is a reference scenario (REF) that assumes no additional policies beyond those in place roughly in 2010 with the exception of a limitation on new coal in the U.S. This scenario serves as a counterfactual against which to consider future policies. However, as relevant policies have, indeed, been put in place over the intervening years, we supplement this scenario with analysis conducted by EIA when exploring the potential implications of the Climate Action Plan (CAP).

The second scenario, referred to as INDC-PRICE, is one in which the INDC is achieved using an economy-wide carbon price within the GCAM-USA modelling framework (INDC-Price). This scenario is used to explore the full economy-wide

---

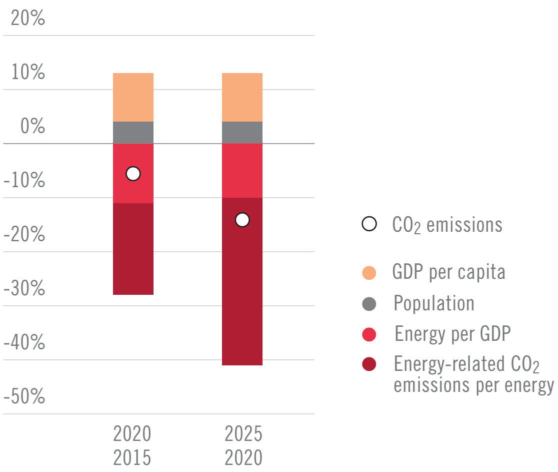
[15] US cover note, INDC and accompanying information. Available at: http://www4.unfccc.int/submissions/INDC/Published%20Documents/United%20States%20of%20America/1/U.S.%20Cover%20Note%20INDC%20and%20Accompanying%20Information.pdf

Figure 17. Emissions by sector, Reference and INDC-PRICE, US



Source: PNNL, GCAM-USA and EIA 2015

Figure 18. High-level drivers of emissions changes, INDC-PRICE scenario, US



Source: PNNL, GCAM-USA

implications of the U.S. INDC inside a comprehensive modelling framework, although the actual policies to implement the INDC will involve a mix of regulatory policies. This is an expedient and instructive modelling approach taken to simulate the achievement of the U.S. contribution in which emissions mitigation is achieved with a common marginal cost of carbon. It is not intended to approximate the complete policy mix being deployed. It is important to note that this scenario, as well, is constructed from the REF, which means that it does not include recent policy actions that will reduce emissions across various sectors.

The final scenario, CPP, explores in more detail the implications of the 'Clean Power Plan' (CPP), a crucial pillar of the regulatory policies used to implement the INDC. This analysis focuses on the electricity mix.

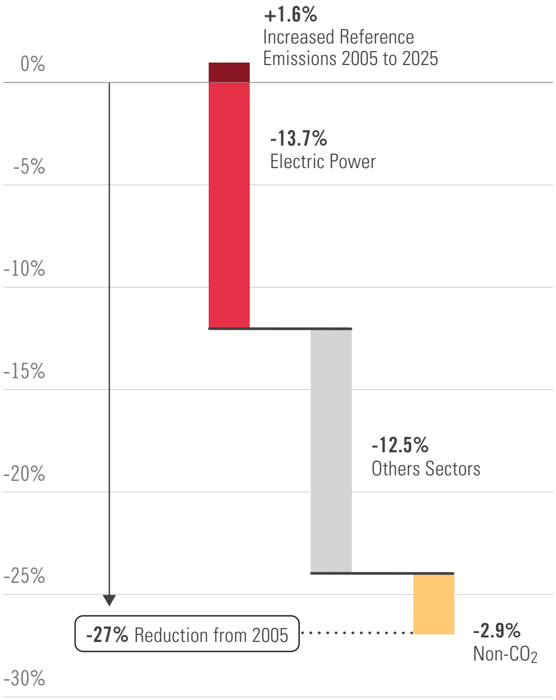
Figure 17 shows United States GHG emissions for 2005 and 2025 for the REF and INDC-PRICE scenarios. Whereas in the REF scenario, the United States' fossil fuel and industrial emissions are little changed between 2005 and 2025, the INDC-PRICE scenario reduces total greenhouse gas emissions by roughly 27 percent, relative to 2005. Figure 18 shows the drivers of emission changes in the INDC-PRICE scenario between 2015-2020 and 2020-2025. It can be seen that a significant share of the emissions reductions is driven by the decarbonisation of energy supply, notably electricity (see below).

For comparison, Figure 17 also shows the reference scenario from the U.S. Energy Information Administration's (EIA's) Annual Energy Outlook (2025 EIA REF). EIA's transportation emissions are lower in 2025 in the reference scenario than in 2005, and well below those in the GCAM reference scenario, in which they continue to grow. This discrepancy between reference scenarios is undoubtedly attributable in large part to the treatment of passenger vehicle policies (e.g., fuel economy standards, biofuels standards, tax incentives) that have emerged over the last several years in the U.S. These policies are included in the EIA REF, but not in the GCAM REF. An obvious but important conclusion of this result is that U.S. policies are already being undertaken to reduce emissions, raising issues about what is meant by a "reference" scenario in the context of analyses such as this one. It is also useful to note that EIA's transportation emissions are below even those in the INDC Price scenario from GCAM. This confirms a standard analytical result that emissions-price-based policies tend to favour supply-side reduction; whereas real policy implementation approaches in the U.S., which are favouring regulatory approaches, can have a very different distribution of effort.

Figure 19 shows the sources of reductions between the 2025 REF scenario and the INDC-PRICE scenario. About half of the emissions reductions needed to implement the US INDC in this case are delivered by the power sector. The remainder comes from CO2 reductions from other sectors (those derived from other measures including those addressing buildings, transport), and from non-CO2 GHG reductions.

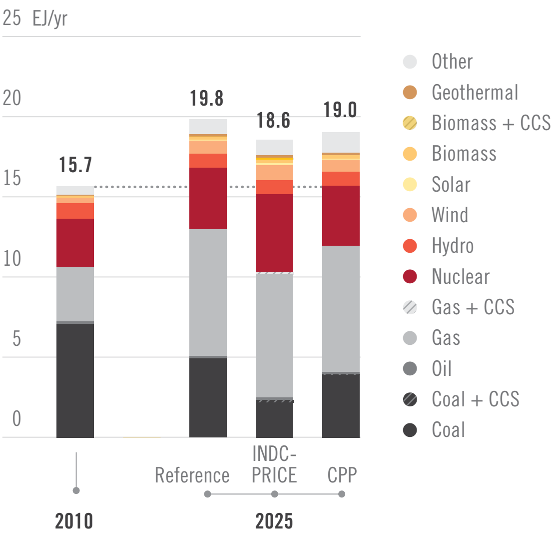
As noted above, the current approach to the U.S. INDC is to rely on measures implemented through existing laws. The most substantial single element of this plan is the Clean Power Plan (CPP). The CPP aims to reduce power sector carbon dioxide emissions from electricity by 32 percent from 2005 levels by 2030.

Figure 19. Sources of emissions reductions between Reference and INDC-PRICE scenarios, US



Source: PNNL, GCAM-USA

Figure 20. Changes in electricity generation compared to 2010 in Reference, INDC-PRICE and CPP scenarios



Source: PNNL, GCAM-USA

For this analysis, we have run the CPP through GCAM-USA to assess its implications for emissions reductions. The CPP leads to electricity CO_2 reductions in 2025 and 2030 relative to 2005 of 27% and 32% respectively, for the country as a whole.

The CPP substantially changes the energy system. In **Figure 20** we compare 2010 and power generation technology in our three scenarios. While there is little difference in total power production across the three scenarios, the technology composition varies substantially. The INDC-PRICE and CPP scenarios contrast sharply to the REF scenario.

The CPP scenario is characterized by reductions in coal use for power generation accompanied by increased use of natural gas, renewables, and nuclear, as compared to 2010 (**Figure 20**). The CPP scenario accelerates the rate of reduction of coal use relative to the reference scenario by an additional approximately 2 EJ/yr. In the CPP scenario, the increased use of natural gas, renewables, and nuclear replace some of the power provided by coal in our reference scenario, which is otherwise identical, but lacks the effect of the CPP. The INDC-PRICE scenario accelerates the transition away from coal still faster than in the CPP scenario, and accelerates deployment of non-emitting power generation technology, particularly nuclear energy.

By comparing **Figure 19** and **Figure 20**, we can see that the changes in the power sector from the CPP are less than half of those implemented by the INDC-PRICE scenario, which was implemented via an economy-wide carbon price. As noted above, the continuing attention to regulatory approaches beyond the power sector in U.S. policy leads to higher reductions outside the power sector than would be associated with an economy-wide carbon price. With respect to technology deployment, the INDC-PRICE scenario produces increased deployment of nuclear, wind, solar, and bioenergy, in contrast to the CPP scenario. It also leads to the deployment of some CCS. This is most notable in its application to coal use, but it also produces the first deployment of bioenergy with CCS. None of this occurs under the CPP case.

For context, it is instructive to compare the results of the INDC-Price scenario with results obtained by the Centre for Climate and Energy Solutions (*C2ES*). We find that the market-based, economy-wide price scenario (**Figure 19**) produces roughly twice the emissions mitigation in other parts of the energy system, as compared to the C2ES analysis. C2ES estimates the range of emissions reductions from measures other than the CPP to be between 4.7 and 8.4 percent relative to 2005. The higher end of this range is roughly equivalent to obtaining an additional 10 percent improvement in energy efficiency, as compared with the reference scenario, in transportation, non-CO_2 and buildings, with associated additional reductions in electricity demands.

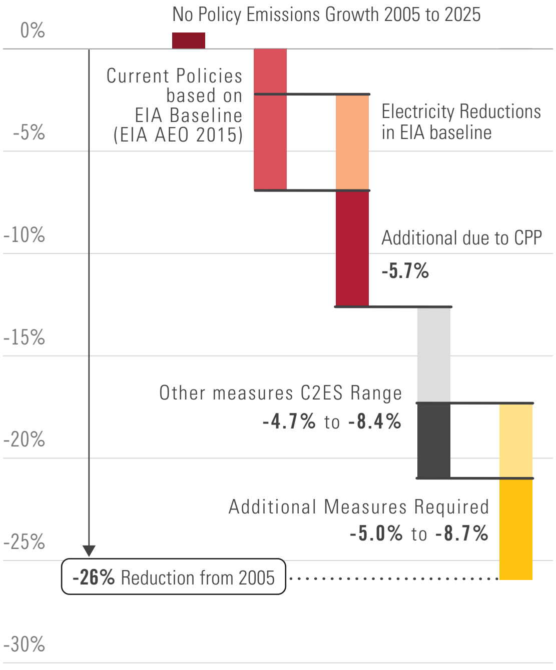
A primary concern in the context of the US INDC is the degree to which the U.S. Climate Action Plan will lead by itself to the 26% reductions intended under the INDC. To explore this issue and supplement previous explorations of this work, we have combined several different analyses with our own to produce a composite assessment. In specific terms, we have combined the CPP reductions from our analysis with the reductions in non-electric CO2 from the EIA baseline along with an assessment of other CO2 reduction possibilities from C2ES. Figure 21 shows economy-wide emissions reductions, relative to 2005, under the CPP scenario (as well as from other measures, discussed below).

The EIA REF scenario includes emissions reduction of roughly 6.9%. However, this reference scenario includes not only reductions in non-electric sectors (primarily transportation emissions, as discussed above). It also includes reductions in electricity emissions. If we eliminate these reductions, we find a total reduction of 2.2% in the EIA baseline net of the power sector. In other words, non-electric measures already in place can be expected, according to EIA, to reduce total emissions by 2.2% relative to 2005 levels.

The CPP then provides additional reductions beyond those from other sectors. The GCAM CPP scenario produces a direct CPP emissions mitigation effect of roughly 10.4 percent relative to 2005. This compares favourably with results obtained from C2ES, which found 10.1 percent reductions from the CPP. Adding in these reductions, we find a total of 12.6% relative to 2005 levels. However, this is only 5.7% beyond the EIA baseline, because the EIA REF scenario (as with the GCAM REF scenario) already includes reductions in electricity sector emissions. This illustrates the important point that it is not viable to simply add the CPP or other elements of the U.S. INDC to existing reference scenarios. Only the net effects from additional measures should be added. It also highlights the importance of the "baseline" scenario, which is inherently uncertain.

The GCAM analysis does not include an assessment of other measures in the CAP beyond the CPP that might be used to meet the 26-28% goal. Here, we conduct an off-line calculation to help understand their potential implications, and then we review the existing literature in this regard to provide a fuller picture. First, to support the off-line analysis, we take from C2ES the additional CO2 reductions they expect to find beyond the CPP. C2ES estimates these to provide reductions of 4.7% to 8.4% relative to 2005. Adding these to the 12.6% already discussed leads to a total reduction of between 17.3% and 21% from CO2 reductions. (Note that we have not assessed whether any of the C2ES reductions may already be embodied in the EIA reference scenario, which would further limit the contributions from these other measures.) This leaves a deficit of between 5.0% and 8.7% that must be made up through reductions in non-CO2 gases and other measures.

Figure 21. Emissions reductions relative to 2005, from the CPP and other actions and the residual in 2025, US



Source: PNNL. GCAM-USA

As a matter of comparison, C2ES finds that 3.1 to 6.6% reductions will be needed beyond actions already included in the present CAP for the United States to meet its goal of 26-28 percent reductions by 2025. Given the large uncertainty in baselines and the nature of implementation, these estimates can be considered roughly comparable. In summary, then we find that as the present measures that the United States has invoked will likely need to be supplemented for the INDC to be successfully met. There is, however, significant time in which to strengthen the present set of measures. Furthermore, the situation for the United States is not entirely different from that of some other major emitters, which have also not yet fully articulated a set of measures that would affect their INDC. And, in fact, the United States has gone further than some in identifying an initial suite of measures that can be employed to implement its INDC.

2.5. China

China submitted its INDC to the UNFCCC on the 30th of June 2015.[16] The Chinese INDC contains the following objectives:

- To achieve the peaking of carbon dioxide emissions around 2030 and making best efforts to peak early;
- To lower carbon dioxide emissions per unit of GDP by 60% to 65% from the 2005 level by 2030;
- To increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030;
- To increase the forest stock volume by around 4.5 billion cubic meters on the 2005 level by 2030.

Table 11: the social and economic development indicators in China

	2010	2020	2030
Population (Millions)	1341	1400	1420
GDP per capita ($/capita, 2010 price)	4604	8819	14504
Urbanization rate (%)	49.3	60	68

Source: authors' China INDC scenario

In this context, a joint INDC scenario was developed by the Chinese researchers in this project to study China's future energy development and carbon emission pathway (actually the scenario represents an coherent average of three INDC scenarios developed by the three Chinese research teams in this project – for this reason, we call it the INDC scenario in this chapter) . We start with the headline drivers of the scenario (Table 11). The population of China is predicted to increase and peak around 2030 with the population of 1420 million, and then gradually fall to 1353 million in 2050. Urbanization rate increases from 49.3% in 2010 to about 68% in 2030, with more than 350 million people moving into cities. Driven by China's continued industrialization and urbanization process, China's economy will still grow in fast pace. However, due to the economic transition characterized as the "New Normal" phase, the GDP growth rate may be somewhat slower in the short-term, while returning to a longer-term trend thereafter. In the INDC scenario, the GDP per capita of China is anticipated to increase by over 3 times from 2010 to 2030. Table 11 displays the headline socio-economic assumptions underpinning the scenario reviewed here.

Driven by the economic and social development parameters listed above, China's primary energy consumption in the INDC scenario will increase by 64% from 90EJ in 2010 to 160EJ in 2030. Electricity consumption doubles to 34EJ in 2030, and electricity consumption per capita increases to about 6700 kWh, still lower than the average level for developed countries in 2010 of 7 800 kWh per capita.

Energy-related CO2 emission will reach its peak around 2030 between 11-12 Gt CO2 emission (Figure 22). The improvement of carbon intensity of GDP reaches about 65% by 2030 against 2005 levels, showing an acceleration of decarbonization. Figure 23 shows the headline drivers of emission changes in China in the period 2010 to 2030; the improvement in the carbon intensity of energy and energy intensity of GDP start to slow the growth of emissions as the peak around 2030 approaches.

According to the analysis of the Chinese research teams, this decarbonization path is consistent with the possible scenario range with more than 50% probability of achieving 2°C goal from IPCC AR5 scenario database. Carbon emission per capita shows a similar trend with national emission, attaining 7.4 and 8.1 tons in 2020 and 2030 respectively, and the highest carbon emission per capita is in 2030, which is about the same level with EU 1990 level.

Figures 24-26 show the drivers of decarbonisation across the three pillars of energy intensity, carbon intensity of electricity and the shift to low-carbon energy sources in final energy, notably electricity. It can be seen that improvements in energy intensity are very significant, although China remains a relatively energy intense economy in 2030. The improvement in the carbon intensity of electricity production is likewise very significant, falling by 40% between 2010 and 2030.

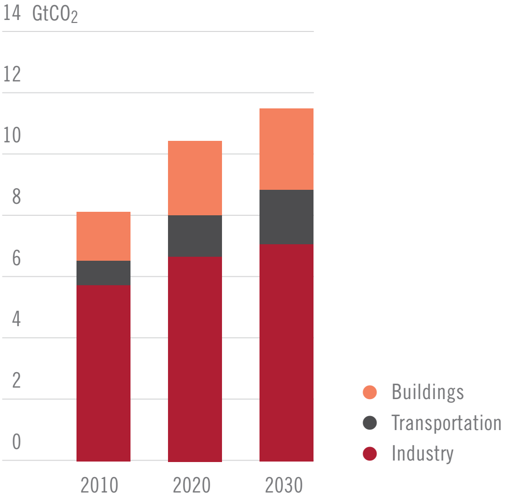
A remarkable optimization of the energy mix plays a key role in the INDC trajectory. The share of coal in primary energy consumption falls from 71% in 2010 to 58% in 2030, while the share of non-fossil fuels and natural gas are predicted to increase from 7.9% and 3.8% in 2010 to 22% and 9.2% in 2030 respectively. Non-fossil fuel will gradually dominate the power sector thanks to continuous support policies and measures, including increasing research funds into reducing the cost of non-fossils, higher priority for newly-built non-fossil power plants, feed-in tariff for renewable power plants, etc.

In 2030, the share of all renewables in total power generation will rise to 32%, while nuclear power will contribute another 11%. Combined with

---

[16] ENHANCED ACTIONS ON CLIMATE CHANGE: CHINA'S INTENDED NATIONALLY DETERMINED CONTRIBUTIONS. Available at: http://www4.unfccc.int/submissions/INDC/Published%20Documents/China/1/China's%20INDC%20-%20on%2030%20June%202015.pdf

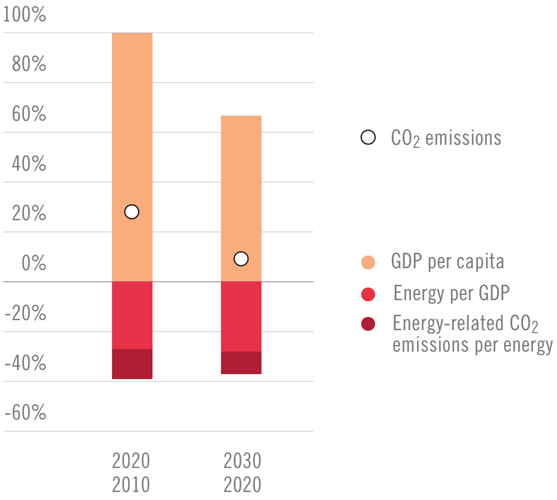
Figure 22. Projected energy related emissions, China



Emissions from energy production are attributed to the sector of final consumption.

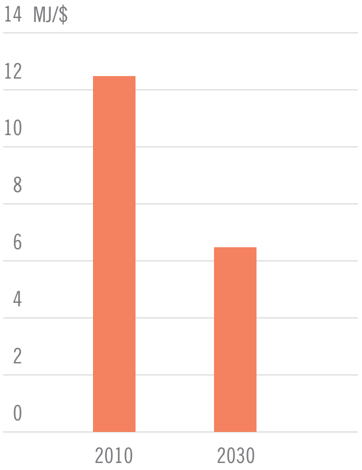
Source: authors' China INDC scenario

Figure 23. High-level drivers of emissions changes, China



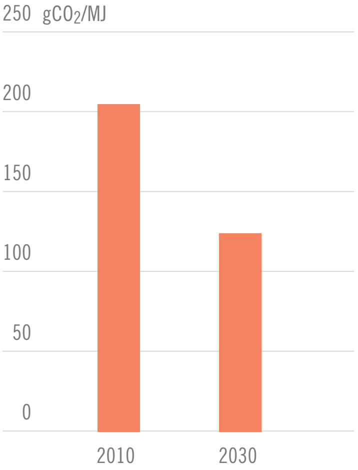
Source: authors' China INDC scenario

Figure 24. Energy intensity of GDP, China



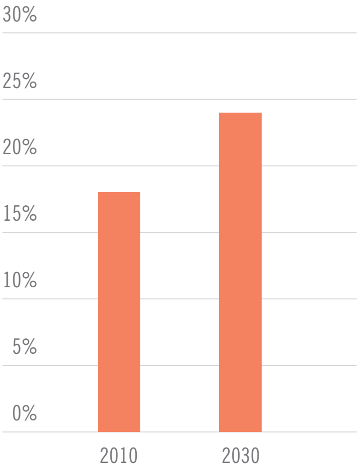
Source: authors' China INDC scenario

Figure 25. Carbon intensity of electricity production, China



Source: authors' China INDC scenario

Figure 26. Electrification of final energy demand, China



Source: authors' China INDC scenario

increasing share of non-fossil electricity and application of some CCS in thermal power generation, the CO2 emission per unit of electricity generation in 2030 will be reduced by more than 40% from the level in 2010, and helps to reduce the carbon intensity per unit of energy use by large degree in China. The decarbonisation of the **power sector** is vital for the decarbonization of end-use sectors, as the electrification rate of China will increase from 18% in 2010 to 21% in 2030 and electricity becomes a major energy source in final energy consumption (Figure 26). Figure 27 shows the electricity mix between 2010 and 2030.

Considering China's development stage and its level of industrialization and urbanization, end use sectors will see different trends in both energy consumption and emissions. Industry will still remain as the biggest end use sector in terms of energy consumption before 2030, and its final energy consumption will increase 52% on its 2010 level with emissions anticipated to peak around 7100 Mt CO2 between 2020 and 2025. Transportation and buildings, the two major sectors closely related to urbanization, will see enormous increases in final energy demand, with their final energy consumption in 2030 increasing by 133% and 102% respectively on their 2010 levels, and their emissions peaking around 2650 and 1850 Mt CO2 by around

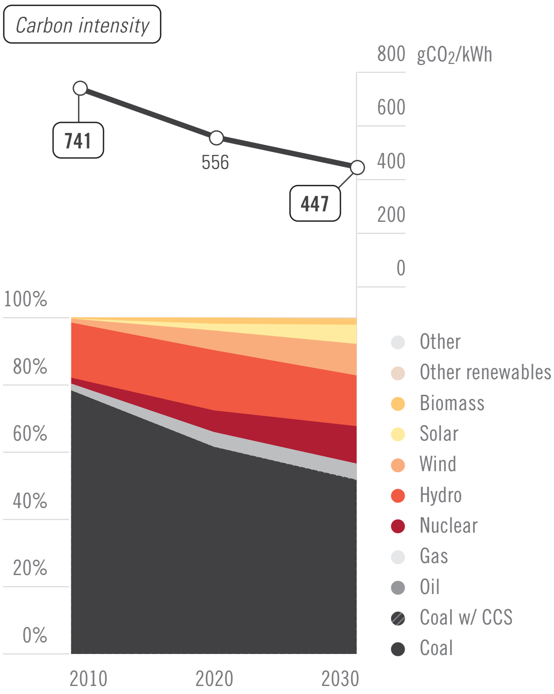
2030 and 2035 respectively.

While China's development needs in terms of advancing people's living standards and eliminating poverty serve as drivers for its economic growth, they also creates large demands for services and products, which drive up China's energy consumption and CO2 emissions. Hence keeping the increase of service demands at a manageable level and converting industrial production to a more sustainable model are prerequisites for China's low carbon development, and policies and measures guiding both producers and consumers covering different end use sectors are essential in the INDC scenario.

In the buildings sector, thanks to administrative measures including better urban planning and restrictions on mass demolishing of old buildings and economic measures including house taxes on residential buildings, the total floor area will continue to rise but will be controlled at a reasonable level, with public building area per capita and residential building area per capita increasing to 11.5 m2 and 37 m2 around 2030 respectively, similar to major EU countries' current levels[17]. With better implementation of clean and low carbon energies, including heat, natural gas, electricity and distributed renewables, the proportion of coal consumption is expected to decrease from 58% in 2010 to 41% in 2030 in the buildings sector, while those of electricity and gas will rise from 47% and 9% in 2010 to 56% and 17% in 2030. Figure 28 shows the emissions trends and energy mix in the buildings sector from 2010 to 2030.

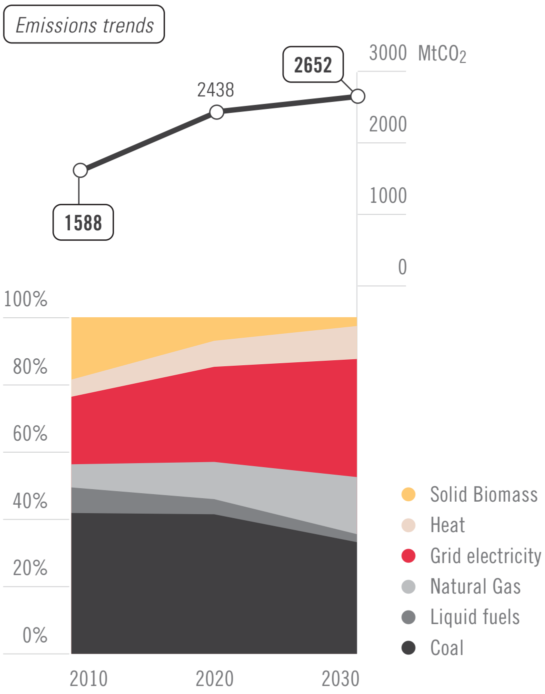
In the transport sector, through the implementation of incentivizing policies for higher capacity public transport modes (such as mass rail transport, bus rapid transport), and the use of information and communication technologies in transport management, freight and passenger turnover will rise to 2.8 times and 3.6 times of that in 2010 level respectively in 2050, and car ownership per thousand persons in 2030 will increase to 200, which is close to 1/4 of US level in 2010.[18] Through enhanced efforts in technology innovation, infrastructure construction and product diffusion, many types of low carbon vehicles will gradually take dominant roles, such as 100% electrically powered vehicle (EPV), plug-in hybrid electric vehicle (PHEV), fuel-cell vehicles (FCV), will take account for more than 25% of total light duty vehicle stock in 2030, and the use of biofuel will be an important option

Figure 27. Electricity generation mix, China



Source: authors' China INDC scenario

Figure 28. Energy mix in building sectors, China



Source: authors' China INDC scenario

---

[17] BPIE, Data hub for the energy performance of buildings, http://www.buildingsdata.eu/

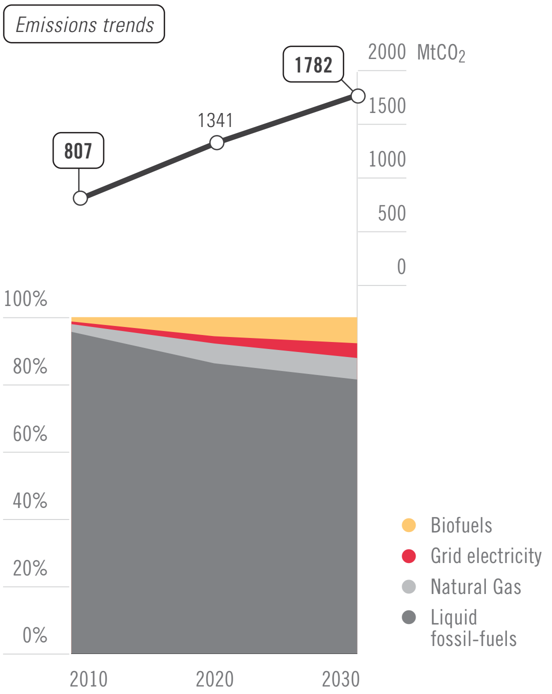
[18] Wardsauto, http://wardsauto.com/special-reports/2011

to reduce the use of gasoline and diesel. Figure 29 shows the emissions trends and energy mix in the transport sector from 2010 to 2030.

In the industry sector, by promoting the development of tertiary industry, controlling overcapacity of major energy-intensive industrial sectors, and eliminating backward production capacity (e.g. prohibiting new industrial capacity until at least that much inefficient capacity is shut down), the share of secondary industry in GDP decreases gradually from 46.2% in year 2010 to 38.5% in year 2030, close to that of Germany in the mid-1990s and the world average level in the early-1990s. This helps to significantly improve the energy and carbon intensity of GDP and reduce emissions (cf. Case Study 5). By promoting the conversion of coal-fired boilers to gas-fired boilers and enhancing the use of electricity, the share of gas and electricity will increase to 18% and 32% in 2030 from less than 4% and 21% respectively in 2010, while coal use decreases from 63% in 2010 to 37% in 2030. Figure 30 shows the emissions trends and energy mix in the industry sector from 2010 to 2030.

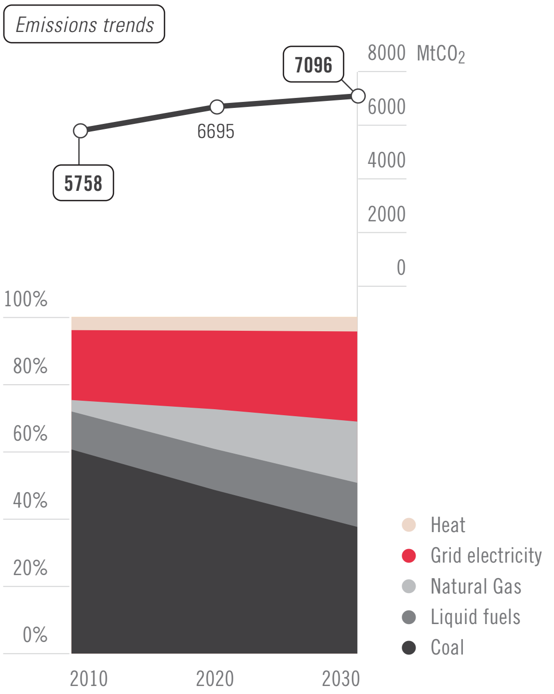
Energy efficiency is an essential component of the INDC scenario. As the world's largest energy consumer, energy efficiency gains will deliver significant benefits in terms of cutting down total energy consumption. Although China has focused on energy efficiency improvement during the past decades and has cut its energy consumption per unit of GDP to less than twice the global average in 2012 from four times higher than the global average in 1990, there's still great remaining potential for improvement. **In power sector,** this occurs through phasing out the outdated coal power plants and broadly deploying higher efficiency power generation units such as ultra-super critical coal, integrated gasification combined cycle coal units and natural gas combined cycle units. **In the transport sector,** by implementing stricter vehicle fuel economy standards, the fuel economy of light duty vehicles will increase by 20% from 2010 to 2030. **In the buildings sector,** by improving insulation properties of buildings and heating pipelines and using waste heat and high efficient heating technologies, the heating energy consumption per unit of area in northern heating area will decrease by about 35% on 2010 level. **In the industry sector**, by adopting the application of energy saving technologies, efficient waste heat recycling technologies and efficient boilers and motors, and by retiring inefficient industrial facilities, the energy consumption will decouple from the economy growth of industry sector, with the final energy consumption growing by 50%, while industry value added increasing by 178%. The

Figure 29. Energy mix in transport sectors, China



Source: authors' China INDC scenario

Figure 30. Energy mix in industry sectors, China



Source: authors' China INDC scenario

energy consumption per value added of the industry sector will be reduced by 45% from 2010 to 2030.

CCS has been identified by IPCC AR5 as an essential technology to meet 2-degree target, and its application in power generation sector and the industry sector is necessary for China to achieve a large–scale reduction in CO2 emissions, given that the Chinese energy system is dominated by fossil fuel especially coal. In the INDC scenario, by accelerated technology development, promoting demonstration projects, improving the regulatory framework and the creation of a substantial price signal from the government, commercial CCS application in power sector and energy-intensive industries will be seen from 2030.

2.6. Brazil

The Brazilian INDC

The Brazilian INDC (Brasil, 2015) establishes absolute emissions targets of 1.3 $GtCO_2eq$ by 2025 and of 1.2 $GtCO_2eq$ by 2030 (GWP-100, AR5), corresponding to reductions of 37% and 43%, respectively, compared to 2005, leading to per capita emissions of 6.2 $GtCO_2eq$ in 2025 and of 5.4 $GtCO_2eq$ in 2030. These percentage reductions are relative to reported emissions of 2.1 $GtCO_2eq$ (GWP-100, AR5) in 2005, according to the Brazilian INDC (Brasil, 2015).

The latest published Brazilian inventory of GHGs is the Second National Communication (SCN) to the UNFCCC (Brasil, 2010) – henceforth the SCN for its acronym in Portuguese –, which reported emissions of 2.29 $GtCO_2eq$[19] in 2005, exceeding the 2.1 $GtCO_2eq$ referred to in the Brazilian INDC as the 2005 base year emissions. As a result, applying the 37% and 43% reductions announced in the INDC to the SCN implies absolute emissions of 1.44 $GtCO_2eq$ for 2025 and of 1.30 $GtCO_2eq$ for 2030 (GWP-100, AR5), which do not correspond to the absolute targets announced. Still under review, the unpublished Third National Communication to the UNFCCC[20] (TCN henceforth) reports different values for GHG emissions for 2005, namely of 2.74 $GtCO_2eq$, which also do not match the 2005 value of 2.1 $GtCO_2eq$ explicitly defined in the INDC as the base year emissions for 2005 (Brasil, 2015). The only place where 2.1 $GtCO_2eq$ is reported as the 2005 emissions is in the 2014 report of annual emissions estimates published by the Ministry of Science, Technology and Innovation (MCTI), which reports 2005 emissions of 2.04 $GtCO_2eq$ (MCTI, 2014), being closer to the figure of 2.1 GtCO2eq. However, these estimates are not an official report to the UNFCCC.

Table 12: Summary of measures included in the Brazilian INDC

Green-house Gases	All Sectors	Absolute targets of:
		1.3 GtCO2eq in 2025
		1.2 GtCO2eq in 2030
		(GWP-100, AR5)
LULUCF	Forestry	Strengthen Forest Code
		Zero illegal deforestation in Amazonia by 2030, with sequestrations compensating for emissions from legal suppression of vegetation.
		Enhancing sustainable forest management practices
		Restoring and reforesting 12 million hectares of forests by 2030
Energy	Primary Energy	45% renewables by 2030
		Non-hydro renewables to 28-33% by 2030
	Electricity generation	Non-hydro renewables at least 23% by 2030
		10% efficiency gains by 2030
	Transportation	Promote efficiency measures
		Improve public transport infrastructure
	Biofuels	18% biofuels in primary energy mix by 2030
	Industry	Promote new standards of clean technology
		Enhance efficiency measures and low-carbon infrastructure
Agriculture		Strengthen Low Carbon Agriculture plan (Plano ABC)
		Restore 15 million hectares of degraded pastures by 2030
		Five million hectares of integrated crop-land-livestock-forestry systems by 2030

Source: http://www4.unfccc.int/submissions/INDC/Published%20Documents/Brazil/1/BRAZIL%20iNDC%20english%20FINAL.pdf

Given these discrepancies among past inventories, we choose to disregard the declared percentage reductions in the Brazilian INDC and, instead, focus on the absolute targets of 1.3 $GtCO_2eq$ for 2025 and of 1.2 $GtCO_2eq$ for 2030. In order to assess the impacts of the INDC, we built scenarios for the AFOLU sector based on existing inventories, studies, and reports from public, private and academic sources, to estimate the emissions budget available to the energy system within the time horizon of the INDC.

The MESSAGE-Brazil-8000 model, MSB8000

---

[19] Using the AR5 conversion factors for emissions of 1.64 $GtCO_2$, 18.1 $MtCH_4$ and 546 ktN_2O reported in the SCN.

[20] http://www.mct.gov.br/index.php/content/view/360077.html, currently closed for public consultation.

henceforth (Rochedo, Szklo, Lucena & Schaeffer, 2015) was then used to optimize the energy system under different levels of carbon values ranging from US$0 to US$200 per ton of CO_2eq. MSB8000 generates demands for energy services from drivers such as GDP and population. Population projections for 2050 were taken from the official estimates of IBGE (IBGE, 2015). Because of the recent slowdown of the Brazilian economy, we revised existing macroeconomic projections to match recent historical values and short-term official projections, as explained in Section 2.

Today, Brazil has one of the cleanest energy systems and a low carbon energy mix based on hydropower for electricity (around 70-80% of electricity generation over recent years) and a strong penetration of biofuels, especially sugarcane products, producing both hydrated and neat ethanol and electricity, and biodiesel currently blended at a 7% (B7) level with diesel (volume basis). Neat ethanol is currently blended with gasoline at 27% level (E27, volume basis). There has been a significant rise in wind generation recently and new auctions for solar power generation.

The INDC targets are summarized in Table 12. The targets announced are moderately ambitious although there is potential for a higher contribution, especially from the AFOLU sectors (see case study). The main challenge comes from the energy systems, since energy demand is projected to continue a growth trend in the coming decades.

Recent studies indicate that, in the absence of mitigation efforts, the current Brazilian energy mix will continue on a trend of increasing carbon intensity, with natural gas and coal gaining importance in the power sector, and the sugar-alcohol sector undergoing a severe crisis that has caused the closure of several ethanol distilleries. The depletion of the hydropower potential outside the Amazon region, and the vulnerability of existing hydro capacity to climate change (Lucena, Schaeffer, & Szklo, 2010; Lucena et al., 2009), means that other sources would take on increasing roles in meeting baseload demand, with results showing coal to be the least cost solution (Lucena et al., 2015; Nogueira et al., 2014; Portugal-Pereira, Koberle, Lucena, Szklo & Schaeffer, 2015). In the ethanol sector in recent years, large international groups acquired Brazilian plants, which were mainly family owned businesses. However, these acquisitions did not result in the installation of new plants but rather in the expansion of existing ones, given the opportunity cost of capital and the control of gasoline prices in Brazil. Climate has been a large critical factor affecting sugarcane production in Brazil. For instance, in the main production areas, the 2009/2010 harvest occurred under rainy conditions, which affected the quality of the raw material and disturbed the crop activities. As a result, some of the sugarcane had to be harvested in the following harvest. The opposite occurred in 2010/2011. Very dry weather during the crop affected the re-sprouting of the sugarcane and caused a decrease in the yield, which happened again in the following year. In addition, the dry weather impeded the treatment of the culture and renewal of the canebrakes (de Barros & Szklo, 2015; IEA, 2013).

The growing demand is fueled primarily by a growing population and rising income levels, with the highest uncertainty coming from the levels of economic activity in the coming decades. Thus, in the Cenergia/COPPE's Brazilian scenario to match the official INDC, we focused first on adjusting GDP projections to match the recent deviations from a high-growth trajectory, and the forecasts for a reduced growth rate in the short-term. We then created plausible scenarios for AFOLU to generate emissions budgets for the energy sector to feed the MSB8000 model of the energy system.

Brazilian GDP and Macroeconomic Projections

The INDC does not specify the macroeconomic assumptions behind its projections, so we use a scenario reflecting current views of the trajectory of the Brazilian economy. There is broad consensus that the Brazilian economy will continue to expand in the coming decades, as is expected from an emerging economy. However, there is much uncertainty as to how fast it will grow; that is, how high the GDP growth rate will be. Official projections by government institutions place it above 3% on annual average between 2010 and 2050, with decadal annual growth rates as high as 4.5% (e.g EPE, 2014). International institutions have also projected high growth rates for Brazilian GDP (IEA, 2013).

Although such high growth rates might have been reasonable to expect a few years ago, recent developments caused a marked reduction in economic activity in Brazil that has made such estimates obsolete. The average growth rate for the period 2011-2014 was just 1.5% per year (IBGE, 2015). The most recent estimates published by the Brazilian Central Bank indicates Brazilian GDP shrinking by 2.66% in 2015, shrinking again by 0.78% in 2016, and returning to modest growth in subsequent years (BCB, 2015). Most available GDP projections for Brazil were constructed before the current recession hit the country and the growth rates that resulted are far too optimistic. Because economic activity is a fundamental driver of the socio-economic scenario underpinning energy service and resource demand, it is essential to have robust assumptions, at least in the historic and short-term periods.

We use SSPs GDP projections as a starting point, and then adjust them to match historical rates and short-term growth projections by the Brazilian Central Bank (BCB, 2015). The Representative Socioeconomic Pathways (SSPs) have estimates for Brazilian GDP annual growth rates ranging between 1.2% and 4.0% for the 2010-2050 period, with the middle SSP2 scenario averaging 2.2% annual average GDP growth rate[21]. These adjusted GDP projections are shown in Table 13. Of these, SSP2 is used as a reference scenario here. The resulting 1.9% annual average growth rate for the period 2010-2050 may seem conservative, but we argue it is a realistic estimate of sustained growth over a long period. This 1.9% annual growth rate compounds over 40 years, resulting in a Brazilian GDP in 2050 that more than doubles compared to 2010. It should be noted that, for the purpose of evaluating the Brazilian INDC, the short term GDP growth projections are more relevant, since the INDC targets are 2025 and indicative to 2030. Hence, using the most up-to-date short-term projections is important.

We used the SSP2-adjusted GPD projection to adjust sectoral demands used previously in our assessments (Herreras-Martínez et al., 2015; Lucena et al., 2015; Nogueira et al., 2014). We call this adjusted scenario the COPPE-sCENario, and it is built by using the same 2010 base year value of our earlier scenarios, and applying the growth rates from the adjusted SSP2 scenarios of Table 13. The correction factor is then calculated as the ratio between the COPPE-sCENario and the old scenario for each 5-year period. The resulting GDP projection is shown in Table 14 .

Sectoral emissions consistent with the INDC

We ran the MSB8000 model using the GDP projections of the COPPE-sCENario under various carbon prices ranging from US$0 to US$200/tCO_2eq. Resulting energy emissions in 2030 for each carbon price applied are shown in Table 15. In order to assess the effects of the INDC on the energy system, scenarios consistent with the INDC targets have to be created for the AFOLU sectors, so that an emissions budget for the energy system can be compared to the MSB8000 results. Previous studies involving emissions cap scenarios have found that it is technically unfeasible for 2030 energy emissions to be less than 70% of 2010 energy emissions (Lucena et al., 2015), implying in

Case study 3: INDC implementation and improving productivity in agriculture

The significant reduction in deforestation rates in Brazil brought the country´s total emissions from a peak of 2.5 $GtCO_2eq$ in 2004 to about 1.2 $GtCO_2eq$ in 2010, and caused the agricultural sector to overtake land-use change (LUC) as the main cause of emissions (MCTI, 2013). Although increases in, and better enforcement of, protected areas by the federal government played an important role (de Souza et al., 2013; Soares-Filho et al., 2010), emissions from the agriculture and land use sectors are closely interrelated, and measures implemented in the agricultural sector were instrumental for the drop in deforestation. A persistent decoupling of agricultural production from deforestation has been observed recently, driven in large part by the intensification of agriculture and cattle ranching (Lapola et al., 2013; Macedo et al., 2012), and by private actor initiatives such as the Soy Moratorium (Nepstad et al., 2009) that reduced pressure for expansion of the agricultural area. Some authors found that the level of agrarian technology in a given region of Brazil is inversely proportional to the rates of deforestation in that region (de Souza et al., 2013). With Brazil expected to supply a large share of future global demand for agricultural products, the intensification of the sector will need to continue if deforestation is to be further reduced or, even better, eliminated.

The cornerstone of the government´s climate policies for the agricultural sector is the Low Carbon Agriculture Plan, or *Plano ABC* (MAPA, 2011), with mitigation targets between 134 and 163 $MtCO_2eq$ by 2020, even though the potential may be much larger. In a recent study, Assad et al (2015) found that the actual emissions mitigation potential of Brazilian agriculture is more than ten times larger than the targets of the *Plano ABC*, about 1.8 $GtCO_2eq$ between 2013-2023. In order to reduce agricultural emissions, both documents agree that most of the mitigation efforts must be directed at the bovine herd, which is responsible for the bulk of the sector´s emissions, mostly in the form of CH_4 from enteric fermentation (Brasil, 2015). About 63% of the mitigation targeted in the *Plano ABC* comes from the recuperation of degraded pastures (MAPA, 2011). Pasture degradation is defined as the progressive loss of natural vigor, productivity and recovering capacity demanded by the animals (Assad et al., 2013). More than half of Brazil´s pastures is in a state of degradation, and recuperation could lead to a marked increase in herd productivity, reduced average age at slaughter and lifetime enteric emissions along with it, and increase soil carbon stocks (Assad et al., 2015; Dias-Filho, 2011). Moreover, Strassburg et al (2014) estimate that improving the productivity of Brazilian pasturelands would free up enough land to meet projected demands of crops and biofuels through 2040.

Restoring degraded pastures involves mechanization for soil preparation, sowing and fertilization, requires capital investments and improved pasture management capacity, and sometimes supplementary irrigation (Dias-Filho, 2014; Smith et al., 2007; Strassburg et al., 2014). Mechanization drives up demand for energy, notably diesel, demanding about 10 machine-hours per hectare (ANUALPEC, 2013), while irrigation drives up demand for electricity (EPE, 2014), and fertilization increases N_2O emissions (Smith et al., 2007). Agriculture accounts for only 4% of primary energy consumption

---

[21] https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about

in Brazil but the ongoing expansion and modernization of the sector has raised energy consumption, particularly diesel, which accounts for roughly 58% of the sector's primary energy consumption (EPE, 2013). Therefore, energy related emissions from the agricultural sector have increased alongside its intensification, and partly because of it. On the other hand, healthy pastures retain greater quantities of soil carbon (Assad et al., 2015; Dias-Filho, 2011), and provide better quality forage that can reduce CH_4 emissions from enteric fermentation (Smith et al., 2007). Determining net emissions from pasture restoration is therefore a complex process, and, in order to remove carbon from the atmosphere, emissions from the energy required in the restoration process would need to be less than the 1 tC/ha/year assumed by Assad et al. (2015) as the removal potential of pasture restoration.

However, if avoided deforestation from reduced agricultural expansion is included in the calculations, the result will certainly be a net carbon removal. Assad et al. (2015) estimate that about 40 million heads of cattle graze on some 53 million hectares of degraded pastures in Brazil, amounting to less than 0.75 animal units per hectare. The current Brazilian bovine herd is approximately 220 million heads foraging on about 225 million hectares (IBGE, 2015), translating to a herd density of just below one head per hectare, well below the carrying capacity estimated by Strassburg et al (2014). Increasing the current density by only 10%, to about 1.1 heads per hectare, would free up some 20 million hectares of land that could be used for agriculture. This amounts to about 28% of the country's total cropland harvested area in 2013 (IBGE, 2015).

Agro-forestry and no-till agriculture also present great mitigation potential in Brazil. The *Plano ABC* has mitigation targets of 34-42 $MtCO_2eq$ by 2020 through adoption of these techniques on 12 million hectares of cropland, representing about 25% of the emissions reductions targeted by the plan (MAPA, 2011). Although such systems reduce emissions from degraded pastures through improvements in soil carbon sequestration capacity (Dias-Filho, 2011; Macedo et al, 2014; Smith et al., 2007; Zimmer et al, 2012), they demand more in terms of energy inputs than simply recuperating pastures through direct methods. For example, Sá et al (2013) reported 28% higher diesel consumption in pasture-soybean co-cultivation than in pasture only recuperation. They also reported that introduction of no-till methods can partially offset this higher demand for diesel. For crop production, no-till methods can lead to both higher carbon sequestration capacity in soils and to lower CO_2 emissions from lower energy use on the on hand, but to higher N_2O emissions on the other (Smith et al., 2007). Reductions in energy use from adoption of no-till methods can vary from 5% (Riquetti, Benez, & Silva, 2012; Sá et al., 2013)to as much as 48% (Rondón, León, & Alfonso, 2005), depending on the crop and on local conditions.

Brazilian agriculture is mostly rainfed, with only 4.5 million hectares, about 6% of planted area, irrigated in 2006 (IBGE, 2007). However, this number is increasing, and doing so at a faster pace than total harvested area. By 2012, the irrigated area had grown to 5.8 million hectares, representing 8.3% of total planted area (ANA, 2013). The irrigation potential in Brazil has been estimated at around 29.5 million hectares (Christofidis, 2008), and total irrigated area is projected to grow to some 7.8 to 9.8 million hectares by 2030 (MIN, 2011). This increase is pointed to as the main driver of growing electricity demand in the agricultural sector (EPE, 2014). Since electricity generation in Brazil is expected to become more carbon intensive in the coming decades (Lucena et al., 2015), this indirectly leads to higher emissions. However, there is considerable room for irrigation efficiency improvements, pointing to an important mitigation option with the potential co-benefit of better water use efficiency (Campana et al, 2000; Guimarães Jr et al, 2006; Lima et al, 2009; Reis et al, n.d.; Zocoler et al, 2012)

There is good potential for Brazil to sustainably supply a significant portion of the global demand for agricultural products. However, policy support and regulation is necessary since the intensification of agriculture leads to higher yields, which in turn can drive up the price of land and lead to renewed deforestation pressures (Galford et al, 2013; Sparovek et al, 2010). In order for Brazil to realize its sustainable agricultural potential, a sustained integrated approach is needed that combines *inter alia* the elimination of incentives to deforestation, the introduction of policies and financial support for productivity improvements, as well as higher use of renewable energy and improved equipment efficiency of the machinery and irrigation systems.

Table 13: Brazil GDP projections: SSPs adjusted for historic and revised short-term projections

	2010-2015	2015-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050	Avg	
SSP1	1.5%	0.3%	4.4%	4.1%	3.8%	3.5%	3.0%	2.6%		2.9%
SSP2	1.5%	0.3%	2.8%	2.4%	2.3%	2.1%	1.9%	1.8%		1.9%
SSP3	1.5%	0.3%	2.1%	1.5%	1.2%	1.0%	0.7%	0.5%		1.1%
SSP4	1.5%	0.3%	2.5%	2.2%	2.0%	1.8%	1.6%	1.4%		1.7%
SSP5	1.5%	0.3%	4.9%	4.6%	4.3%	3.9%	3.4%	3.0%		3.2%
	Hist	Proj								

Source: COPPE

Table 14: COPPE-sCENario projections of Brazilian GDP

COPPE-sCENario									
	2010	2015	2020	2025	2030	2035	2040	2045	2050
2013US$ million	2163738	2332740	2366914	2721249	3069272	3431802	3810216	4194482	4576259
% annual growth over each five year period		1.52%	0.29%	2.83%	2.44%	2.26%	2.11%	1.94%	1.76%

Source: COPPE

Table 15: Resulting GHG emissions in 2025 and 2030 associated with each level of carbon pricing from MSB8000 model (MtCO2eq)

US$/tCO2eq		Base	$0	$5	$10	$20	$30	$40	$50	$75	$100	$150	$200
MtCO2eq	2025	803	713	707	689	689	685	680	672	669	667	646	639
	2030	890	778	770	750	747	740	733	722	717	686	658	641

Note: Emissions include fossil fuel combustion from all sectors, industrial processes, waste treatment, and fugitive emissions Emissions from LULUCF are not included.

Source: COPPE

energy-related emissions of around 410 MtCO$_2$eq in 2030. Therefore, to arrive at this budget for energy, AFOLU emissions must be less than 790 MtCO$_2$eq in 2030 in order to meet the INDC total emissions target of 1.2 GCO$_2$eq by 2030.

Land-Use, Land-Use Change and Forestry

For the LULUCF sector, we analyzed three possible scenarios for deforestation in Brazil in 2030 using the same methodology as Cenergia (2015), but adjusting the targets to those of the INDC:

- Scenario 1: Deforestation remains at the same level as 2010,
- Scenario 2: Deforestation drops to 50% of 2010 by 2025, and
- Scenario 3: Net-zero deforestation by 2030.

Base year 2010 emissions were calculated via a proxy of emissions per km^2 calculated for 2005 based on deforestation of 19,014 km^2 reported by PRODES for Amazonia (INPE, 2014) and LULUCF emissions of 1.24 MtCO$_2$eq reported in the SCN (Brasil, 2010), resulting in an emission factor of a little over 70 tCO$_2$eq per km^2 of deforestation. If this value is assumed to remain constant between 2005-2010, multiplying it by 7,000 km^2 deforestation in 2010 reported by PRODES (INPE, 2014) we arrive at an estimate for LULUCF emissions of 490 MtCO$_2$eq for the base year 2010. This is very similar to estimates from the REDD-PAC Project (OC, 2015), and to the unpublished TCN.

Although the INDC pledges to compensate for "legal suppression of vegetation", this seems to relate only to Amazonia, and it remains unclear to what extent this can be interpreted as net-zero emissions from deforestation (see below and case study). However, as we show in below, achieving net-zero emissions from deforestation is crucial to arrive at an economy-wide emissions level consistent with the INDC.

Agriculture

Agriculture represents about a third of Brazilian emissions today and is expected to continue on a growing trend in absolute terms. We project the 1990-2005 agricultural emissions time series of the SCN (Brasil, 2010) to 2030, and subtract the mitigation targets of the *Plano ABC* (MAPA, 2011)[22], assuming the minimum target is reached

---

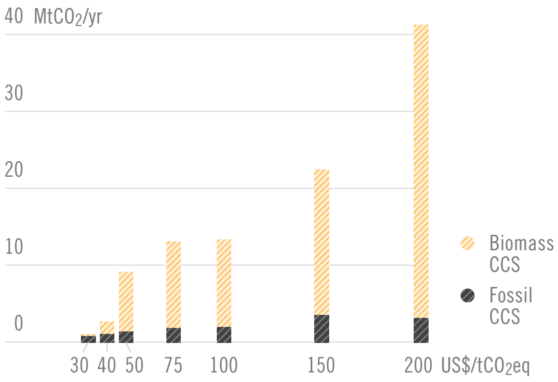
[22] The Plano ABC is the Brazilian government's low

in 2020 (134 $MtCO_2eq$) and the maximum in 2030 (163 $MtCO_2eq$)[23]. This results in agricultural emissions of 437 $MtCO_2eq$ in 2025 and of 475 $MtCO_2eq$ in 2030. This is also very similar to estimates from REDD-PAC (OC, 2015), and to the unpublished TCN. Therefore, mitigation from Plano ABC offsets emissions growth trend and agriculture emissions would be broadly stable over the INDC period.

Transformation in the Energy Sector of Brazil

The resulting emissions in 2030 of each LULUCF scenario were added to the agricultural emissions, and the total subtracted from the 2030 INDC target of 1.2 $GtCO_2eq$, to estimate how much room is left for the remaining emissions (basically energy-related emissions). Of the possible AFOLU combinations, only Scenarios 2 and 3 led to a technically feasible energy emissions budget (>410 $MtCO_2eq$). In other words, only the full implementation of the *Plano ABC* combined with deforestation less than 50% of 2010 levels will lead to an *energy* emissions budget greater than the technically feasible 410 $MtCO_2eq$ in 2030 estimated by Lucena et al. (2015). Scenario 2 leads to energy emissions budget of 480 $MtCO_2eq$ in 2030, making it technically feasible but economically challenging, since not even a shadow price of carbon exceeding US$200/$tCO_2eq$ would be enough to implement such a target (Table 15). Scenario 3 leaves room for 725 $MtCO_2eq$ for emissions from the energy sector in 2030. Therefore, Scenario 3 is the only scenario that is technically and economically feasible, although it would imply a shadow mitigation cost of around US$50/$tCO_2eq$ (so-called BC50[24]). In this case, a B50 scenario would imply in the investment in carbon capture facilities, particularly in ethanol distilleries (bio-CCS) – see Figure 31.

Figure 31. Carbon Capture in Low Carbon scenarios as a function of different CO_2 prices



Note: Fossil CCS means capture in thermal power plants, oil refineries (including hydrogen generation units) and ammonia, cement and iron and steel facilities. Bio CCS includes capture in ethanol distilleries and, for higher prices, capture in biomass fueled thermal power plants.

Source: COPPE, MSB8000 model

However, the language in the INDC suggests mitigation that goes beyond the measures implemented above for the AFOLU sectors. For the LULUCF sector, the INDC pledges to restore and reforest 12 million hectares of forests, leading to carbon removal from the atmosphere. The mitigation potential of this measure is uncertain and no value was given in the INDC. There are also pledges to net-zero deforestation in the Amazon by 2030, and compensation for deforestation that is legal, although, again, no specific measures are put forward. The REDD-PAC project[25] estimates that net emissions from LULUCF will reach 240 million $MtCO_2eq$ in 2030, in spite of net-zero deforestation in the Amazon and reforestation of 5 million hectares.

For the agricultural sector, the INDC pledges to strengthen the *Plano ABC*, "including by restoring an *additional* 15 million hectares of degraded pasturelands by 2030, and enhancing 5 million hectares of integrated cropland-livestock-forestry systems (ICLFS) by 2030" (Brasil, 2015, our emphasis). The word *additional* suggests that this is in addition to the targets in the *Plano ABC* of restoring 163 million hectares of degraded pastures (MAPA, 2011) This could potentially lead to mitigation of around 55 $MtCO_2eq$ per year if we apply the 1 tC/ha/year estimated by Assad et al. (2015) as the removal potential of pasture restoration. This would allow for energy emissions of 780 $MtCO_2eq$, exactly what would be possible in a 'no-regret mitigation scenario' with a US$0/$tCO_2eq$ shadow price of carbon (Table 15). This no-regret scenario includes measures in the energy system that have negative costs, such as energy efficiency, but are not implemented because of market failures, such as, *inter* alia, transaction costs, lack of information, lack of financing, split incentives and/or monopoly markets.

We, therefore, adopt this no-regret scenario as the COPPE INDC scenario[26] to assess the effect of

---

carbon agriculture plan

[23] The plan's targets are supposed to be reached by 2020, but there are little indications that it will be accomplished by that time.

[24] From the Portuguese "Baixo Carbono", which means low carbon.

[25] http://www.observatoriodoclima.eco.br/lei-de-floresta-zeraria-desmate-na-amazonia/

[26] The COPPE INDC scenario was developed independently by a group of experts affiliated with COPPE and

the INDC on the energy sector. As will be shown below, the COPPE INDC scenario meets INDC both targets for non-hydro renewables, of 23% in electricity generation, and of 45% in primary energy consumption, as well as the target of minimum 18% biofuels in the primary energy mix. These goals can be met with the non-regret COPPE INDC scenario, but our analysis shows that, with higher marginal abatement costs, even further mitigation would be feasible.

Figure 32 shows the evolution of emissions in the baseline and in the COPPE INDC scenario, indicating a reduction from 890 to 778 $MtCO_2eq$, a 13% drop from baseline in 2030. Figure 33 shows the evolution of sectoral emissions, and, as can be seen in Table 16, reductions vary greatly with some sectors increasing their emissions (Agriculture, Services, and Process emissions), which are offset by the reductions in the others (particularly Industry, Buildings, Waste Treatment and Fugitive emissions). The increase in energy emissions from agricultural emissions comes from the increasing mechanization and intensification of Brazilian agriculture (see case study). Reductions in waste treatment emissions come from higher penetration of waste collection and treatment, while reductions in fugitive emissions come from a general improvement in industrial processes and the reduction of flaring especially in petroleum production in offshore platforms.

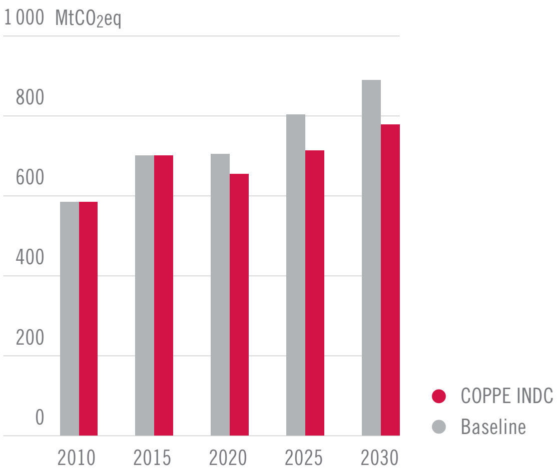
Table 16: Percent change in Low Carbon COPPE INDC emissions from baseline in 2030

Industry	-16.7%
Agriculture[1]	5.9%
Transport	-4.1%
Buildings	-19.7%
Energy Sector[2]	4.0%
Electricity Production	-2.1%
Industrial Processes	-13.2%
Waste Treatment	1.4%
Non-CO2[3]	-32.2%

Source: COPPE, MSB8000 model

Note: Emissions include fossil fuel combustion from all sectors, industrial processes, waste treatment, and fugitive emissions. [1] Emissions from energy consumption in the agriculture sector; [2] Fuel combustion for self-consumption in energy conversion facilities; [3] Fugitive emissions

Figure 32. Annual energy system emissions in Baseline and Low Carbon COPPE INDC scenarios



Note: Emissions include fossil fuel combustion from all sectors, industrial processes, waste treatment, and fugitive emissions.

Source: COPPE, MSB8000 model

The sectoral emissions from Table 16 are pictured in Figure 33, highlighting the baseline increases in emissions from processes, waste treatment, industry and transportation, and their contribution to the reduction in the INDC scenario.

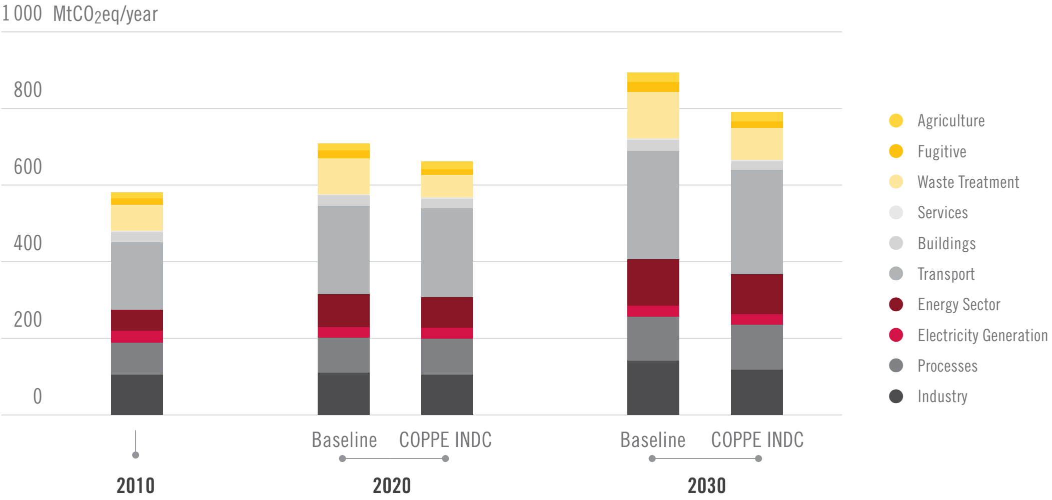
As can be seen, the transport sector remains a major source of GHG emissions in the INDC scenario, with only a slight 4% reduction from baseline in 2030. However, there is potential for further reductions, albeit at a higher mitigation cost. At US$50/tCO2eq, for example, the sector's emissions drop by close to 7%, and surpasses 8% at US$100/tCO2eq. These may seem modest compared to potential reductions in OCDE countries, but country-specific barriers limit further reductions. First, there is the challenge of timely deployment of mass transportation, with metro lines, for example, only present in a few of the major cities in the country today and even so with limited capillarity. Second, the renovation of the light-duty fleet is slower than in OCDE countries due to the high cost of vehicles relative to income levels, which leads to older cars remaining active for a longer time. Third, there is a strong preference for individual modes of transport, especially as income levels rise. Finally, freight transport is heavily reliant on trucks riding on inadequately paved roads, with a modal shift to rail or water facing serious challenges from lack of investment and inefficient bureaucracy.

These factors imply in growing final energy and energy service indicators for the transportation sector, from 1343 MJ/US$-2013 in 2010 to 2242 MJ/US$-2013 (in terms of the ratio between final

---

do not necessarily reflect the views of the Brazilian government. It should also be noted that the COPPE INDC scenario has no normative purposes, while it is aimed at exploring one of the different possible pathways compatible with the achievement of the Brazilian INDC target.

Figure 33. Greenhouse Gas Emissions



Note: Emissions include fossil fuel combustion from all sectors, industrial processes, waste treatment, and fugitive emissions.

Source: COPPE, MSB8000 model

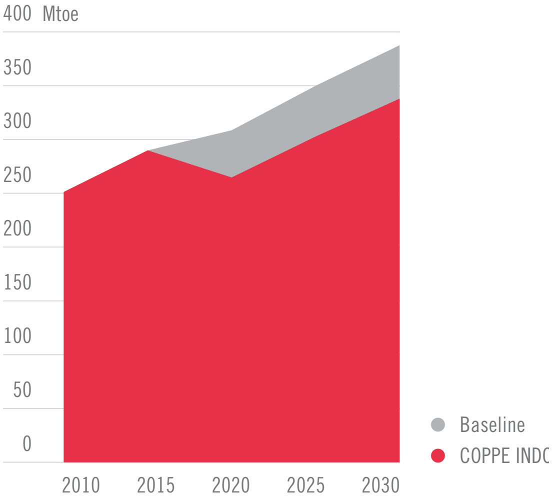
energy and GDP), and from 0.84 pkm/US$-2013 to 1.08 pkm/US$-2013 (in terms of the ratio between energy service and GDP).

The greatest mitigation potential is in the industrial thermal energy consumption, through low-cost measures such as substitution of burners, adjustment of air-fuel ratio in the burners, thermal isolation, heat exchange networks and improvement of processes control. Industrial emissions drop by almost 17% in the COPPE INDC scenario, being the cheapest option to curb emissions under the integrated energy assessment of MSB8000. On the other hand, process emissions rise by 1.4% in the COPPE INDC scenario. This is mostly due to increased hydro-treatment (HDT) in petroleum refineries for production of highly specified fuels, implying in higher hydrogen production. However, for shadow prices of carbon higher than US$30/ tCO_2eq, these process emissions can be mitigated via CCS in hydrogen production units (as was shown in Figure 31).

The annual reduction in primary energy consumption in the COPPE INDC scenario compared to baseline (Figure 34) indicates a drop of about 13% from baseline in 2030. Total primary energy consumption rises in the time horizon in pace with growing population and income levels.

Figure 35 shows primary energy consumption by source with an overall increase from 2010, but a reduction from baseline in the INDC scenario driven in large part by a drop in most energy carriers (oil 12%, coal 11%, biomass 18%, sugarcane products 11% and solar 10%) and a concomitant large increase in gas consumption of 19% accompanied by a slight increase in hydropower consumption of a little less than 1%.

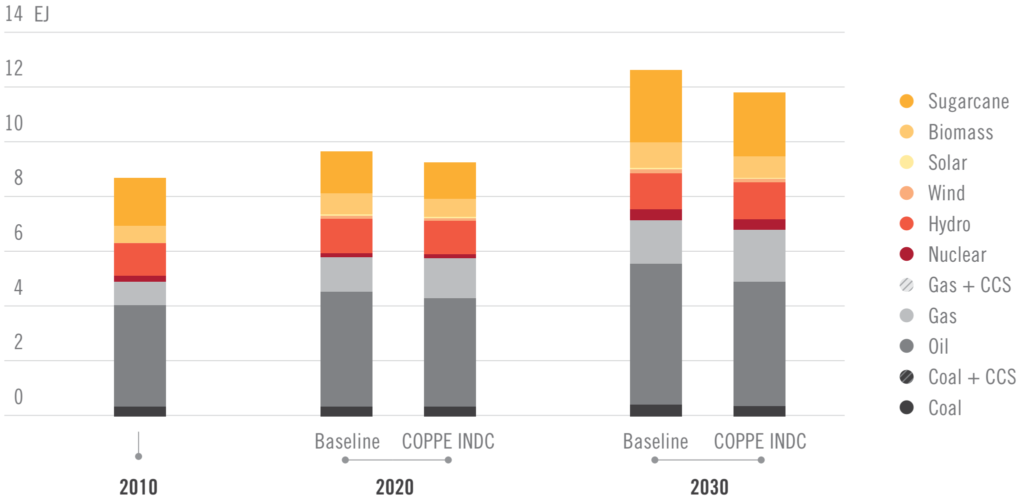
Figure 34. Primary Energy Consumption



Source: COPPE, MSB8000 model

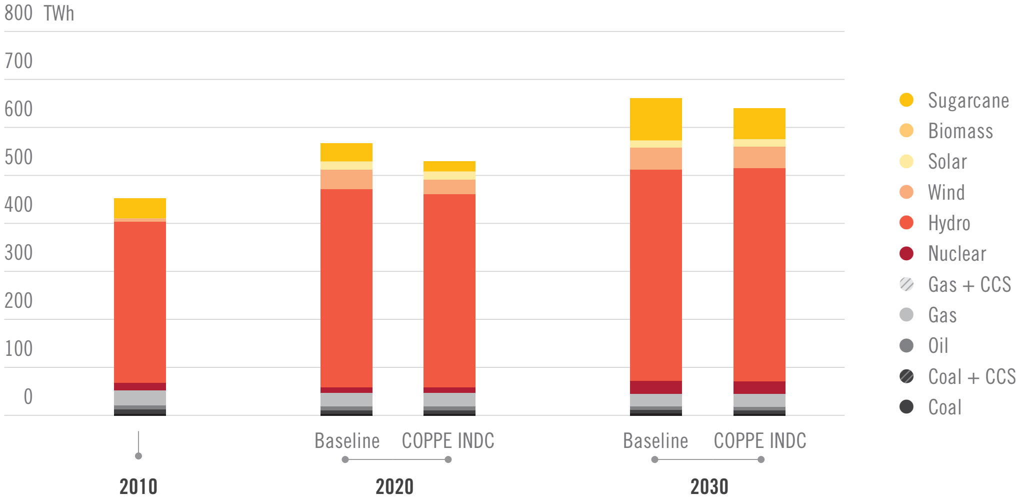
Figure 36 shows electricity generation highlighting the continuing dominance of hydropower along with an increasing presence of sugarcane bagasse, onshore wind and distributed solar PV. There is a drop in electricity consumption of about 3.3% from 675 TWh to 653 TWh in 2030, caused by efficiency gains in the electricity sector. This is exactly a third of the INDC target of 10%. Energy efficiency potential is a challenge to quantify given is diffuse nature, and no concrete measures are offered in the INDC. The round value of 10% is perhaps the lowest round number that could be included in a document of the nature of an INDC,

Figure 35. Primary Energy Consumption Baseline and COPPE INDC



Source: COPPE, MSB8000 model

Figure 36. Electricity Generation in Baseline and COPPE INDC



Source: COPPE, MSB8000 model

and most likely does not reflect a hard target but, rather, signals a preoccupation to include energy efficiency as part of the mitigation efforts. There is certainly room to improve efficiency in electricity uses, be it from reducing the currently high 16% losses in transmission and distribution (EPE, 2013), or from a myriad of possibilities in all sectors of the economy, from irrigation in the agricultural sector to other end uses in residential, services and industrial sectors. Still, given the lifetime of appliances and the gradual substitution for more efficient equipment, energy efficiency policies may take time to show large reductions in demand.

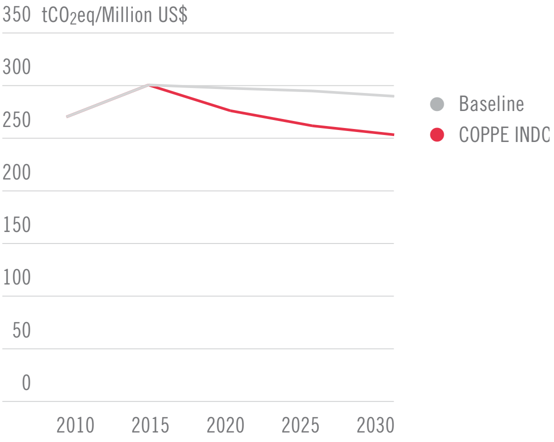
Sugarcane bagasse responds the most to the reduction in demand from the baseline to COPPE INDC scenario, with an almost 28% drop, followed by a reduction in coal generation using domestic coal (of low quality), which falls by about 17%, and CHP by 4.5%. In contrast, there is no change to electricity generation from other sources, except for a small increase in hydropower generation of 0.8%, which still translates to about 3.5 TWh given the large share of hydropower in the Brazilian electricity mix. Other renewable sources remain unaltered.

The no-regret COPPE INDC scenario has net negative costs for the energy system, indicating a net benefit to the sector[27] as can be seen in Fig-

---

[27] It should be noted that this result depends on the discount rate assumed, in this case, 10% per year.

Figure 37. Carbon intensity of the Brazilian economy, from energy related GHG emissions in the Baseline and COPPE INDC scenarios



Source: COPPE, MSB8000 model

ure 38. This benefit, however, can only be realized by the elimination of widespread barriers and market failures that plague the Brazilian economy and reduce its overall efficiency[28]. These include high-interest rates (currently at 14.25% per year), high inflation (9.6% forecast for 2015) and low investor confidence that is fueled by high political and economic uncertainty in the short-term, and structural inefficiencies in the long-term such as an overly complex tax system, a heavy tax load (currently ~35% of GDP), low labor productivity and inadequate infrastructure. These problems are often referred to collectively as the "Brazil-cost", which puts a premium on prices, effectively functioning as a barrier to investment. A reduction in the Brazil-cost could potentially lead to a more efficient economy, and consequently to improvements in the energy and carbon efficiencies of the country.

Although we only report results through 2030, the MSB8000 model time horizon is 2050, and important dynamics occur past 2030 that make the case for a more ambitious mitigation effort in the medium term. In particular, more coal generation capacity is deployed pre-2030 in the COPPE INDC scenario than in higher-CO_2 price scenarios, indicating the danger of a carbon lock-in that would make mitigation in later years more challenging. Actually, in the Baseline the coal share in the electricity generation evolves from 2% in 2030 to 18% in 2050, while in the COPPE INDC scenario it evolves from 2% in 2030 to 8% in 2050 and in BC50 it remains sTable in 2% from 2030 to 2050. Therefore, a strategy involving further effort after 2030 would be hampered by coal power plants installed pre-2030 that would not have reached the end of their lifetime.

Table 17 shows the share of renewables under various shadow costs of mitigation, indicating that most renewable energy targets in the INDC can be met by the COPPE INDC scenario. The major exception is the 45% share of total renewables in primary energy consumption (PEC) indicated by the INDC, a share that only realized with shadow costs higher than US$50/$tCO_2eq$. All other targets are met with the COPPE INDC scenario, including INDC targets of 23% of non-hydro renewables in electricity generation and 18% share of biofuels in PEC. Clearly, it is worth stressing that Brazil's INDC did not provide the macroeconomic scenario behind the targets. Nor did it highlight if these targets were based on an integrated analysis. Therefore, given our results, it is possible to say that most of INDC targets related to the energy system are feasible at relatively low carbon prices.

Table 17 – Share of renewables under various shadow costs of mitigation (PEC = primary energy consumption; EG = electricity generation)

2030	COPPE INDC	BC10	BC20	BC50	BC100	BC200
Total renewables in PEC	39%	40%	40%	43%	47%	49%
Biofuels in PEC	26%	27%	28%	30%	33%	36%
Sugarcane in PEC	20%	20%	21%	23%	26%	28%
(Wind + Solar + Biofuels) share in PEC	28%	28%	29%	32%	35%	38%
Hydro share in EG	68%	68%	68%	66%	66%	65%
(Wind+Solar) share in EG	21%	21%	21%	23%	23%	23%

Source: COPPE, MSB8000 model

Table 18 shows Brazil's energy and carbon intensity in the baseline and COPPE INDC scenarios, as well as the electricity grid emission factor under both scenarios. There is a drop in all indicators, reflecting an improvement to both the energy and carbon intensity of the economy. By 2030, the energy intensity drops from 126.4 toe/kUS$ in the baseline to 110.2 toe/kUS$, a 12.6% drop, while the carbon intensity falls from 253.4 tCO_2eq/kUS$ in the baseline to 253.4 tCO_2eq/kUS$, a 12.8% drop. In contrast to the economy-wide improvement in carbon intensity, there is an increase in the grid factor from 42.2 kg/kWh to 42.7 kg/kWh, a 1.2%

---

[28] It should be considered that policies to reduce these barriers would have a cost, which is not considered in the modeling effort.

Table 18: energy sector indicators under the COPPE INDC scenario and Baseline, 2010-2030, Brazil

				2010	2015	2020	2025	2030
Baseline	Total	Emissions	MtCO2	584.9	701.2	704.1	802.6	889.8
		Energy	Mtep	249.2	290.4	308.9	350.4	388.0
		Carbon Int.	$\text{tCO}_2\text{eq/kUS\$}$	270.3	300.6	297.5	294.9	289.9
		Energy Int.	toe/kUS$	115.2	124.5	130.5	128.8	126.4
	Power Sector	Emissions	MtCO2	30.86	40.65	28.23	28.13	28.47
		Generation	GWh	510.6	527.0	577.2	618.2	675.3
		Grid Factor	$\text{kgCO}_2\text{eq/kWh}$	60.4	77.1	48.9	45.5	42.2

				2010	2015	2020	2025	2030
COPPE INDC	Total	Emissions	MtCO2	584.9	701.2	653.8	712.7	777.8
		Energy	Mtep	249.2	290.2	265.0	303.1	338.3
		Carbon Int.	$\text{tCO}_2\text{eq /kUS\$}$	270.3	300.6	276.2	261.9	253.4
		Energy Int.	toe/kUS$	115.2	124.4	111.9	111.4	110.2
	Power Sector	Emissions	MtCO2	30.86	42.96	28.38	28.27	27.87
		Generation	GWh	510.6	521.6	540.1	602.1	653.0
		Grid Factor	$\text{kgCO}_2\text{eq /kWh}$	60.4	82.4	52.5	47.0	42.7

Note: Emissions include fossil fuel combustion from all sectors, industrial processes, waste treatment, and fugitive emissions.

Source: COPPE, MSB8000 model

increase in carbon intensity in electricity generation, underlining the exclusion of mostly sugarcane bagasse and coal, with bagasse generation dropping by a larger amount than coal, thus increasing the electricity grid emission factor.

Conclusions

The land use emissions pledges in the INDC have elicited criticism from observers saying that although relatively ambitious, they do not go far enough, especially in light of the potential for mitigation in Brazil (see case study). Much of the challenge will be in the implementation of adequate measures to reach the targets, especially given the recent changes to the Forest Code in 2012. Particular controversy exists around the so-called "amnesty" to land owners who illegally deforested their land prior to 2008, as there is a powerful "ruralist" lobby claiming that without such amnesty, most Brazilian rural properties would be "unfeasible"[29]. The issue is under review by the Brazilian Supreme Court (*Supremo Tribunal Federal*).

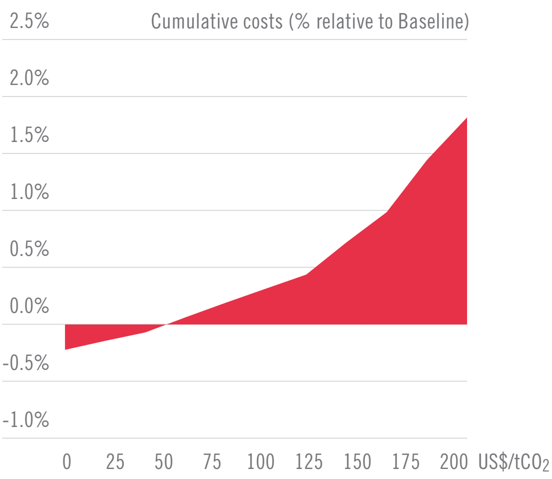
In addition, there is the controversy around the environmental reserve quota (or CRA for *Cota de Reserva Ambiental*), a flexible mechanism that allows farmers that have overshot the clearing limit on their land can buy quotas from other farmers who keep more forest coverage on their properties than required by law. Using the land use model GLOBIOM, the Redd-Pac study estimated that without the amnesty and without the CRA, there is considerable potential for recovering almost 30 million hectares of forest, twice as much as the 15 million hectares pledged in the INDC. In a scenario where the CRA is only available for croplands but not to pasturelands, the potential falls to 21 million hectares. Although this is still more than the INDC pledge, the study shows that the CRA can be a perverse incentive, especially for the *caatinga* and *cerrado* biomes, and if adopted without further policies, the CRA could become a disincentive for forest recuperation in 2 million hectares in the *Cerrado* alone. In fact, the *cerrado* is the biome that bears much of the brunt of agricultural expansion, and is expected to lose much of its area as a consequence of more visible support to halt deforestation in the Amazon.

We have focused here in the COPPE INDC scenario because the targets for AFOLU permit a less ambitious effort from the energy system, and because it is the least cost scenario that still meets most of the INDC targets. However, and we have pointed to this throughout the text, mitigation in the Brazilian energy system can certainly go further with higher shadow costs of carbon. As shown in Figure 38, the results of the optimization model, which optimizes the energy system from 2010 to 2050, indicates that up to 15 $\text{US\$/tCO}_2$ the low carbon scenarios can be seen (from the microeconomic perspective of the energy system) as non-regret.

---

[29] http://www.observatoriodoclima.eco.br/lei-de-floresta-zeraria-desmate-na-amazonia/

Figure 38. Cost differential between Baseline and COPPE INDC scenarios, from 2010 and 2050



Note: Emissions include fossil fuel combustion from all sectors, industrial processes, waste treatment, and fugitive emissions.

Source: COPPE, MSB8000 model

Even for higher CO_2 prices the differences between the costs seems not to be huge.

Certainly, should more be done to abate energy emissions, less will be required from AFOLU for the country to meet its INDC targets. Although AFOLU mitigation measures tend to bring the most co-benefits, including a higher net present value, there are important barriers that may stand in the way such as transaction costs.

2.7. India

Background

India submitted its INDC to the UNFCCC on the 2nd of October 2015[30]. It outlines eight inter-related action points focusing on mitigation, adaptation, technology, finance and capacity building. From the perspective of the energy sector it sets aspirational quantitative goals on 2 specific aspects, namely (a) reducing emission intensity of GDP by 33-35% by 2030 compared to 2005 levels, and (b) achieving 40% cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030, with the help of technology transfer and low cost international finance. To facilitate achieving these goals, throughout the INDC text, particular emphasis has been placed on institution building at the national and international level for mobilization of finance and technological capabilities, especially from developed countries. This institution building is aimed at strengthening collective action and creating an inclusive and equitable framework globally to work towards "climate justice"[31]. The Indian INDC is "contingent upon an ambitious global agreement including additional means of implementation to be provided by developed country parties, technology transfer and capacity building"[32]

Although the main section on its INDCs in the Indian submission does not talk about sectoral targets except for creating an additional carbon sink of 2.5 to 3 billion tonnes of CO_2eq through additional forest and tree cover by 2030, the INDC document refers to various directional/indicative measures and policies that could facilitate the achievement of the INDC targets. The document mentions 100 GW of Solar, 60 GW of Wind and 10 GW of biomass by 2022 and alludes to 63 GW installed capacity of nuclear energy by 2032. It mentions that annual fuel savings due to continuation of the National Mission on Enhanced Energy Efficiency are estimated to reach 23 million toe per year by 2020. 100 billion kWh of annual energy saving is expected from higher penetration of LED bulbs. More energy savings are likely to come through the Super-Efficient Fan Program and successive Corporate Vehicular Fuel Consumption Standards in 2017 and 2022. Some new policy initiatives integrating the imperatives of sustainable development such as the Smart Cities Mission, Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Green Transportation Network, JalMargVikas, Metro Rail Systems (MRTs), Green Highways (Plantation & Maintenance) etc. have also been highlighted.

While India's INDC continues to stress that the extent of low carbon transformation is contingent upon the provision of technology transfer and finance by developed countries,[33]ongoing and new initiatives to mobilize domestic resources to support clean energy transition such as the National Clean Energy Fund (NCEF) have also been emphasized. In particular the effective increase in carbon tax on fossil fuels has been highlighted, of which the tax per metric ton of coal produced and imported in India to fund the NCEF, which was

---

[30] India's intended nationally determined contribution: Working towards climate justice Available at: http://www4.unfccc.int/submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf, last accessed 07/10/2015

[31] Indian INDC.

[32] Indian INDC, page 30.

[33] NitinSethi (2015) Javadekar says Subramanian's views on climate change policy not India's, *Business Standard, 25 August 2015.* http://www.business-standard.com/article/economy-policy/javadekar-says-subramanian-s-views-on-climate-change-policy-not-india-s-115082400708_1.html

established in 2013 is one component. Importantly, the tax on coal has been continuously increased from 50($0.8) in 2013 to 100($1.6) in 2014 and to 200($3.2) in 2015.[34] The Economic-Survey 2015 further suggests that it could be increased over time up to 498 ($8.0) per metric ton.[35]

From the listing of ongoing and new policy initiatives and the eight point action plan to achieve INDCs it is evident that India would need to further strengthen its action across various sectors by not only continuing along the strategies outlined in India's National Action Plan on Climate Change, but moving even more ambitiously towards clean and efficient energy use. In the energy sector, the two mainstays of policy intervention will be promoting energy efficiency in end use sectors such as buildings, appliances and industry and increasing the share of renewable energy in the energy mix. Indications to this effect have already been given by the government by raising the aspirational targets for non-fossil fuel electric power capcity to 175 GW (100 GW of Solar, 65 GW of Wind and 10 GW of Nuclear) by 2022[36] and exploration of "deepening" (including new Designated Consumers in the currently covered 8 sectors) and "widening" (including new sectors: Railways, Refineries and Power Distribution Companies) options under the Perform Achieve and Trade (PAT) scheme for energy efficiency under the National Mission on Enhanced Energy Efficiency (NMEEE).[37]

Transformation Implied by the INDC

The above discussion outlines the direction of transformation. How this transformation may be distributed across activities and what challenges it may face in implementation is not elaborated upon in the INDC. This preliminary analysis here therefore examines these aspects for the energy sector by complementing an earlier modelling study undertaken by TERI (2015) and adjusting the clean and efficient energy targets in 2030 along the direction mentioned in the INDC. This exercise considers only energy sector CO_2 emissions as opposed to GHG emissions covered under the INDC.

This Study

CO_2 emissions from the energy sector have been steadily increasing. In 1994, energy sector accounted for 62% of total GHG emissions, in 2000 about 67% and in 2007, around 71%. However, given the need for improving access to energy and infrastructure for basic services, and the aspiration of high and inclusive growth, the energy sector and in particular energy intensive sectors like cement and steel are expected to grow more rapidly than other sectors.

Our analysis indicates that in achieving the INDC target, the power sector will have to play a critical role. Total centralized installed capacity for electricity generation will have to increase around five times from 138 GW in 2006 to 702 GW in 2031 to meet the needs of the economy. Of this, 100 GW comes from solar, 70 GW from large hydro and 60 GW from wind. The share of non-fossil fuel based energy will be 37% (see Figure 39). It is important to note that this modelling exercise assumes a lower rate of growth (8.3%) and rate of urbanization (37%) for the period 2006-2031 compared to those indicated in the INDC i.e. 8.6% and 40% respectively for the period 2014-2030. Hence, the total centralized installed capacity as well as of non-fossil fuel based sources commensurate with INDCs is likely to be higher than what this preliminary analysis suggests. The corresponding increase in end use energy demand from different sectors are given in Table 19.

Table 19: increase in end-user energy demand 2006-2031, India

	Increase in 2031 over 2006
Industry	Factor 3
Transport	Factor 4
Commercial (services)	Factor 5

Source: TERI scenario based on the India MARKAL model

Given the level of GDP growth, based on our exercise, the total primary energy supply would increase 4 times, due to increase in final demand (Table 19). The share of traditional biomass decreases from 33% to 11%, while contribution of fossil fuels increases in primary demand from 63% to 84% with higher access to modern fuels for cooking, lighting etc. and also increase in the number of household with electricity ("energy for all" programme). The existence of biomass, especially in the traditional form is a cause of concern since it implies that this is being used for cooking even in 2031. Coal still remains an important part of the mix for various reasons: 1) It remains an economically competitive method to produce electricity;

---

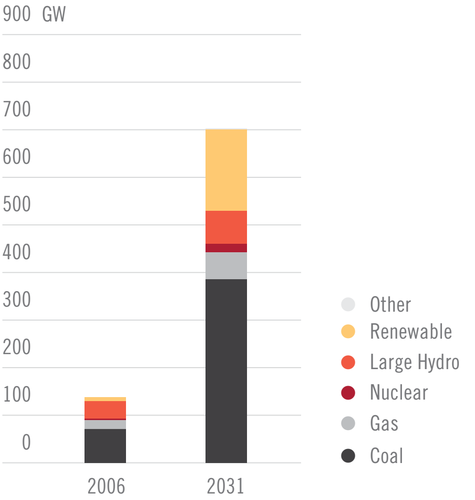
[34] Minister of Finance (2015). Budget 2015-2016 Speech of ArunJaitley Minister of Finance.

[35] Ministry of Finance (2015).Economic Survey 2014-15, Vol. I. pp 128.http://indiabudget.nic.in/es2014-15/echapter-vol1.pdf

[36] Ministry of New and Renewable Energy (MNRE) (2014). Renewable Energy Programmes Gets A New Impetus; Focus on Development of Energy Infrastructure.

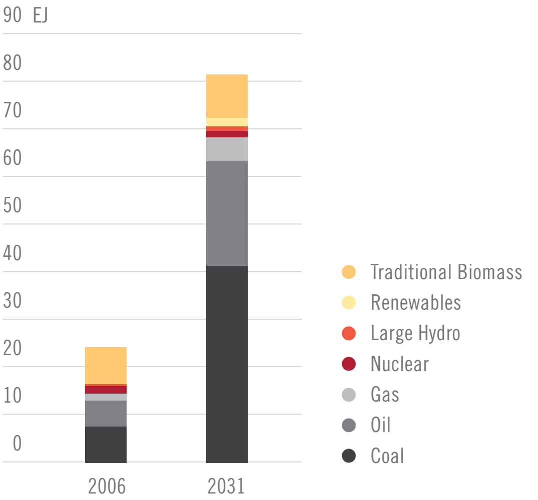
[37] Bureau of Energy Efficiency (Bee)(2015), Perform Achieve &Trade (PAT) Scheme: Looking Back and Way Forward, http://www.iipnetwork.org/KEP01-01.pdf2

Figure 39. Electricity generation capacity, India



Source: TERI scenario based on the India MARKAL model

Figure 40. Primary energy supply, India



Source: TERI scenario based on the India MARKAL model

and 2) limited options in fuel switching available in the industry sector. The challenge of meeting the INDC levels of energy demand is likely to be more since it aspires towards providing a more rapid and inclusive growth than that envisaged in our scenario.

The industry sector is a strong contributor to GDP growth. In a developing economy like India's, it has the critical role to provide jobs and material for a rapidly growing, industrializing and urbanizing economy. It is the second largest energy consuming sector after transport. Overall demand from the industry sector as estimated in our exercise would be 3 time that of 2006 levels by 2031. This increase is due to the magnitude of industrial growth and associated infrastructure requirement after taking into account the improvements in industrial energy efficiency. Given that Indian cement plants are second best only to Japan in terms of efficiency, and that the steel industry also has achieved significant efficiency gains in the past few years of ~5% and the PAT (Perform Achieve and Trade) Scheme of the Bureau of Energy Efficiency (BEE), Ministry of Power has delivered 4-5% energy intensity gains between 2012-15 for more than 450 large plants in 8 sectors, further energy efficiency improvements are not likely to be easy. Further reductions in energy intensity would generally not be low hanging fruits but more capital intensive emission reduction options.

By 2031, passenger mobility requirements are expected to be three times compared to 2006. Requirements for freight transport mobility would be five times. Transport sector will need 4 times more energy in 2031 compared to 2006. To decarbonize the transport sector, there is an urgent need to move towards public transport. Further, fuel switching must be achieved towards advanced biofuels, which may be carbon neutral and would be able to substitute away from petrol and diesel. Indeed, India's oil consumption growth is led by a growth in the transport sector. Among oil consuming sectors, demand from the transport sector has grown the fastest in the last couple of decades and is expected to grow the fastest among all sectors at around 8% per year until 2031. India's mobility needs are far from being met for both people and goods, with a low base and high growth rate. So while India would like to significantly increase the use of public networks – metro and railways, which are more efficient options - the sector's growth may well exceed the rate at which these solutions can be deployed.

Our analysis suggests that share of public transport is an important contributor to overall decarbonisation of the economy, since the pressure from road vehicles increase leads to a direct increase in oil consumption. Moving higher levels of passenger and freight traffic to rail based mobility is another important aspiration, albeit the rapid growth in road based movement has provided tough competition to rail in the last decades. Our scenario assumes that we are able to reverse the decrease in the share of rail based transport.

Given the trend of urbanization, it is important that India focuses on proper and integrated urban planning and reducing the pressure on urban centres.

Further, the commercial sector is expected to lead to an increase in demand of about five times the current levels. It is anticipated that 70% of the building stock in 2031 would be new buildings;

this implies that even though capacity is being created at the best standard for energy efficiency, it is expected that the increase in total capacity and therefore energy requirement could increase by 5 times.

Conclusion

India has a population of 1.2 billion of which 304 million do not have access to electricity; 380 million do not have access to modern forms of cooking fuel, and 92 million are without access to safe drinking water. The per capita energy consumed is 0.6 toe, which is a third of the world average. India is faced with a formidable challenge of maintaining rapid and inclusive growth but through clean and sustainable forms of energy. When one juxtaposes this primary objective with India's INDC it becomes clear that not only is this very challenging, it is also a challenge that no other large country has undertaken previously. Although other countries are also ramping up their transition to a low-carbon economy, there is no obvious historical benchmark available which India can follow that will enable it to overcome this challenge of sustainable development and climate mitigation. Our analysis suggests the following conclusion:

The level of transformation that is faced by India is tremendous, it must be appreciated in terms of the energy and other services that need to be provided to a large under-served and poor population

Given this scale of transformation, a 33-35% reduction in intensity is very ambitious and would entail a path that has never before been followed by other countries

To achieve this scale of transformation it is critical that globally an inclusive and equitable framework is developed that not only provides for framework on commitments but also on technology innovation, demonstration and global availability, and international finance support and innovation.

Case Study 4: The Challenges of Long-term Transformations in the Light of INDCs

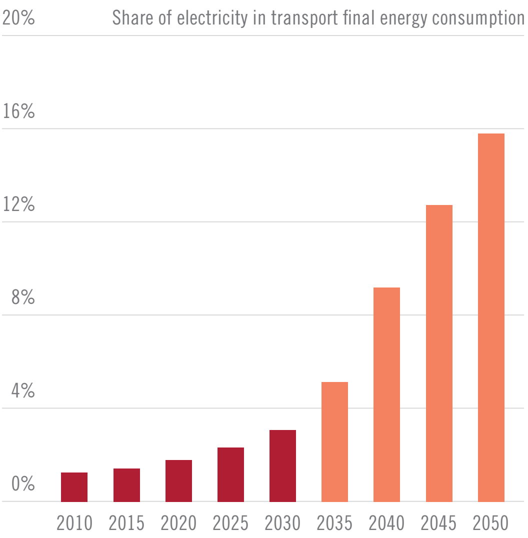
The analysis in this chapter has focused largely on 2025 and 2030, being the relevant time horizon for INDCs. However, short-term transformation needs to be coherent with long-term goals of very low emissions at the global level, and hence in all major emitters (around 1.7 tons of energy related emissions in 2050 at the global level). This case study examines some of the challenges associated with these long-term objectives, and builds the case for the need to analyse INDCs in the light of the coherence with long-term deep transformation. It explores the challenges facing some of the countries in this chapter of moving from INDCs in 2030 to deep decarbonisation by 2050.

Section 2.2 noted that the European Union sees relatively little decarbonisation of transport energy by 2030, under the INDC (Figure 7). This is also confirmed by the global results in section 4, which show relatively little decarbonisation of transport energy by 2030 (see Figure 48). However, by 2050 a very significant decarbonisation of transport energy needs to take place, notably through the electrification of transport and the deployment of advanced biofuels. In Europe, the share of electricity is projected to be required to reach about 16% by 2050, up from 3% in 2030 under the INDC. Given that it is very difficult to electrify freight transport, the share of electricity in passenger transport would have to be even higher. In 2030, in the order of 30% of annual vehicle sales would need to be electric in order to ensure that the share of electricity in final energy consumption in transport grow sufficiently in order to meet challenge of the decarbonisation of transport energy. This is a major industrial, innovation, and infrastructure challenge, which needs to be prepared for in the coming 15 years.

A similar example can be drawn from the INDC analysis of China. In the Deep Decarbonization Pathways Project (DDPP), the Chinese Deep Decarboniation Scenario followed broadly the same pathway to 2030 as the INDC scenario in this report. Thereafter, continued reductions are pursued through notably the deployment of carbon capture, usage and storage (CCUS) in the power and industry sectors (as well as electric mobility – see above). In this scenario, by 2050 CCUS facilities are expected to be installed in about 75% of coal power plants by 2050.

This discussion highlights three important points. Firstly, there are multiple pathways towards 2025/2030 objectives, but not all of them are consistent with 2050 deep reductions. China and the EU could meet their 2030 targets, but in so doing still fail to unlock the necessary technological, infrastructural and industrial capacity to deploy these crucial solutions after 2030. Secondly, this underscores the need to prepare now the technologies and solutions that will be required in the long-term given the inertia of the economic and physical systems that need to change. International and domestic policy-making needs to give greater attention to unlocking these solutions post Paris. Thirdly, it highlights the need for dynamic policy making to allow a timely change of course if these solutions do not come online.

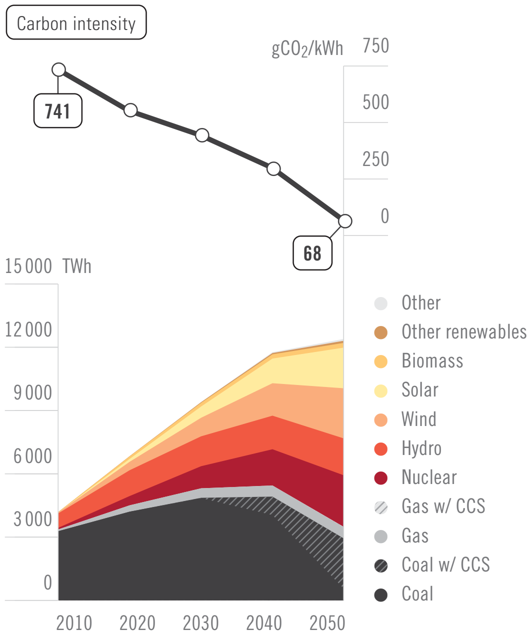
Figure. The challenge of post 2030 electric mobility in the EU



Note: ligth red represent what is modelled as required after the INDC timeframe in order to reach -80% reductions by 2050.

Source: PRIMES

Figure. The challenge of CCS deployment in China post-2030 deep decarbonisation scenarios



Source: Lui Q. and Fei, T (2015)

3. CO-BENEFITS AND TRADE OFFS OF INDCS

3.1. Cross-Cutting Analysis

Climate mitigation can trigger synergies and trade-offs with other policy objectives at the national level, such as poverty reduction, clean air, public health, or energy independence. Synergies (often referred to as co-benefits) are thus important because they influence the national support for climate mitigation policies and more directly impact the life of local populations. The IPCC AR5 Working Group III Assessment provides a large, qualitative overview of potential co-benefits and adverse side-effects (see Table 6.7 in IPCC AR5 WGIII), and highlights that local circumstances will to a large degree influence whether or not (and to which extent) certain co-benefits and trade-offs will materialize. In the "multi-objective" framing, it's clear that a sustainable energy transition goes beyond climate concerns and can include everything from ensuring energy security and air quality to decreasing water use and biodiversity loss (Stechow et al. In press). Here we carry out a quantitative analysis at the national level, and examine the synergies and trade-offs that are projected to materialize under the implementation of the INDC. We explore two dimensions: (1) local air quality and (2) energy trade and independence.

In the context of the project, INDC assessments with sufficient detail were available for five countries: Brazil, Japan, the European Union (EU27), China, and USA. Detailed country-level analyses estimate how much INDCs would reduce CO_2 emissions at the national level (Table 20). These CO_2 emission reductions are then used, together with stylized relationships that were derived from the results of large-scale studies with global integrated assessment models (IAM) of the energy-economy-land system[38], to estimate the extent of synergies and trade-offs under the INDCs (see Annex for details).

Table 20: Overview of emission reductions in 2030 under the INDCs

	Reductions in 2030 of CO_2 from energy and industrial sources	
Country	relative to 2010	*relative to reference**
Japan	-23%	-20%
EU28	-29%	-9%
USA	-22%	-24%
Brazil	35%	-11%
China	+34%	-12%

*Because different national modelling teams included different assumptions on which policies to include in their 'reference', the reductions relative to reference are not directly comparable. For example, the reference pathway of the EU28, already includes climate policies.

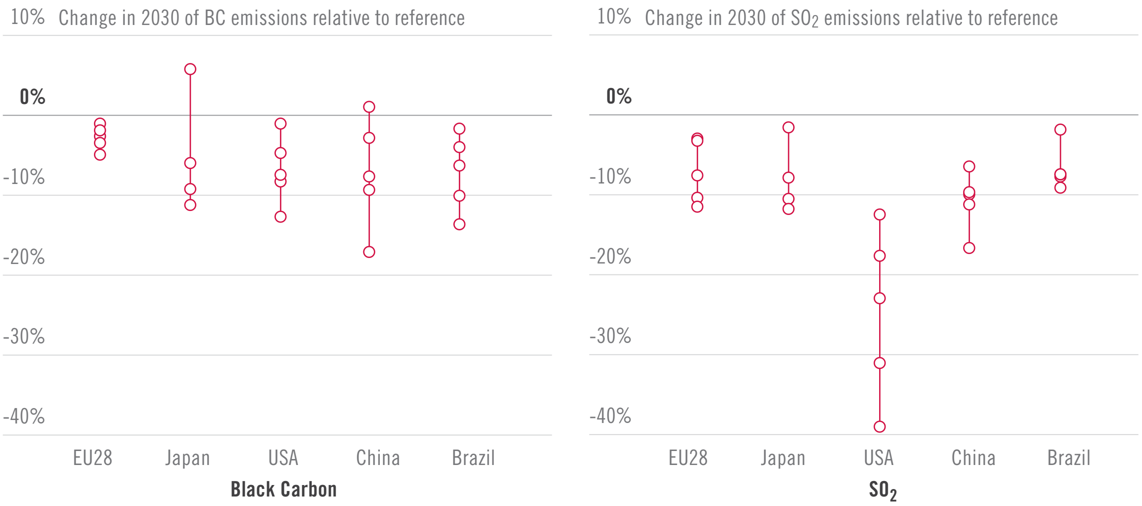
The changes in local air quality that are projected under the implementation of the respective INDCs of countries are quantified by looking at the reductions of two key air pollutants: black carbon (soot) and sulphur dioxide. These changes are expressed relative to a reference case in absence of the INDC and earlier climate commitments, like the Cancún pledges.

Air pollution is significantly reduced in most of the assessed INDC cases (Figure 41). Black carbon emissions can be reduced up to about 15% relative to the situation without new climate action, and in most cases similar reductions are found for SO_2. However, these values vary strongly among countries, with countries that currently already have stringent air pollution controls (like the EU28 or Japan) seeing less of an air pollution co-benefit.

---

[38] In particular, data from the LIMITS project was used, which received funding under the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 282846.

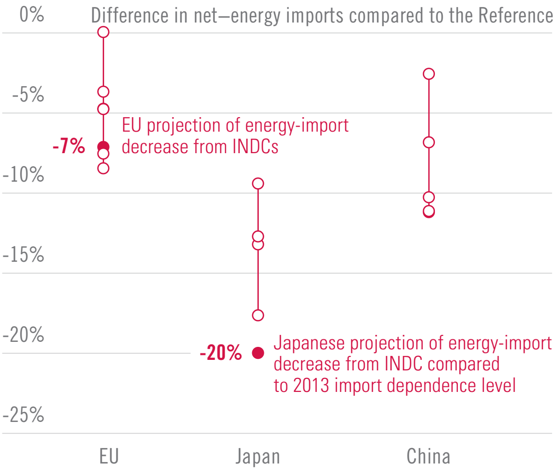
Figure 41. Estimates of the reduction in national emissions of black carbon (soot) and SO_2 in 2030 as a result of implementing the respective INDCs.



Source: IIASA calculations

Each dot represents the estimate based on a different model ○

Figure 42. Estimates of the reduction in net-energy imports in 2030 as a result of implementing the respective INDCs



Note: each dot represents a single model estimate. The Japanese projection of energy import decrease from the INDCs (from Case Study 5) is presented in terms of decrease compared to 2013 net-import levels.

Source: IIASA calculations

As SO_2 is mainly co-emitted with CO_2 by coal fired power plants, sources of SO_2 are more closely linked to key emissions of CO_2 from the power and industrial sectors. Therefore, the estimated synergies are generally larger, leading to a reduction in SO_2 pollution in all models. Finally, in Japan and China, the possible increase in black carbon emissions under the implementation of their INDC is a result of a more extensive use of biomass, for which black carbon emissions can be high. This is illustrated by the positive values in the left panel of Figure 41. For these two countries the black carbon co-benefits are thus more uncertain.

For the most part, climate mitigation measures lead to a decrease in energy import dependence by increasing the use of domestic renewables and energy efficiency measures. At the same time, climate policies can increase energy import dependence by curbing the use of domestic coal. These conflicting forces lead to uncertainty in estimating net-trade impacts of GHG emission reductions. In the case of net-energy imports, the INDCs for the EU28, Japan and China depict up to a 25% decrease in net-energy imports compared to the reference case (Figure 42).

For the U.S. and Brazil, the story is a bit different. The biggest uncertainty for the US' net-energy trade is not domestic climate policies but rather how the demand and price of oil, gas and coal develop both within the country and in international markets. That's because, under most assumptions, in the absence of any climate policies, the US becomes energy independent over the next several decades (as early as 2025 and in all except one by 2060). Thus while the US' net-energy imports will be influenced by climate policy, the bigger uncertainty is the development of fossil fuel markets globally. Brazil, with its biofuels program has very low energy imports today. While there is a modest growth in some models (up to about half of primary energy supply) other models depict the country as exporting small amounts of oil over the next twenty years. Thus, similar to the U.S., the biggest uncertainty with Brazil isn't what will happen to the country's climate policy but rather how the demand and price of oil, gas and coal develop internationally.

Case study 5: structural change, macroeconomic strategy and climate mitigation in China

China's economic structure is a major determinant of its GHG emissions. In comparison with other countries at a similar level of development, China's economy is heavily dependent on fixed investment and industrial production. In 2014, investment made up 47% of China's GDP, up from 38.3% in 2000. A notable jump occurred in 2009, when investment's share in GDP increased by 4.9 percentage points. This was due to a significant stimulus package and monetary easing unleashed in the wake of the global financial crisis. On the production side, China's GDP is dominated by the industry sector, which made up 43.9% of Chinese GDP in 2013.[39]

China's GHG emissions are therefore largely driven by the industrial sector, which was responsible for 65% of growth in energy-related CO2 emissions between 2000 and 2013.[40] Rapid investment in physical infrastructure has driven in turn investment in industrial production facilities (steel, cement), which in turn has driven investment in (coal-fired) generation capacity to feed the industrial sector. China's economic structure has thus been a key driver of CO_2 emissions.

Table : assumptions in the structural change scenarios

	Fixed structure scenario	Medium structural change	High structural change
GDP growth rate 2010-2030 (%)	5.5	5.5	5.5
Share of industry sector 2014 (%)	47	47	47
Share of industry sector 2030 (%)	48	42	38
Share of tertiary sector in 2010 (%)	44	44	44
Share of tertiary sector in 2030 (%)	48	53	57

Source: Authors, based on structural assumptions in China INDC scenario, chapter 2.5

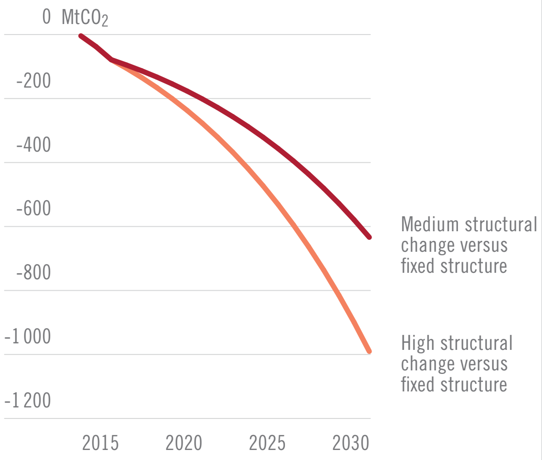
There is substantial evidence and understanding among Chinese policy makers that this investment- and industry-driven economic model is starting to falter. Headline growth has slowed significantly; debt has grown rapidly; there is overcapacity in the power generation, real estate and manufacturing sectors; exports are no longer contributing positively to growth, and there are signs of financial instability. The government has recognized the need to restructure the Chinese economy with the concept of the "New Normal", i.e. slower headline growth and a progressive restructuring of the economy towards domestic consumption and services.

This would have significant benefits for climate mitigation, as the Chinese macro-economy would transition towards less energy and emissions-intensive sectors. This structural adjustment is expected to bring a significant improvement in energy intensity, alongside technological improvements in efficiency. The importance of this is illustrated in the figure below, which shows the effects of structural change in mitigating Chinese emissions, by comparing two structural change scenarios with a counter-factual fixed structure scenario. The major assumptions are shown in the Table.

In order to isolate the effect of structural change, the scenarios assumes that the carbon intensity of the industrial and tertiary sectors remains fixed at their 2014 levels, i.e. 2.18 tCO2/1000 USD and 1.16 tCO2/1000 USD respectively.[41] This also means that the case-study focuses only on the effects of macro-economic restructuring, and ignores the effects of restructuring within the industrial sector, i.e. away from value added generated by emissions intensive industries such as cement and steel, and toward more emissions-efficient industrial activities.

The figure below shows the difference in the level of CO2 emissions between the two structural change scenarios and the fixed structure scenario, holding all other assumptions constant. It can be seen that structural change can make a very significant contribution to GHG mitigation in the coming couple of decades (about 10% in 2030, assuming an emissions peak 2030 at about 11 Gt). This illustrates well the synergy between the Chinese government's macroeconomic policy (engineering a gradual and smooth transition to the 'New Normal') and the objectives of climate mitigation. It also illustrates a major source of uncertainty in Chinese climate policy and emissions scenarios, namely the future direction of the Chinese macro-economy. A dynamic approach to policy making is required to progressively resolve this uncertainty, as well as full integration of macroeconomic policy and climate policy considerations.

Figure. illustration of the energy related CO2 impacts of structural change in China



Source: Authors, based on structural assumptions in China INDC scenario, chapter 2.5

---

39. Data from Oxford Economics.

40. Authors' calculations based on Enerdata.

41. Authors' calculations based on data from Enerdata. N.B. this includes only CO2 from fossil fuel combustion, not industrial process emissions.

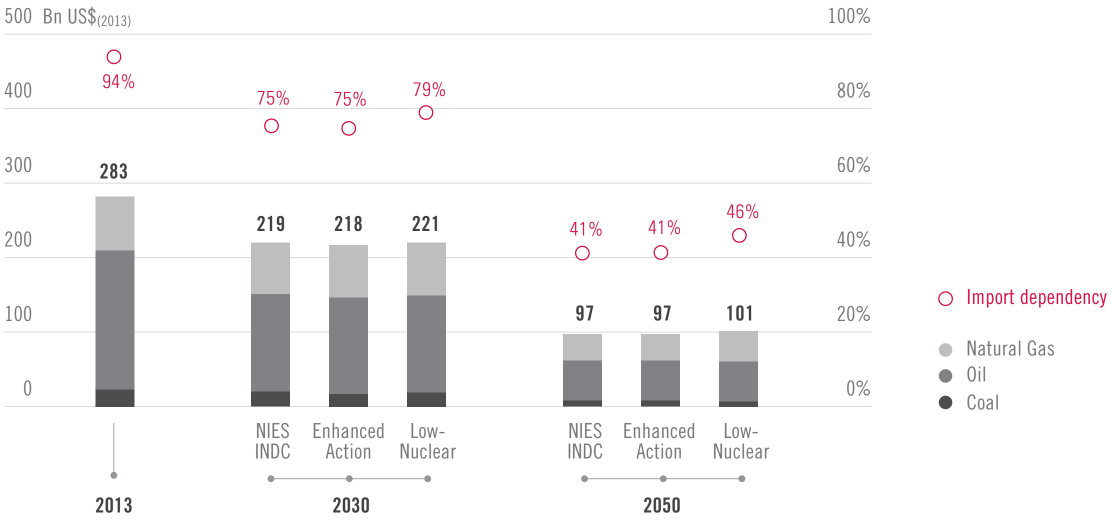
Case study 6: energy security and import dependency in Japan

In Japan energy supply is highly dependent on imported fossil fuels because of a lack of domestic resources. In the 2000s, import dependency of primary energy supply (hereafter import dependency) in Japan was more than 80%, even if nuclear power is accounted as a domestic resource. Moreover, since 2011, import dependency has substantially increased due to the suspension of nuclear power, rising to approximately 94% in 2013. In addition, import bills for fossil fuels have been also increased since 2011 and grown to approximately 280 billion USD in 2013, together with rise in crude oil prices in this period. Combining decarbonisation in the mid- to long-term with energy security is a particular challenge for resource poor countries; however, decarbonisation can also provide substantial synergies with energy security.

The scenarios developed by NIES for the MILES Project include fossil fuel import bills and import dependency in 2030 and in 2050 as shown in the figure below. In 2030, because of energy efficiency improvement, promotion of renewable energies and restart of nuclear power, import dependency accounts for around 75% and import bills falls to around 220 billion USD despite of rise in crude oil prices, which are taken from IEA's Energy Technology Perspectives 2015. Even in Low-Nuclear Scenario, in which nuclear plant operates no more than 40 years, import dependency in 2030 falls to around 79% which is lower compared to the 2000s level. Moreover, continuing decarbonisation efforts after 2050 drive down import dependency to less than a half of primary energy supply in 2050. Thus decarbonisation in the mid- to long-term generally contributes to enhance energy security and to decrease import dependency. However, a switch from coal to LNG might cause a rise in total fossil fuel import bills, since LNG is likely to be more expensive than coal and pipeline gas. Import bills in the Enhanced Action Scenario, in which GHG emissions in 2030 falls by approximately 25.3% with respect to the 2005 level, stays almost the same level as NIES INDC Scenario due mainly to increased use of imported natural gas, despite additional deployment of renewable energies. Hence, promotion of natural gas entails challenges associated with energy security issue in the nations which import natural gas resources as LNG.

The main point, however, remains that implementing the Japanese INDC could lead to a significant improvement in energy security, measured in terms of import dependency and import bills.

Figure. Import dependency and bills of fossil fuels in Japan for the scenarios developed by NIES



Source: NIES, AimEnduse Japan model

Case study 7: international technology learning, renewables deployment and energy access in India

Renewable energy policy in India dates back to early 1980s responding to episodes of energy crisis in the 1970s. Since then, international cooperation has been central to India's renewable energy strategy. In addition to North-South technology transfer, emphasis on South-South cooperation has gained specific attention in recent years. As many as 35 bilateral/multilateral cooperation frameworks between India and other countries for new and renewable energy have been signed between 2007 and 2015.[42]

According to the Census of 2011, close to 32% of population relies on kerosene for basic lighting and a little over 67% use grid electricity. More than 300 million have no electricity at all. Close to 60% households use inefficient biomass based technologies for cooking with serious implications for health, air quality and GHG emissions. The imperatives of energy access and climate change in India therefore require the provision of affordable and reliable modern clean energy solutions for cooking and lighting to all its citizens. Accordingly, renewable energy is the mainstay of India's climate policy for its multiple development co-benefits, including creation of green jobs. In particular, decentralized renewable energy systems which offer a relatively cheaper option to providing electricity to those living in remote areas where gird connected electricity is not an economically viable option.[43]

Most successful experience in international cooperation on the supply side has been in the wind sector. As a result the installed capacity has increased over 20 times during 1998 and 2014 with a sustained annual investment in the range of USD 3 billion per year since 2006 and increasing competition in the domestic manufacturing market (Chaudhary, 2014).

India began exploring wind energy options in early 1980s. The first commercial project was set up in 1989 with support from the Danish International Development Agency (DANIDA). However, it needed another decade of sustained government policies and international support to facilitate technology transfer, demonstration and market creation before the wind sector could take off in India. It created a market dynamism that drew improved technology systems (still not the most sophisticated systems) through foreign firms setting local manufacturing units and an aggressive collaboration and global network strategy of the Indian company Suzlon Energy Limited. Suzlon used multiple strategies for acquiring different technologies such as licensing agreements, joint ventures, equipment supply agreements and acquisition of companies and developed a global network of supply across countries including India, Germany, Austria, Netherlands, USA and so on (Lewis, 2007).

The key lesson from India's wind sector is: sustained mutually assuring efforts in terms of cooperation between governments and between companies are critical, mere national policies are not enough. Before developing countries can go for commercial acquisition of technologies, international cooperation for technical and commercial capacity building is critical.

On the delivery side, however, Indian experience with distributed renewable energy systems (biomass and solar) has been more diverse and insightful. For a variety of social, economic and geographical factors, modern cooking fuels and grid connected electricity are unlikely to be accessible to all in immediate future (TERI, 2014). Hence continuous upgradation and adoption of technologies to ensure affordability, suitability to local context and reliability is necessary. It is evident from the experience with multiple government and NGO led initiatives to provide renewable energy solutions at the household level focusing on solar energy for lighting and improved cook-stoves or biogas for cooking e.g. National Biogas and Manure Management Programme (NBMMP), the Unnat Chulha Abhiyan Programme, Akshya Urja, Remote Village Electrification (RVE) Programme by the Ministry of New and Renewable Energy[44] and programs such as Lighting a Billion Lives (LaBL) and development and diffusion of improved cook-stoves and biomass gasifiers by The Energy and Resources Institute (TERI).

Interestingly, the experience shows that distributed renewable energy solutions require little North-South technology transfer, yet the role of international cooperation is critical. Collectively, the success stories (or the instances of failures) indicate that deployment of distributed renewable energy solutions requires building an ecosystem of mutual learning and cooperation among different actors for transfer of knowledge and capacities. The most important role of international cooperation has been to provide timely financial and technical support to build this ecosystem which enables critical learnings over the years related to soft-technologies necessary for successful deployment and technological R&D. The support from the Swedish Development Agency, for example, enabled TERI to develop multiple business models and technological capabilities for biomass gasifiers that are now enabling TERI to transfer these technologies and capacities to Africa. The key insight from this experience is that international cooperation can facilitate extending North-South cooperation into South-South collaboration and in that process enable innovations (hard as well as soft) to adopt technologies to suit diverse local contexts.

---

[42] http://mnre.gov.in/schemes/support-programmes/international-cooperation-3/

[43] http://mnre.gov.in/schemes/decentralized-systems/

[44] http://mnre.gov.in/file-manager/annual-report/2014-2015/EN/Chapter%205/chapter_5.htm

Case study 8: The Indian perspective on energy security and climate change

Energy security and climate change are intricately linked policy challenges for India. The development imperatives of India demand rapid increase in energy consumption (hence supply) which is likely to increase GHG emissions. At the same time India is severely vulnerable to climate change induced risks due to poverty, direct dependence of large population (~70%) on the agriculture sector and a long coast line (approximately 7500 km). The number of deaths by disaster and the number of people affected have increased 8 times between 2009 and 2013. The economic loss from disasters between 1990 and 2013 is approximately 50 billion dollars. The need to build both adaptation capacities to climate change and infrastructure for development is linked to the challenges of ensuring reliable energy supply as well as controlling GHG emissions from it.

India's development and energy security concerns are defined in the context of providing reliable quality energy services to a population of 1.2 billion, which is expected to reach 1.8 billion in 2050. Over 300 million people (about 4.5 times the population of France) are without access to electricity today. There are also fractions of the population on the margins, who get access to electricity but for limited number of hours. Similar or even more numbers do not have access to modern fuel for cooking and, therefore, are exposed to excess amount of indoor air pollution, in particular the female population. Exacerbating the problem of energy inaccessibility is the energy delivery system that is rather primitive and inefficient. There is a pressing need to modernize and strengthen this system with regard to delivering energy for cooking as well as lighting services.

Currently, India's energy supply is heavily dependent on fossil fuels large part of which is imported: about 80% of the crude oil accounting for 30% of import bill in 2010 and a third of the natural gas consumption. With projected energy demand growing by more than 3 times during 2011-2031 (TERI, 2015), the reliance on imported fuel and vulnerability to international price fluctuations is bound to increase. Hence, from energy security perspective non-fossil fuel based energy options are critical for India. These options are also in alignment with the imperatives of climate change.

Renewable energy options are potentially very attractive. The estimated wind potential at 80 m hub height is around 500 GW. Over 58% of the land receives solar insolation to the tune of 5 kWh/m^2/day. This makes solar energy a preferred option for India. Large hydro is estimated to have a potential of 148 GW at 40% availability factor (AF) while small hydro has around 15 GW potential at the same AF. Precise estimates of geothermal, tidal and off shore-wind are not available yet (Mathur, 2014). However, these huge potentials are difficult to exploit due to their poor economic viability and technological barriers, with exception of wind. With the current techno-economic circumstances, therefore, India's options for increasing energy supply keeping in mind the concerns of climate change give equal importance to coal (of which India has large reserves) with emphasis on clean coal technologies in the short run and promote renewable energy, particularly wind and solar with a long term perspective.

In addition, and more importantly, efforts to reduce the overall effective energy demand by promoting energy efficiency across sectors are critical for partially offsetting the potential GHG impacts of economic development. This has been the main thrust of the Electricity Conservation Act of 2001. Substantial possibilities of energy efficiency improvement lie in the industry, buildings and transport sector. While large industrial units are being regulated for reducing their energy intensity under the PAT (Perform, Achieve and Trade) scheme, the MSMEs (Medium, Small and Micro Enterprises) are being incentivised as they are highly unorganized and hence difficult to regulate. Similarly, while large energy consuming buildings are subjected to energy efficiency codes, households are being incentivised to use energy efficient appliances and lighting systems. In the transport sector efforts are being made to increase share of railways in freight, shift towards mass urban transit systems, and improved vehicular fuel efficiency for private vehicles.

An aggressive embark towards transforming India's energy supply in favour of renewable energy is possible only at high upfront costs supported by timely commercially viable technological breakthroughs across sectors, particularly in storage technologies, second and third-generation biofuels, and electrical vehicles along with high penetration of energy efficiency solutions. Such a scenario may allow India to reduce her total CO_2 emissions from the energy sector (Mathur, 2014). However, technological breakthroughs alone are not sufficient as the constraints of land availability, further exacerbated by the high pressure of urbanization, will require difficult political and institutional solutions. In addition adequately accelerated build-up of supporting infrastructure, appropriate skill sets, regulatory and institutional frameworks, and adequate renewable manufacturing capacities will also have to be a real possibility.

Clearly efficient use of fossil fuels and promotion of renewable energy over a long time horizon are India's options for responding to climate change and energy security concerns simultaneously. India's National Action Plan on Climate Change (NAPCC) reflects this understanding, which is further deepened in India's INDC.

Case study 9: perspectives for coal, implications for the transition pathway, lock-in and alternative options.

India's total primary energy demand (TPED) for 2013-14 was 837 million ton of oil equivalent (mtoe) (WEO, 2014), which has been growing 5.5% annually since 2010. Coal constituted 44% of TPED at 778 million tons (Mt) in 2013-14. Domestic production of all types of coal was 610 Mt and imports were 168 Mt. Coal imports have been growing at 25% per year since 2010.

The Indian domestic coal's average heat value was 3500 Kcal/Kg in 2013-14 with average ash content of 41%, and 0.51% sulfur by weight (MoC, 2015a). These parameters for imported coal[45] were 5995 Kcal/kg, ash 13% and 1% S by weight.

Industrial coal consumption is mainly for power generation (525 Mt) in 2013-14, steel (75 Mt) and cement plants (24 Mt) (MoC, 2015b). The average boiler efficiency in power sectors has been 30% with a PLF of 66% last year (CEA, 2014). There has been a decline in PLF since 2010 from a high of 75%, mainly due to coal shortages.

India's coal based power capacity stands at 165 Giga Watt (GW) (CEA, 2015) with another 88 GW under various stages of construction (World Bank, 2014). Total projected additional demand for coal in power sector is therefore around 400 Mt/year. Indian coal consumption is thus projected to cross at least one billion ton (Bt) within next 5 years. It may be much higher. For instance, the Power and Coal Minister had indicated his plans to set up coal washeries for 500 Mt of coal every year for next five years, indicating a total coal handling of above 2.5 billion ton per year (TOI, 2015a). The government owned Coal India Ltd., one of the largest coal mining company in the world, produced 462 Mt in 2014 (CIL, 2015) and has been increasing production by 20-25 Mt/year since the last 4 years. The CIL is planning to expand mining capacity by around 115 Mt by 2017. Realistically, it may add another 200 Mt by 2020. Enhanced energy efficiency by existing large coal consumers, under Perform Achieve Trade policy of the Indian government, could save 50 Mt/year. The newly auctioned coal-blocks and other captive mines could produce around 200 Mt by 2020. This would still require over 200 Mt demand-supply gap, which has to be met through imports.

This highlights two issues – coal is projected to remain mainstay of the Indian energy system in near to medium-terms and coal imports are most likely to continue around 150-200 Mt/year.

India emitted 2479 Mt-CO_2 in 2013-14 with coal contributing 1146 Mt. Clean coal technologies, including super critical pulverized coal power plants, coal washing, and enhancing combustion efficiency through renovation and modernization of existing plants could provide GHG mitigation. India has already established 27.5 GW of supercritical units and around 50 GW capacities are under construction. Government of India has already taken several initiatives to improve the efficiency of coal based power plants and to reduce their GHG emissions. For instance, all new, large coal-based generating stations have been mandated to use the highly efficient supercritical technology. Renovation and modernization, and life extension of existing old power stations is being undertaken in a phased manner. About 144 old thermal stations have been assigned mandatory targets for improving their energy efficiency. Coal beneficiation has been made mandatory. Introduction of ultra-supercritical technology, as and when commercially available is part of future policy. Besides, stringent emission standards being contemplated for thermal plants would significantly reduce emissions. Indian INDC has also identified Super Critical Pulverized Combustion, Ultra Super Critical, Pressurized Circulating Fluidized Bed Combustion, Combined Cycle, Integrated Gasifier Combined Cycle, and Fuel Cell as priority clean coal technologies for India. About 100 GW installations using new clean coal technologies at around a 20% improvement in current efficiency of coal plants could mitigate about 1400 Mt CO_2e vis-a-vis traditional coal technologies during 2015-2030.

The Restructured-Accelerated Power Development and Reforms Programme (R-APDRP) of the Indian government envisages state utilities having aggregated technical and commercial (AT&C) losses above 30% to reduce these by 3% per year, while those having AT&C losses below 30% to reduce these by 1.5% per year. National average T&D losses have significantly improved from about 32% in 2005 to 22% last year, and are projected to reduce to around 15% by 2022 (Lok Sabha, 2015). Projected reduction to 15% by 2022 implies a saving of around 500 Mt CO_2e during 2015-2030.

These indicate large plans for cleaner coal in India. Carbon dioxide Capture and storage (CCS) technology could also provide a way forward to continue using coal in India without associated GHG emissions to the environment. Our preliminary estimates indicate that India has a potential to mitigate around 800 Mt-CO_2 each year from coal use at below $60 per t-$CO_2$. Research however has to be done to estimate storage locations and their potential, especially near large point sources of GHG emissions, along with a large CCS demonstration pilot project in India.

Coal production, transport, usage and ash disposal deploy almost one million persons. Income from coal royalty constitutes almost 50% of total earning of states like Jharkhand and Odisha (ToI, 2015b; GoO, 2007), which are some of the least developed large Indian states. Path dependencies of coal use therefore have strong socio-economic and political linkages, apart from the huge investments in coal infrastructures that have to be managed in case coal use has to be strongly discontinued in India. On the other hand, the latest policy of targeted simultaneous strong push to renewable energy in India through 100 GW of new solar and 36 GW of new wind capacities by 2022, would need fresh investments to the tune of US$ 140 billion by 2022 (MNRE, 2015). More renewable capacities may be installed beyond 2022 until 2030. 100 GW solar could save up to 1680 Mt CO2e emissions during 2015-2030 vis-à-vis baseline coal power. Similarly wind and other renewables could save up to 1100 Mt CO2e during 2015-2030. It is also noted that the additional power capacities planned may provide up to additional 220 GW by 2022, which should be able to wipe off energy deficit in India in near future. India had an energy deficit of 5.1% and peak power deficit of 2% during 2014-15, which is projected to go down to around 2% this year.

---

[45] Average of coal from Indonesia, South Africa, USA and Australia

4. BUILDING THE BRIDGE FROM INDCS TO 2 DEGREES: IMPLICATIONS FOR THE PARIS AGREEMENT

4.1. Introduction

The UNFCCC process has recognized the goal of limiting warming to 2°C above preindustrial levels as the long-term objective of the global community. This requires deep cuts in global GHGs as documented in the IPCC reports. It is therefore an important question to what extent the INDCs put the world on track towards reaching the 2°C goal. This section gives an overview of the aggregate global effect of the INDCs on greenhouse gas emissions, but more importantly on the underlying energy system transformation and the challenges associated with reaching the 2°C goal after 2030. Furthermore, it discusses options to build on and strengthen the mitigation action implied by INDCs.

The 118 INDCs (covering 145 countries) submitted to the UNFCCC and published on its website[46] before October 2, 2015, represent ca. 85% of global GHG emissions in 2012. Most of those mainly report emission targets for 2025 or 2030, with several offering explicit information on policies and technologies to be employed for reaching these targets. We use an integrated global energy-economy-climate modeling system to derive a comprehensive picture of the global implications of these INDCs and of the post-2030 mitigation requirements to adhere to the stated objective of limiting global warming to 2°C degrees. This global modelling framework also allows consideration of countries without an explicit emissions target, and of indirect effects such as technology spillovers and leakage. Obviously, due to the aforementioned gaps in the INDC information, many assumptions on policies in the various model regions are crucial for such an analysis. A short description of the methodology is provided in Section 4.2, and the Annex to this section (at the end of this report) provides more detail on the modeling assumptions for the INDCs. Section 4.3 aims to provide a best-guess interpretation of INDCs in terms of their global emissions and energy implications, but does not explicitly explore the uncertainty range of INDC outcomes. Its main focus is the analysis of the post-2030 transition requirements towards the 2°C goal that would follow from the INDCs. As these requirements include a substantial and very rapid strengthening of the global mitigation effort in the period 2030-2050, we also explore a bridging scenario that allows a smoother transition towards the 2°C goal by overachieving the INDCs in 2030 (Section 4.4). Such a scenario could emerge from ratcheting up INDC ambition levels and underlying policies in the coming years to keep the 2°C target within reach. Such strengthening of policies would signal a credible commitment to the long-term goal causing actors in the energy and other sectors to account for this commitment in their investment decisions early on.

4.2. Methodology

The aggregate impact of the INDCs on global emissions and energy use in 2030, and the transitioning from the INDCs towards the long-term goal of limiting global warming to 2°C were investigated with the integrated assessment modeling framework REMIND-MAgPIE (Bauer et al. 2012, Luderer et al. 2013, Bertram et al. 2015, Klein et al. 2013,

---

[46] (http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx)

Popp et al. 2014)capturing the dynamics of the global energy-economy-land-climate system. Since the focus of this report is on the energy transition, the analysis was mainly conducted in REMIND, with the land use model MAgPIE providing information on land use emissions and their reduction potentials as well as bioenergy availability and associated co-emissions.

REMIND is a macro-economic growth model with eleven world regions[47] and a detailed representation of the energy sector[48]. It has been frequently used in international integrated assessment modeling studies and contributed a significant portion of mitigation scenarios assessed in the 5th Assessment Report of the IPCC (Kriegler et al. 2013, Kriegler et al. 2014, Riahi et al. 2015, Clarke et al. 2014). The general framework of the analysis is to compare a baseline scenario of the future development of the energy-economy system until 2100 with a set of climate policy scenario in which emissions reductions are implemented through carbon pricing and technology policies.

The analysis in this report was based on four climate policy scenarios in addition to the counterfactual baseline scenario without climate policy (**BASE**):

- **INDC-extended**: In this scenario, the INDCs were implemented on the level of the 11 REMIND regions, and extended beyond 2030 by an extrapolation of the regional carbon prices that emerged under the INDCs as well as technology targets for selected regions. The modelled carbon price trajectories can be interpreted as a proxy for mitigation measures undertaken in a region without taking a view on the actual instruments that are used to achieve the emissions reductions (implicit carbon pricing). The long-term climate outcome of the INDC scenario is highly sensitive to assumptions about the extrapolation of regional carbon prices beyond 2030, and therefore is not the focus of this chapter.

A more detailed description of the INDC implementation can be found in the Annex. The aggregation of INDCs to REMIND regions relied in large part on a detailed country-by-country analysis of the emissions implications of INDCs conducted by the Netherlands Environmental Assessment Agency (PBL) (PBL 2015). Therefore, the global emissions outcome of INDCs in the year 2030 as calculated in the INDC scenario reflects the global estimate of the PBL analysis.

- **INDC-2°C**: This scenario has been developed to analyze the transition from the INDCs in 2030 to the 2°C goal after 2030. To this end, the model was fixed to the INDC scenario until 2030, and then allowed to respond to the emissions constraint imposed by the 2°C goal after 2030 (by implementing a globally uniform carbon price post-2030 that increases with the marginal cost of abatement). Due to the fixing to the INDC trajectory until 2030, there is no anticipation in the model of the carbon constraint and carbon price post-2030 implied by the 2°C target.
- **Bridge-2°C**: Since the INDC-2°C scenario implies abrupt and very rapid changes to the energy system in the period 2030-2050, we also analyze a scenario where investors anticipate the significant strengthening of policies post-2030, and therefore can prepare with additional measures in the period 2020-2030 to allow for a more continuous transition. This anticipation effect leads to adjusted investments so that most INDCs are overachieved (see Section 4.4). The driver of this scenario is strengthened policies and targets by 2020 for the period 2030 and post-2030.
- **Immediate-2°C:** In this scenario, the 2°C goal is imposed immediately in 2015 (in terms of a radiative forcing target of 2.6 W/m²) and implemented in the model with a globally uniform carbon price that increases over time with the marginal cost of abatement. This scenario is used as a benchmark to assess differences between the INDC scenarios and a 'optimal' 2°C scenario in 2030 and the period 2030-50. It is a pure counterfactual as actual policies will take into account equity considerations and differentiated regional responsibilities and capabilities in addition to cost-effectiveness.

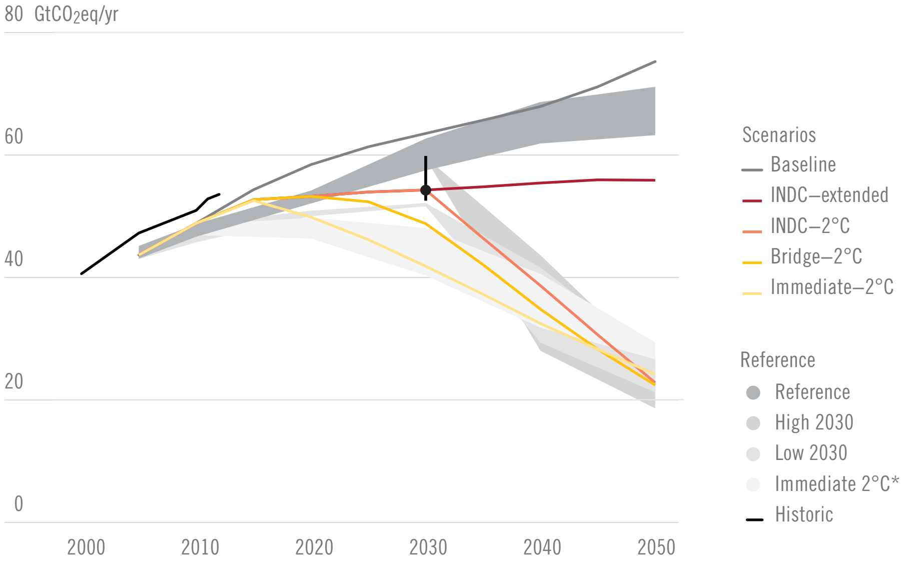
The results from these scenarios are put into the context of the mitigation scenario literature assessed by the 5th Assessment Report (AR5) of Working Group 3 of the IPCC. Besides baseline and cost-effective immediate implementation 2°C scenarios, the AR5 also assessed 2°C scenarios with delayed additional mitigation until 2030. Those scenarios were derived in the AMPERE and LIMITS projects (Kriegler et al 2015, Riahi et al. 2015, Kriegler et al. 2013), which conducted a series of international integrated assessment modeling

---

[47] The REMIND model resolves six major economies (China, EU28, India, Japan, Russia, USA), and groups remaining countries into five larger regions (Latin America; Subsahara Africa excl. South Africa; Middle East & North Africa; Other Asia; and a hybrid region of remaining countries)

[48] The REMIND models traces the production and use of energy from primary energy sources (coal, oil, gas, uranium, biomass, other renewable energy sources) to secondary energy (electricity, liquids, gases, solids, hydrogen, heat) to final energy use in the transport and stationary sectors. It includes around 70 energy conversion technologies.

Figure 43. Greenhouse gas emissions in the scenarios of this study, compared with literature



Greenhouse gas emissions in the scenarios of this study (solid lines), compared with the 2030 range and best estimate from the country-level analysis of conditional INDCs of PBL (www.pbl.nl/indc, vertical black line and dot), and the inter-quartile ranges of the FullTech-450-OPT (Immediate 2°C), FullTech-450-LST (Low 2030) and FullTech-450-HST (High 2030) scenarios of the AMPERE study, as well as the reference policy scenarios of the AMPERE and LIMITS studies. While section 4.3 discusses the INDC-2°C scenario, section 4.4 explores the possible effect of an early announcement of 2°C compatible policies (Bridge-2°C). Total greenhouse gas emissions were calculated based on global warming potentials from IPCC's second assessment report (SAR).*

Source: REMIND model calculations, EDGAR (JRC/PBL, historical emissions),
PBL INDC Tool calculations (www.pbl.nl/indc INDC range and best estimate) and IPCC AR5 scenario database

** with action starting after 2010*

studies on the implication of short-term action on the attainability of long-term climate goals. Although these scenarios were mostly based on an extrapolation of the Cancun pledges, and thus projected higher emissions in 2030 than in the INDC scenario, they are qualitatively similar to the INDC-2°C scenario analyzed here and therefore provide an important point of reference and connection of our study to the findings of the AR5 of IPCC.

4.3. Aggregate Impact of the INDCs

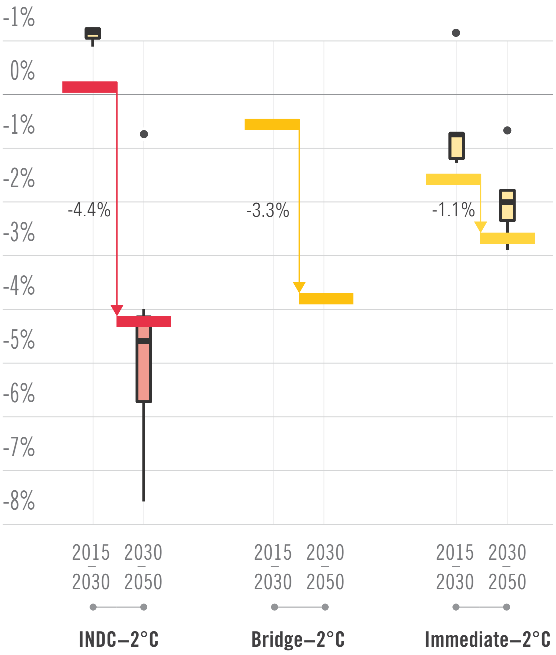
On a global level, the estimated aggregate 2030 emissions outcome in the INDC scenario (red line, Figure 43) results in a clear deviation from baseline and a strong reduction of emission growth until 2030. The 2030 emission level is also below the extrapolation of existing Cancun pledges analysed in the AMPERE and LIMITS studies (Reference funnel in Figure 43) that provided the basis for the discussion of delayed mitigation efforts (High 2030 funnel in Figure 43) in the IPCC's AR5 (Clarke et al., 2014).

A number of observations that can already be found in the relevant literature (Kriegler et al. 2013, 2015 (LIMITS, AMPERE WP3), Riahi et al. 2015 (AMPERE WP2), Luderer et al 2013) apply to the INDC scenario as well. A significant gap towards an immediate implementation of policies consistent with a 2°C target can be observed in 2030. In order to still reach 2°C after following the INDC trajectory until 2030, an abrupt downturn in emissions and very rapid emissions reductions (Riahi et al. 2015) in the two following decades would be needed (Figure 44). Furthermore, long-term emissions in the second half of the century would need to be even lower, including increased levels of carbon dioxide removal from the atmosphere to compensate residual emissions and obtain net negative emissions in the long run (van Vuuren 2011, Kriegler et al 2013, Fuss et al 2015). As shown in Figure 44, the rate of emissions reductions over the period 2030-2050 increases significantly in the **INDC-2°C** scenario to more than -4% per year, compared to a slight emissions increase in the 2015-2030 period. In the immediate action **Immediate-2°C scenario, the annual rate of reduction is less than -3%**[49]. This points to the challenge of maintaining the 2°C target as long term objective after 2030 in the **INDC scenario**. Emissions reduction rates of more

---

[49] In Figure 44 the higher reduction rate from 2030-2050 in the Immediate-2°C scenario, with respect to AMPERE's FullTech-Base scenario, is due to the later start date of stringent policies (after 2015 compared to after 2010 in the AMPERE study).

Figure 44. Annual rate of change in GHG emissions



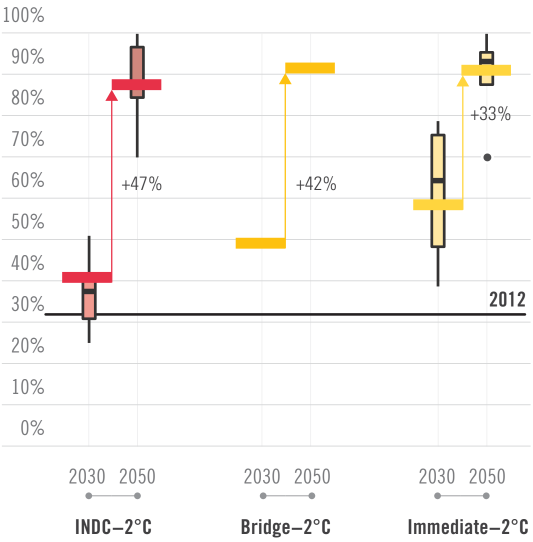
The colored bars denote the scenarios of this study, while the boxplots show results from the FullTech-450-OPT (right) and FullTech-450-HST (left) scenarios of the AMPERE study, respectively. The boxes denote the interquartile range, while the whiskers show the full range. Two outliers in the AMPERE study (scenarios with >800EJ potential for biomass) are represented by dots.

than 4% per year have little historical precedent, particularly on the global level. The greater the degree of low-carbon transformation in 2030, the smaller the required increase in ambition levels after 2030 to keep climate change below 2°C degrees warming.

In accordance with previous studies, we find a large part of early mitigation occurring in the electricity sector. The INDC scenario achieves roughly a third of the expansion in low-carbon electricity production until2030 that one would observe in an immediate action 2°C pathway. The 2030 share of low carbon electricity is higher in the new INDC scenario compared to the 'moderate policy scenarios' from the AMPERE and LIMITS projects. This shows the impact of dedicated low-carbon technology targets (see Table A.1 in the Annex) in the INDCs of the major economies (Figure 45). However, the increase in the INDC scenario lags behind the development in the cost-effective **Immediate-2°C scenario**, which has to be compensated by a much stronger ramp up of low carbon electricity in the 2030-2050 timeframe, increasing its share by nearly 50% in just 20 years.

In the transport sector on the other hand, progress in terms of carbon intensity improvements of transport energy supply by 2030 is very limited, as the transport system stays dominated by petroleum-based fuels, even in the immediate 2°C scenario (Figure 46). This result is confirmed by the analysis of INDC-based transformation pathways for six major economies in Section 2. By mid-century, however, a profound change of the transport sector is foreseen in all **2°C compatible** scenarios, with electro-mobility and biofuels providing each

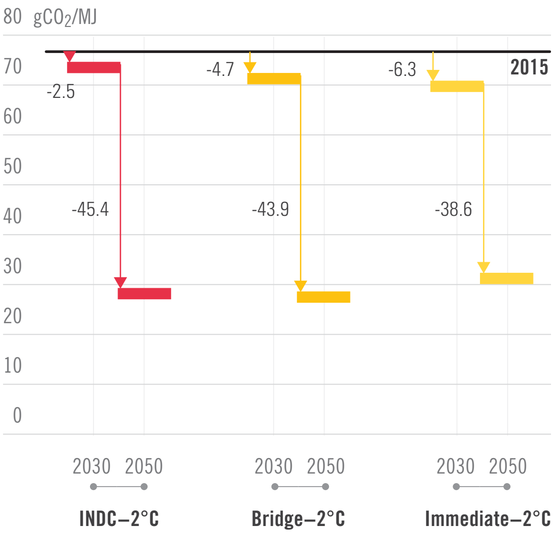
Figure 45. Low-emission electricity share



The boxplots represent the results from the FullTech-450-OPT (right) and FullTech-450-HST (left) scenarios of the AMPERE study, respectively and the horizontal line in the background marks the 2012 historic value (IEA 2014).

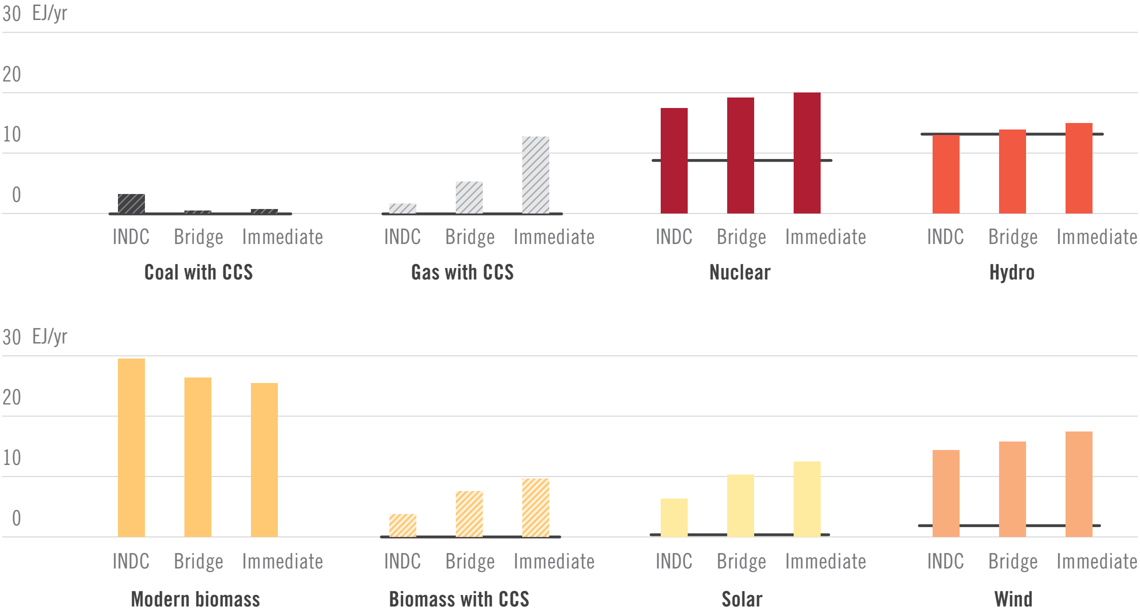
Source: REMIND model analysis, IEA, and IPCC AR5 scenario database

Figure 46. Carbon intensity of transport fuels, including indirect emissions from electricity and hydrogen generation



The horizontal line at the top marks the 2015 model value, as an equivalent accounting by the IEA is not available.

Figure 47. Primary energy deployment of different low-carbon technologies in 2030



Note: Modern biomass excludes traditional biomass use and biomass deployment with CCS, and therefore is higher in the INDC scenario than in the Immediate scenario. The horizontal line in the background marks the 2012 historic value (IEA 2014) with the exception of modern biomass, for which an equivalent accounting is not available. Direct equivalent accounting method is used for non-combustible fuels.

Source: REMIND model analysis and IEA

significant shares of total mobility[50].

When separating low-carbon energy supply by technology (Figure 47) it can be seen that especially for wind power, the INDC scenario already comes close to the deployment level in the Immediate 2°C scenario. On the other hand, particularly high deployment gaps between the "INDC" and the "2°C" scenario can be observed for the CCS technologies. Gas-CCS only receives explicit support under the Chinese Low-Carbon target of 20% of primary energy consumption. Bio-CCS is only supported by carbon price revenues for the carbon dioxide removed from the atmosphere, which is in most regions not enough to incentivize its deployment, so that there is more biomass deployment without CCS in the INDC scenario.

From Table A.1 in the Annex it can be seen that the majority of technology policies are targeted to the support of renewable energy. This is an effective means of increasing the share of low-carbon technologies in electricity generation (Figure 45), but is not effective in stopping the further build-up of very carbon-intensive infrastructure. Therefore one of the most striking differences between the INDC and the 2°C scenario in 2030 is the much higher use of coal, while gas consumption differences are much smaller and there is hardly any change in oil consumption (Figure 48).

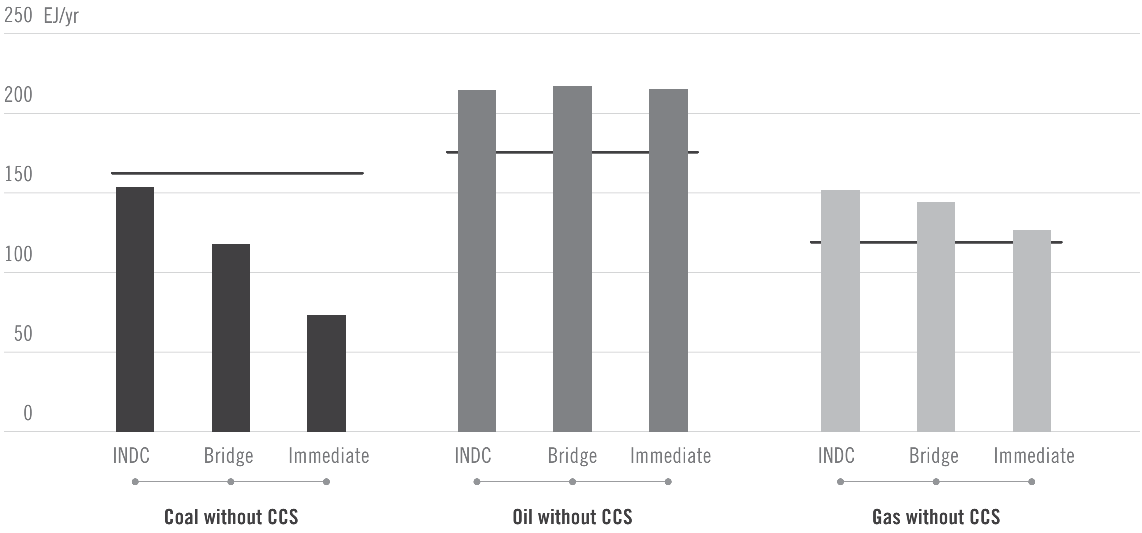
Annex 8.2. shows the development of carbon prices over time in the different world regions. Importantly, the carbon prices until 2030 are not necessarily reflecting the marginal costs of abating an additional ton of emissions, but are indicative of the marginal effort required to reach 2030 emissions cuts beyond those reductions achieved through sectoral or technology policies that were included in the model analysis for several major economies. Such policies drive down the explicit carbon price that would emerge in an emissions trading system imposed in conjunction with them (Bertram et al., 2015). In order to derive more robust conclusions on the carbon price implications of INDCs, more explicit statements in future communication by parties on the intended policies to reach INDC emission targets would be important.

Nevertheless, it appears to be a robust finding that the focus of policy INDCs is placed on renewable energy support schemes. This is not a bad thing as such, indeed it is necessary. However, it needs to be complemented by measures to limit further carbon lock-in such as emissions regulation of coal-fired power plants or a moderate

---

50. The carbon intensity of transport fuels in 2050 is slighty lower in the INDC-2°C scenario than in the immediate 2°C scenario, as the higher effective carbon prices in the long-term lead to less remaining petroleum-based vehicles. Given the shorter lifetime of vehicles compared to power generating infrastructure, this effect of higher effective carbon prices in the post-2030 period is already visibly in 2050.

Figure 48. Deployment of unabated fossil energy in 2030



Note: Total gas consumption varies less than shown here, as the deployment of gas with CCS (see Figure 47) partly compensates the lower consumption in the Bridge-2°C and especially the Immediate-2°C scenario. The horizontal line in the background marks the 2012 historic value (IEA 2014)

Source: REMIND model analysis and IEA

carbon price. Those measures are equally important as low carbon technology support measures to achieve the desired emissions reductions (Bertram et al. 2015).

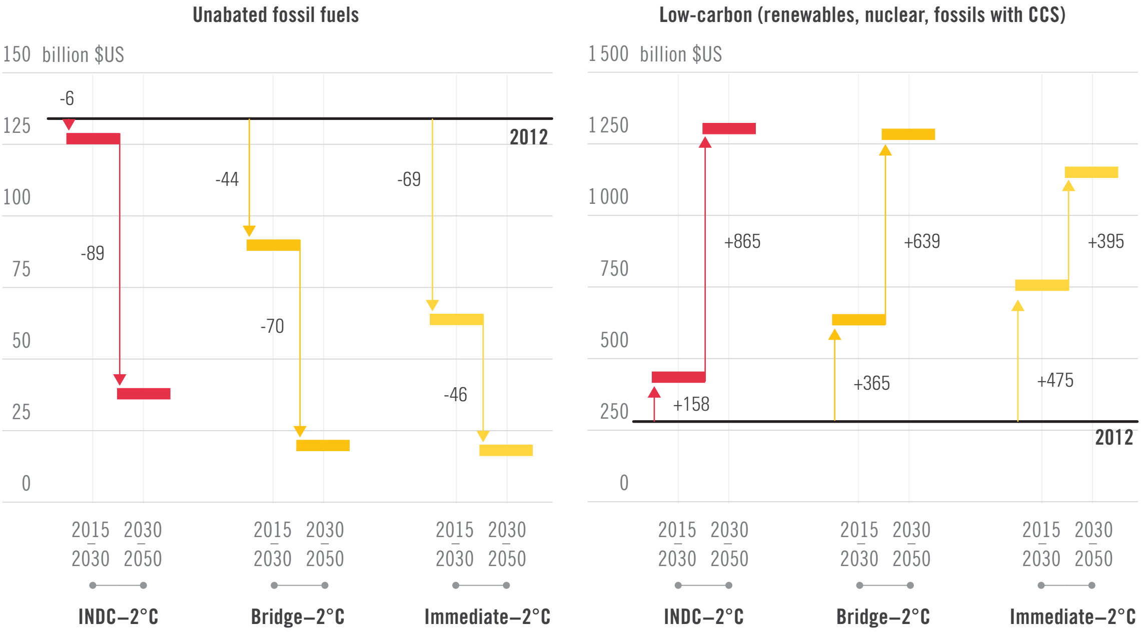
The significant increase in emissions reductions rates between 2020-30 and 2030-50 is reflected in a substantial increase of the carbon price after 2030 in the INDC-2C scenario. Due to more moderate mitigation action until 2030, post-2030 carbon prices in the INDC-2°C scenario reach higher values than in the 2°C scenario, again signifying the scope of the mitigation challenge to stay below the 2°C limit after 2030.

4.4. Impacts of an Early Strengthening and Extension of INDCs

The analysis of the INDC-2°C scenario shows that an abrupt shift of policy would be needed to still achieve the 2°C target after following the INDC trajectory until 2030. Therefore, one important element of the Paris Agreement to be negotiated later this year will be the provision of mechanisms for strengthening ambition levels over time towards the goal of limiting warming to 2°C. Incremental strengthening of INDCs for the post-2030 period alone is unlikely to cause the trend-break needed to reach 2°C. The rate of transformation of the global energy system needs to be increased already in the decade 2020-30 beyond what is implied by the INDCs. There are three complementary ways of doing so:

- Increasing the ambition of existing INDC targets for the years 2025 or 2030. This has the advantage of bringing short-term commitments further in line with the 20°C goal, thus re-affirming the commitment to the long-term goal. However, it may have the disadvantage of not providing a sufficient timeframe for implementing the short-term commitments.
- Adopting much more ambitious, transformational INDC targets for the post-2030 period. This has the advantage of providing a longer-time horizon for the necessary deep transformation. If relevant actors, e.g. in the energy sector, perceive such a policy commitment to be credible, they will in anticipation adjust their investment decisions early on (Bosetti et al 2009, Blanford et al 2009). However, if the required degree of strengthening post-2030 commitments becomes too large, actors may doubt that they will be followed through with.
- Committing to and adopting new policies for decade 2020-2030 and the period beyond. This has the advantage of targeting particular aspects of the transformation (such as the deployment of CCS, or electrification of transport), and can also make targets more credible. Given the need to adopt policies targeted to the reduction of fossil fuel use in addition to low carbon support policies, announcements of measures establishing an implicit or explicit carbon price could be particularly effective in stabilizing investor expectations and enhancing the credibility of the climate policy commitment.

Figure 49. Average annual investment into power generation capacity



Note: Monetary values are given in $US-2012. REMIND 2005 monetary values are scaled by 1.18 for conversion to 2012. Horizontal lines in the background mark the respective 2012 historic value (IEA 2014b)

These three strategies are therefore complementary. **We therefore propose that: by 2020 at the latest, countries strengthen existing INDCs for 2025 or 2030 and adopt ambitious post-2030 INDCs, along with the commitment to adopt and implement specific policies to strengthen the energy system transition in the decade 2020-2030 and beyond.**

To illustrate the significant effect such a credible commitment would have, we analyse in this section the “Bridge-2°C” scenario that provides a bridge between the INDCs as starting point and the 2°C goal. This scenario assumes the same policies of “INDC-2°C”, i.e. moderate ambition levels until 2030 and a significant increase thereafter, but allows for anticipation of the rapid increase in effective carbon pricing after 2030 that maintaining the 2°C limit would entail. As can be seen in Figure 43, the anticipation of such a rapid increase after 2030 leads to strong overachievement of the 2030 emission targets implied by the INDCs, as further investments into carbon-intensive infrastructure would not be economical in such a scenario. Instead, investments are redirected into low-carbon energy technologies early on. As shown in Figure 49 (left panel), average annual investments into low-carbon electricity generation capacities over the period 2020-2030 are 47% higher in the “Bridge-2°C” than in the “INDC-2°C” scenario. This helps to close the “investment gap” to the “Immediate-2°C” scenario significantly. While the INDCs mobilize only around 60% of the investments deployed in the “Immediate-2°C” scenario over the period 2030-30, already 85% of these investments are mobilized in the “Bridge-2°C” scenario. Also, the “Bridge-2°C” scenario allows for a much smoother increase in investment volumes after 2030 than in the “INDC-2°C” scenario. While average annual investment volume for the period 2030-50 would only increase by 50% in the “Immediate-2°C” scenario relative to 2020-30, they would double in the bridge scenario, and would even have to triple in the “INDC-2°C” scenario. Cumulative investment in low carbon power generation over the period 2020-2050 is around $30-32 trillion (undiscounted) in all three scenarios achieving shares of low carbon electricity generation between 87-91% in 2050 (see Figure 45).

The “Bridge-2°C” scenario also has significant implications for the gradual phase-out of investments into new freely-emitting fossil fuel power generation, thus helping to prevent a carbon bubble of investments that would be stranded by a sharp strengthening of climate policies. As can be seen in Figure 49 (right panel), the INDCs as currently proposed are not enough to initiate a significant reduction of investments into fossil fuel power generation until 2030 compared to present levels, while the “Bridge-2°C” scenario would reduce such investments over the period 2020-30 by one third (compared to cutting 2020-30 high carbon investments in half in the “Immediate-2°C” scenario). Both the “Bridge-2°C” and “INDC-2°C” scenarios cut investments into fossil fuel power generation over the period 2030-50 by a further 70-80% compared to the period 2020-30. This enables the "Bridge-2ºC" to reach substantially lower levels of residual investments into freely emitting fossil-fuel power plants over the period 2030-50 than in the "INDC-20C" scenario (15% vs 28% of investment levels in 2012), again constraining the risk of a carbon bubble and stranded assets.

As a result of this early restructuring of energy investments, the energy transformation and emissions trajectory is much smoother and thus in no point of time exhibits the abrupt changes apparent in the "INDC-2°C" scenario in 2030 or in the "Immediate-2°C" scenario in 2015. As can be seen from Figure 43, the "Bridge-2ºC" scenario leads to an additional reduction of about 5 GtCO2eq/yr from projected INDC levels in 2030, constituting a substantial overachievement of currently proposed INDCs. From the respective columns in Figures 44-46, we see that the challenges of reaching the 2°C target are considerably reduced compared to the "INDC-2°C" scenario, as the additional early action in terms of restricting coal use (Figure 48) and expanding low carbon options (Figure 45 and Figure 47) reduces the pressure on the necessary decarbonisation rates post-2030 (Figure 44). In that context it is noteworthy to mention that this advantage might even be bigger than what the model results imply, as the model cannot capture all the path-dependencies (e.g. on the demand side, in the development of technologies etc.) that might make an abrupt trend-break as in the INDC-2°C scenario difficult to realize.

The "Bridge-2ºC" scenario highlights the key advantages of a credible commitment to strengthen ambition levels. It helps to avoid the abrupt changes implied in the "INDC-2ºC" scenario by means of stabilizing expectations of relevant actors early on. The obvious challenge for this effect to happen is to establish sufficient credibility, as uncertainty over the implementation of the policies and their strengthening in the future would weaken the effect of anticipation. Such credibility will likely have to build on mechanisms to raise ambition levels of **both existing (2025 or 2030) and future (post-2030) commitments, accompanied with specific policy commitments to address crucial aspects of the transition (carbon pricing, technology innovation + deployment etc**). If the Paris Agreement includes transparent mechanisms to strengthen this policy ambition, the "Bridge-2°C" scenario shows that it could provide the needed signal for the timely adjustment of investment decisions, avoiding carbon lock-in and stranded assets and enabling early deployment of key mitigation options.

5 CONCLUSION AND OUTLOOK

This report has investigated the impact of INDCs on the energy sector in five countries and one region, as well as at the global level in aggregate. Other reports from the UNFCCC and UNEP will provide cutting-edge analysis of the impact of INDCs on aggregate emissions by 2030, and of the implications thereof in the light of the 2°C trajectory. This analysis complements those studies. In addition to aggregate emissions trajectories, the INDCs should be judged in terms of their capacity to catalyse a transformation of energy systems that would allow their deep decarbonisation by 2050. By 2030, multiple pathways can lead to a given emissions level, but not all of them are compatible with this deep decarbonisation, if for example the necessary long-term technologies are not adequately prepared or if infrastructure decisions lock-in high carbon economic and social structures (such as sprawling, inefficient cities). It is therefore crucial to understand the concrete technological, infrastructural and policy changes that INDCs would imply. Doing so can also help to formulate post-Paris policy recommendations.

This report concludes with three main findings:

In the analysis of this report, INDCs accelerate and consolidate action on climate change in key major economies and at the global level. A significant transition appears in the electricity sector, with the dynamic of technology deployment approaching what is required for 2°C. In aggregate from 2010 to 2030 the carbon intensity of electricity production declines by 40% in the five countries and one region assessed. At the global level, the deployment of low-carbon electricity production under the global INDC scenario is 42% in 2030, an increase of roughly 10 percentage points from 2012 levels, but still below what is seen in 2030 in 2°C scenarios. Similar positive trends are seen regarding energy efficiency in the end-use sectors: transport, buildings and industry. Transport in particular would see significant improvements in energy intensity, falling in aggregate by 30% between 2010 and 2030 in the in the five countries and one region assessed individually. In Japan and the European Union, the energy intensity of GDP drops a further 33% and 34% between 2010 and 2030, while it drops 48% in China over the same time period. In the USA, energy intensity of GDP drops 26% between 2010 and 2025. The whole process towards the Paris negotiations has established a positive dynamic on which future policy and business strategies can build.

There appears to be uneven progress on addressing the drivers of GHG emissions, when we consider what actions are projected to underpin the implementation of INDCs. Some crucial low-carbon solutions, like CCS, electric vehicles, advanced biofuels, sustainable urban planning, appear unlikely to be developed under the INDCs at the scale and speed required for a 2°C scenario, given the implied lock-in of carbon-intensive infrastructure in 2030 under the INDC scenario. By 2030, unabated coal deployment is more than 50% higher in the global INDC scenario developed for this paper than in the immediate 2°C scenario. However, the national and global INDC scenarios demonstrate little deployment of CCS, with a share of CCS in electricity generation of about 3% in 2030 for the USA, China, Japan and the EU. Yet, given the scale of fossil fuel infrastructure in 2030 under the INDC scenario, it seems that CCS will need to be a crucial technology for mitigation post-2030. The risks of lock-in into high carbon infrastructures and technologies thus appear significant, if the INDC trajectory is followed to 2030. Future international cooperation and national policy should also focus on accelerating specific crucial solutions, such as innovation and deployment of post-2030 mitigation options and limiting carbon lock-in.

The INDCs are an entry point to put the world on a trajectory towards 2°C, but as currently submitted may not be enough to keep the 2°C goal in reach. The global INDC scenario in this report showing emissions of 56 GtCO2eq in 2030 is above the emissions range of cost-effective scenarios consistent with the 2°C goal as estimated by the IPCC's Fifth Assessment Report (30-50 Gt CO2e in 2030). With this level of emissions in 2030, emissions reductions would need to be extremely rapid after 2030, in the order of 4-5% per year, if the 2°C objective is to be met. This rate of reduction would imply significant risks to feasibility and high costs. For this reason, this report develops a bridge scenario representing a situation in which by 2020 targets and policies for 2030 are strengthened, and ideally new ambitious targets proposed for the period after 2030. The report shows that this can lower global emissions in 2030 substantially to around 50 GtCO2eq/yr, close to the upper bound of the range of cost-effective 2°C scenarios in AR5, amounting to an overachievement of current INDCs by about 6 GtCO2eq/yr in 2030. The Paris agreement should establish a clear mechanism to allow the regular, predictable and timely revision of national contributions and the global framework.

REFERENCES

Akimoto, K. (2012). "Potential for Energy Efficiency Improvement and Barriers". In: *Climate Change Mitigation, A Balanced Approach to Climate Change*, Yamaguchi, M. (ed.) 161-177 Springer, London.

ANA (2013). *Conjuntura dos recursos hídricos no Brasil*, Agencia Nacional de Aguas.

ANUALPEC (2013). *ANUALPEC 2013*. (J. V. Ferraz, Ed.). São Paulo, Brasil: Informa Economics FNP.

Assad, E.D., Pavão, E. de M., Assad, M.L.R.C.L., & Martins, S.C. (2013). *Agricultura de Baixa Emissão de Carbono: A evolução de um novo paradigma*. São Paulo, Brazil: Observtório ABC. Retrieved from http://www.observatorioabc.com.br/ckeditor_assets/attachments/38/2013_06_28_relatorio_estudo_1_observatorio_abc.pdf

Assad, E., Pavão, E., Jesus, M. de, & Martins, S. C. (2015). *Invertendo o sinal de carbono da agropecuária brasileira. Uma estimativa do potencial de mitigação de tecnologias do Plano ABC de 2012 a 2023*. São Paulo, Brazil: Observtório ABC. Retrieved from http://www.observatorioabc.com.br/relatorio-5-invertendo-o-sinal-de-carbono-da-agropecuaria-brasileira?locale=pt-br

Bauer, N., Brecha, R. J., Luderer, G. (2012). "Economics of nuclear power and climate change mitigation policies", *P. Natl. Acad. Sci. USA* 109, 16805–16810.

BCB (2015). Sistema de Expectativas de Mercado. Retrieved September 22, 2015, from https://www3.bcb.gov.br/expectativas/publico/consulta/serieestatisticas

Bertram, C. *et al.* (2015). "Complementing carbon prices with technology policies to keep climate targets within reach", *Nature Clim. Change* 5, 235–239. doi:10.1038/nclimate2514.

Blanford, G.J., Richels, R.G., Rutherford, T.F. (2009). "Feasible climate targets: The roles of economic growth, coalition development and expectations", *Energy Economics*, International, U.S. and E.U. Climate Change Control Scenarios: Results from EMF 22, 31, Supplement 2 (Dezember 2009): S82–93. doi:10.1016/j.eneco.2009.06.003.

Bosetti, V., Carraro, C., Tavoni, M. (2009). "Climate change mitigation strategies in fast-growing countries: The benefits of early action", *Energy Economics*, International, U.S. and E.U. Climate Change Control Scenarios: Results from EMF 22, 31, Supplement 2 (Dezember 2009): S144–51. doi:10.1016/j.eneco.2009.06.011.

Brasil (2010). Segunda Comunicação Nacional do Brasil à Convenção-Quadro das Nações Unidas sobre Mudança do Clima. Brasilia: Presidencia da República: Presidencia da República. Retrieved from http://www.mct.gov.br/index.php/content/view/326988/Texto_Completo_Publicado.html

Brasil (2015a). Intended Nationally Determined Contribution towards achieving the objective of the UNFCCC. Brasilia: Presidencia da República.

Brasil (2015b). *Terceira Comunicação Nacional do Brasil à Convenção-Quadro das Nações Unidas sobre Mudança do Clima*. Brasília, Brasil: Ministério da Ciência, Tecnologia e Inovação (MCTI).

Campana, S., Oliveira Filho, D., Soares, a a, & Hermsdorff, W. (2000). Inversores de freqüência – uma alternativa para racionalização do uso da energia elétrica em sistemas de irrigação pivô central. In *3° Encontro de energia no meio rural* (pp. 1–11). Campinas, Brazil. Retrieved from http://www.proceedings.scielo.br/scielo.php?script=sci_arttext&pid =MSC0000000022000000200029&lng=en&nrm=abn

Capros, P. *et al.* (2014). European decarbonisation pathways under alternative technological and policy choices: a multi-model analysis, *Energy Strategy Rev.* 2 (3-4) (February 2014) 231 e245.

CEA (2014). "Highlights of Performance Review of Thermal Power Stations 2013-14", Central Electricity Authority, New Delhi, http://www.cea.nic.in/new_website/reports/annual/thermalreview/thermal_review-2013.pdf

CEA (2015). "Highlights of Performance Review of Thermal Power Stations 2014-15", Central Electricity Authority, New Delhi, http://www.cea.nic.in/publication.html

Cenergia (2015). *Unpublished report submitted to the World*

Resources Institute (WRI). Rio de Janeiro: PPE/COPPE/UFRJ.

Chaudhary, A., Krishna, C. and Sagar, A. (2014). “Policy making for renewable energy in India: Lessons from wind and solar power sectors”, *Climate Policy,* 15(1):58-87.

Clarke, L. *et al.* (2014). in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, O. Edenhofer *et al.*, Eds. (Cambridge University Press, Cambridge, UK, and New York, NY, USA, 2014; http://www.mitigation2014.org).

CIL (2015). “Coal Production”, Coal India Limited, Government of India, https://www.coalindia.in/en-us/performance/physical.aspx

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS: A policy framework for climate and energy in the period from 2020 to 2030.

Cramton, P., Ockenfels, A., Stoft, S. (2015). “An International Carbon-Price Commitment Promotes Cooperation”, *Economics of Energy & Environmental Policy* 4, Nr. 2 (1. April 2015). doi:10.5547/2160-5890.4.2.aock.

De Barros, M.M., & Szklo, A. (2015). Petroleum refining flexibility and cost to address the risk of ethanol supply disruptions: The case of Brazil. *Renewable Energy*, *77*, 20–31, http://doi.org/10.1016/j.renene.2014.11.081

De Lucena, A.F.P. *et al.* (2009). The vulnerability of renewable energy to climate change in Brazil. *Energy Policy*, *37*(3), 879–889, http://doi.org/10.1016/j.enpol.2008.10.029

De Lucena, A.F.P., Schaeffer, R., & Szklo, A.S. (2010). Least-cost adaptation options for global climate change impacts on the Brazilian electric power system. *Global Environmental Change*, *20*(2), 342–350, http://doi.org/10.1016/j.gloenvcha.2010.01.004

De Souza, R. A., Miziara, F., & Marco Jr, P. M. (2013). Land Use Policy Spatial variation of deforestation rates in the Brazilian Amazon : A complex theater for agrarian technology , agrarian structure and governance by surveillance. *Land Use POlicy*, *30*, 915–924.

Dias-Filho, M. B. (2011). *Degradação de Pastagens: Degradação de pastagens. processos, causas e estratégias de recuperação*. Belém, PA : Embrapa Amazônia Oriental. Retrieved from http://www.diasfilho.com.br/Livro/Degrad_Past_4a_ed_Moacyr_Dias-Filho.pdf

Dias-Filho, M.B. (2014). *Diagnóstico das Pastagens no Brasil*. Belém, PA : Embrapa Amazônia Oriental. Retrieved from http://conevajr.ufsc.br/files/2015/03/DOC-402.pdf

EPE (2013). *Balanço Energético Nacional 2013*. Rio de Janeiro, Brasil: Empresa de Planejamento Energético (EPE).

EPE (2014a). *Consumo de Energia no Brasil Análises Setoriais*. Rio de Janeiro, Brasil: Empresa de Planejamento Energético (EPE). Retrieved from http://www.epe.gov.br/mercado/Documents/Série Estudos de Energia/DEA 10-14 Consumo de Energia no Brasil.pdf

EPE (2014b). *Cenário Econômico 2050* (No. Nota Técnica DEA 12/14). Rio de Janeiro, Brasil: Empresa de Planejamento Energético (EPE). Retrieved from http://www.epe.gov.br/Estudos/Documents/PNE2050_Premissas econômicas de longo prazo v2 (31032015).pdf

(2011a).

(2011b).

Fuss, S. *et al.* (2014). “Betting on Negative Emissions”, *Nature Climate Change* 4, Nr. 10 (Oktober 2014): 850–53. doi:10.1038/nclimate2392.

Galford, G.L., Soares-filho, B., & Cerri, C.E.P. (2013). Prospects for land-use sustainability on the agricultural frontier of the Brazilian Amazon. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, http://doi.org/http://dx.doi.org/10.1098/rstb.2012.0171

GoO (2007). “Economics of Mining in Orissa”, Orissa Overview 2007, http://odisha.gov.in/e-magazine/Orissareview/nov-2007/engpdf/Pages69-76.pdf

Guimaraes Junior, S.C., Lima, A.C. de, Camacho, J.R., & Salerno, C.H. (2006). Desenvolvimento de uma metodologia para a avaliação da eficiência energética de pivôs centrais de irrigação. In *VI Encontro de Energia no Meio Rural*. Campinas, Brazil. Retrieved from http://www.proceedings.scielo.br/pdf/agrener/n6v1/048.pdf

Herreras-Martínez, S. *et al.* (2015). “Possible energy futures for Brazil and Latin America in conservative and stringent mitigation pathways up to 2050”, *Technological Forecasting and Social Change*. http://doi.org/10.1016/j.techfore.2015.05.006

IBGE (2007). Censo Agropecuário 2006. Retrieved January 1, 2015, from http://www.sidra.ibge.gov.br/bda/pesquisas/ca/default.asp?o=2&i=P

IBGE (2015a). Produção Agrícola Municipal 2013. Retrieved August 12, 2015, from http://www.sidra.ibge.gov.br/bda/pesquisas/pam/default.asp?o=28&i=P

IBGE (2015b). Contas Nacionais Trimestrais. Retrieved October 2, 2015, from http://www.ibge.gov.br/home/estatistica/indicadores/pib/defaultcnt.shtm

IEA (2013). *World Energy Outlook 2013*. Paris, France: International Energy Agency (IEA): OECD Publishing, http://doi.org/10.1787/weo-2013-en

IEA (2014). *World Energy Outlook 2014*, Paris, France: International Energy Agency (IEA): OECD Publishing, http://www.worldenergyoutlook.org/publications/weo-2014/

IEA/OECD (2014). *World Energy Investment Outlook 2014*.

INPE (2014). Projeto PRODES. Retrieved April 8, 2015, from http://www.obt.inpe.br/prodes/index.php

Jenkins, J.D. (2014). “Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design?”, *Energy Policy* 69 (Juni 2014): 467–77. doi:10.1016/j.enpol.2014.02.003.

Klein, D. *et al.* (2013). “The value of bioenergy in low stabilization scenarios: an assessment using REMIND-MAgPIE”, *Climatic Change* 123, 705–718.

Kriegler, E. *et al.* (2013a). “Is Atmospheric Carbon Dioxide Removal a Game Changer for Climate Change Mitigation?”, *Climatic Change* 118, Nr. 1 (1 May 2013): 45–57.

doi:10.1007/s10584-012-0681-4.

Kriegler, E. *et al.* (2013b). "What does the 2°C target imply for a global climate agreement in 2020? The LIMITS study on Durban Platform scenarios", *Climate Change Economics* 04, Nr. 4 (2013): 1–30. doi:10.1142/S2010007813400083.

Kriegler, E. *et al.* (2014). "The role of technology for achieving climate policy objectives: overview of the EMF 27 study on global technology and climate policy strategies", *Climatic Change* 123, 353–367.

Kriegler, E. *et al.* (2015). "Making or breaking climate targets: The AMPERE study on staged accession scenarios for climate policy", *Technological Forecasting and Social Change* 90, Part A (2015): 24–44. doi:10.1016/j.techfore.2013.09.021.

Lapola, D.M. *et al.* (2013). Pervasive transition of the Brazilian land-use system. *Nature Climate Change*, *4*(1), 27–35. http://doi.org/10.1038/nclimate2056

Lewis, J.I. (2007). "Technology Acquisition and Innovation in the Developing World: Wind Turbine Development in China and India", *St Comp Int Dev,* DOI: 10.1007/s12116-007-9012-6.

Lima, A. C. De, Jr, S. C. G., Fietz, C. R., & Camacho, J. R. (2009). Avaliação e análise da eficiência energética na irrigação em sistemas pivô central. *Revista Brasileira de Engenharia Agrícola E Ambiental*, *13*(4), 499–505. Retrieved from http://www.agriambi.com.br

Lucena, A.F.P. *et al.* (2015). Climate Policy Scenarios in Brazil: A Multi-Model Comparison for Energy. *Energy Economics*. http://doi.org/10.1016/j.eneco.2015.02.005

Lotze-Campen, H., Müller, C., Bondeau, A., Rost, S., Popp, A. and Lucht, W. (2008). "Global food demand, productivity growth, and the scarcity of land and water resources: a spatially explicit mathematical programming approach", *Agricultural Economics* 39, 325–38.

Lucena, A.F.P. *et al.* (2015). Climate Policy Scenarios in Brazil: A Multi-Model Comparison for Energy. *Energy Economics*. http://doi.org/10.1016/j.eneco.2015.02.005

Luderer, G. *et al.* (2013). "Economic Mitigation Challenges: How Further Delay Closes the Door for Achieving Climate Targets", *Environmental Research Letters* 8, Nr. 3 (1 September 2013): 034033. doi:10.1088/1748-9326/8/3/034033.

Macedo, M.N., DeFries, R.S., Morton, D.C., Stickler, C.M., Galford, G.L., & Shimabukuro, Y.E. (2012). Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(4), 1341–6. http://doi.org/10.1073/pnas.1111374109

Macedo, M.C.M., Zimmer, A.H., Kichel, A.N., Almeida, R.G. de, & Araújo, A.R. de. (2014). Degradação de pastagens, alternativas de recuperação e renovação, e formas de mitigação. In *ENCONTRO DE ADUBAÇÃO DE PASTAGENS DA SCOT CONSULTORIA*. Brasília, Brasil: Empresa Brasileira de Pesquisa Agropecuária - Embrapa: Scot Consultoria. Retrieved from http://ainfo.cnptia.embrapa.br/digital/bitstream/item/95462/1/Degradacao-pastagens-alternativas-recuperacao-M-Macedo-Scot.pdfMAPA (2011). *Plano Setorial de Mitigação e Adaptação às Mudanças Climáticas para Consolidação da Economia de Baixa Emissão de Carbono na Agricultura – PLANO ABC* (Vol. 4). Brasilia: Ministério da Agricultura, Pecuária e Abastecimento (MAPA). Retrieved from http://www.agricultura.gov.br/desenvolvimento-sustentavel/plano-abc

MAPA (2011). *Plano Setorial de Mitigação e Adaptação às Mudanças Climáticas para Consolidação da Economia de Baixa Emissão de Carbono na Agricultura – PLANO ABC* (Vol. 4). Brasilia: Ministério da Agricultura, Pecuária e Abastecimento (MAPA). Retrieved from http://www.agricultura.gov.br/desenvolvimento-sustentavel/plano-abc

Mathur, R. *et al.* (2014). "What Would India Need for Moving to a 100% Renewable Energy Scenario by 2050?", TERI Discussion Paper. New Delhi: TERI.

MCTI (2013). *Estimativas anuais de emissões de gases de efeito estufa no Brasil*. Brasilia: Ministério da Ciencia, Tecnologia e Inovacao (MCTI). Retrieved from http://www.mct.gov.br/upd_blob/0226/226591.pdf

MCTI (2014). *Estimativas Anuais de Emissões de Gases de Efeito Estufa no Brasil. Segunda edição*. Brasilia: Ministério da Ciencia, Tecnologia e Inovacao (MCTI). Retrieved from http://www.mct.gov.br/upd_blob/0235/235580.pdf

Metcalf, G. E. (2009). "Cost containment in climate change policy: alternative approaches to mitigating price volatility", *University of Virginia Tax Law Review*, http://works.bepress.com/gilbert_metcalf/84/.

MIN (2011). Organização, descrição, análise e interpretação de dados sobre a agricultura irrigada no Brasil.

MNRE (2015). "RE-INVEST, 2016", Ministry of New and Renewable Energy, Government of India, New Delhi, http://mnre.gov.in/file-manager/UserFiles/Announcement-RE-INVEST-2016.pdf

MoC (2015a). "Coal Grades", Ministry of Coal, Government of India, New Delhi, http://coal.nic.in/content/coal-grades

MoC (2015b). "Coal Demand", Coal and Lignite Production, Annual Report 2014-15, Ministry of Coal, Government of India, New Delhi, http://www.coal.nic.in/sites/upload_files/coal/files/coalupload/chap6AnnualReport1415en.pdf

MoSPI (2015). "Energy Statistics 2015", Ministry of Statistics and Program Implementation, Government of India, New Delhi, http://mospi.nic.in/mospi_new/upload/energy_stats_2015_26mar15.pdf

Nepstad, D. *et al.* (2009). "The End of Deforestation in the Brazilian Amazon", *Science*, *326*, 1350–1351.

Nogueira, L.P.P. *et al.* (2014). Will thermal power plants with CCS play a role in Brazil's future electric power generation? *International Journal of Greenhouse Gas Control*, *24*, 115–123. http://doi.org/10.1016/j.ijggc.2014.03.002

OC (2015). Lei de floresta zeraria desmate na Amazônia. Retrieved October 2, 2015, from http://www.observatoriodoclima.eco.br/lei-de-floresta-zeraria-desmate-na-amazonia/

Oda, J., Akimoto, K., Tomoda, T., Nagashima, M., Wada, K. and Sano, F. (2012). "International comparison of energy efficiency in power, steel and cement industries", *Energy*

Policy 44: 118-129.

Oda, J., Akimoto, K., Sano, F., Wada, K. and Tomoda, T. (2013). "International Comparison of Energy Efficiency and CO_2 Reduction Potential in Steel Sector", 29th Conference on Energy, Economy, and Environment, Tokyo (Japan).

PBL Netherlands Environmental Assessment Agency (2015). PBL Climate Pledge INDC tool, http://infographics.pbl.nl/indc/

Planning Commission (2013). "Vision 2020: Sustainability of India's Material Resources" by R.K. Pachauri and P. Mehrotra, The Energy Research Institute, New Delhi. http://planningcommission.nic.in/reports/genrep/bkpap2020/13_bg2020.pdf

Popp, A., Humpenöder, F., Weindl, I., Bodirsky, B. L., Bonsch, M., Lotze-Campen, H., Müller, C., Biewald, A., Rolinski, S., Stevanovic, M. and Dietrich, J. P. (2014). "Land-use protection for climate change mitigation", *Nature Climate Change* 4, 1095–8.

Portugal-Pereira, J., Koberle, A., Lucena, A., Szklo, A., & Schaeffer, R. (2015). Overlooked impacts of power generation: The life cycle side of the story. In *2nd International Conference on Energy and Environment: Bringing together Engineering and Economics* (pp. 467–475). Guimarães, Portugal: University of Minho, School of Engineering.

Reis, Cl. G., Freitas, A.R., Soares, A.R., Vicente, M.R., & Mantovani, E.C. (n.d.). CONSUMO DE ÁGUA E ENERGIA ELÉTRICA EM SISTEMAS DE IRRIGAÇÃO POR PIVÔ CENTRAL EQUIPADOS COM EMISSORES TIPO LEPA UTILIZADOS NA CAFEICULTURA. In *VII Simpósio Brasileiro de pesquisa em cafeicultura irrigada* (pp. 1–4).

Riahi, K. *et al.* (2015). "Locked into Copenhagen pledges—Implications of short-term emission targets for the cost and feasibility of long-term climate goals", *Technological Forecasting and Social Change* 90, Part A: 8–23. doi:10.1016/j.techfore.2013.09.016.

Riquetti, N., Benez, S., & Silva, P.R.A. (2012). Demanda enérgetica em diferentes manejos de solo e híbridos de milho. *Energia Na Agricultura*, *27*(2), 76–85.

Rochedo, P., Szklo, A., Lucena, A., & Schaeffer, R. (2015). How a very detailed representation of energy efficiency options in the objective-function of MESSAGE-Brazil (MSB8000) can affect the penetration of renewables (VRE) into the Brazilian power grid. In *Integrated Assessment Modelling Conference*. Potsdam, Germany.

Rondón, P.P., León, P., & Alfonso, A. (2005). Costo energético de tres sistemas de labranza en el cultivo de maíz Energy cost of three tillage systems in the corn cultivation. *Revista Ciencias Técnicas Agropecuarias*, *14*(2), 23–27.

Sá, J.M. e *et al.* (2013). Balanço energético da produção de grãos, carne e biocombustíveis em sistemas especializados e mistos. *Pesquisa Agropecuaria Brasileira*, *48*(1), 1323–1331. http://doi.org/10.1590/S0100-204X2013001000003

Smith, P. *et al.* (2007). Agriculture. In B. Metz, O. R. Davidson, P. R. Bosc, R. Dave, & L. Meyer (Eds.), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, USA: Cambridge University Press. Retrieved from https://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch8.html

Soares-Filho, B. *et al.* (2010). Role of Brazilian Amazon protected areas in climate change mitigation. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(24), 10821–6. http://doi.org/10.1073/pnas.0913048107

Sparovek, G., Berndes, G., Klug, I., & Barreto, A.G.O.P. (2010). Brazilian Agriculture and Environmental Legislation : Status and Future Challenges. *Environmental Science and Technology*, *44*, 6046–6053. http://doi.org/10.1021/es1007824

Spencer, T. *et al.* (2015). "Reframing Climate and Competitiveness: Is there a Need for Cooperation on National Climate Change Policies?", Background paper for the 31st Round Table on Sustainable Development, 2-3 February 2015 OECD Headquarters, Paris.

Stechow, von, C., McCollum, D., & Riahi, K. (2015). "Integrating Global Climate Change Mitigation Goals with Other Sustainability Objectives: A Synthesis", *Annual Review of Environment and Resources,* http://doi.org/10.1146/annurev-environ-021113-095626

Strassburg, B.B.N. *et al.* (2014). When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. *Global Environmental Change*, *28*, 84–97. http://doi.org/10.1016/j.gloenvcha.2014.06.001

TERI (2014). *Analysing Rural Energy Transitions and Inequities,* New Delhi: The Energy and Resources Institute. 196 pp.

TERI (2015). *Energy Security Outlook: Defining a Secure and Sustainable Energy Future for India,* New Delhi:TERI.

TOI (2015a). "LED bulbs to save up to Rs. 40,000cr, says Piyush Goyal", *The Times of India*, September 13, 2015, http://timesofindia.indiatimes.com/home/environment/developmental-issues/LED-bulbs-to-save-up-to-Rs-40000cr-says-Piyush-Goyal/articleshow/48941146.cms

TOI (2015b). "Jharkhand to earn Rs 14k cr in coal royalties", *The Times of India*, http://timesofindia.indiatimes.com/india/Jharkhand-to-earn-Rs-14k-cr-in-coal-royalties/articleshow/46354084.cms

van Vuuren, ,Riahi, K. (2011). "The relationship between short-term emissions and long-term concentration targets", *Clim. Change* 104, 793–801.

Weitzman, M.L. (2014). "Can Harmonized National Carbon Taxes Internalize the Global Warming Externality?", National Bureau of Economic Research, http://www.nber.org/papers/w19644.

World Bank (2014). "More Power to India: The Challenge of Electricity Distribution", by Sheoli Pargal and Sudeshna Ghosh Banerjee. International Bank for Reconstruction and Development/The World Bank, Washington DC, https://openknowledge.worldbank.org/bitstream/handle/10986/18726/889060PUB0978100Box385252B00PUBLIC0.pdf?sequence=1

Zimmer, A.H., Macedo, M.C.M., Kichel, A.N., & Almeida, R.G. (2012). *Degradação, recuperação e renovação de pastagens*. Belém, PA : Embrapa Amazônia Oriental. Retrieved from http://www.infoteca.cnptia.embrapa.br/bitstream/doc/951322/1/DOC189.pdf

Zocoler, J., Lima, A.S., Hernandez, F.B.T., Maggi, M.F., & Yano, E.H. (2012). EFICIÊNCIA DE APLICAÇÃO DA IRRIGAÇÃO EM PIVÔ CENTRAL UTILIZANDO INVERSOR DE FREQUÊNCIA NO SISTEMA DE BOMBEAMENTO. In *XXII CONIRD*. Cascavel (PR), Brazil. Retrieved from http://www.agr.feis.unesp.br/pdf/Conird_2012/ artigos_novos/eficiencia_pivo_zocoler_CONIRD2012.pdf

BIBLIOGRAPHIE

CAIT. CAIT Climate Data Explorer. 2015. http://cait.wri.org/ (accès le September 14, 2015).

Council, European. «Presidency Conclusions, 29/30 October.» 2009. (accès le September 14, 2015).

EC. Intended Nationally Determined Contribution of the EU and its Member States. 2015. (accès le 14 09, 2015).

ANNEX

REMIND-MAgPIE assumptions for modelling the energy and emissions impact of the INDCs

This study wants to contribute an understanding of the global energy system transformation implications of the INDCs, as well as of challenges for reaching 2°C in both a scenario following the INDC trajectory until 2030 and a scenario that foresees strengthening trough anticipation of post-2030 policies in 2020. The implementation of the scenarios in the model REMIND (Bauer et al. 2012, Luderer et al. 2013, Bertram et al. 2015) therefore tries to both capture the emission and energy system impacts adequately, employing a best-guess strategy in light of the considerable uncertainties related to actual policy implementation. Furthermore, due to the limited sectoral and regional model resolution, a stylized representation of policies is used.

At the core of most INDCs is a statement about emission targets, either specified in absolute terms or relative to a base year or a reference scenario trajectory without INDC policies. We represent this emissions component of the INDCs by prescribing emission targets for the year 2030 (2025 in the case of the USA) and implementing a region-specific exponentially increasing carbon price from 2020-2030 to make the model reach these bounds. As a minimum, we impose a 1$/t CO2 carbon price even if the quantity target is non-binding, to represent the effect of the diverse policies mentioned in different INDCs. The carbon prices reflect the marginal effort required to reach 2030 emissions cuts beyond those cuts achieved through technology policies that are included in the model analysis for several major economies (see below). Table A below details the calculation of emission targets for the REMIND model regions based on the information contained in the INDCs. As the exact determination of the 2030 emission level to be expected from the INDC is not the core goal of this exercise, we build on the work of PBL (PBL 2015) that has performed detailed country-level analysis of the emissions implications of INDCs for a large number of countries. We adjust our assumptions for countries for which we lack exact 2030 emission quantity information to arrive at a global 2030 emission level comparable to the best estimate of PBL.

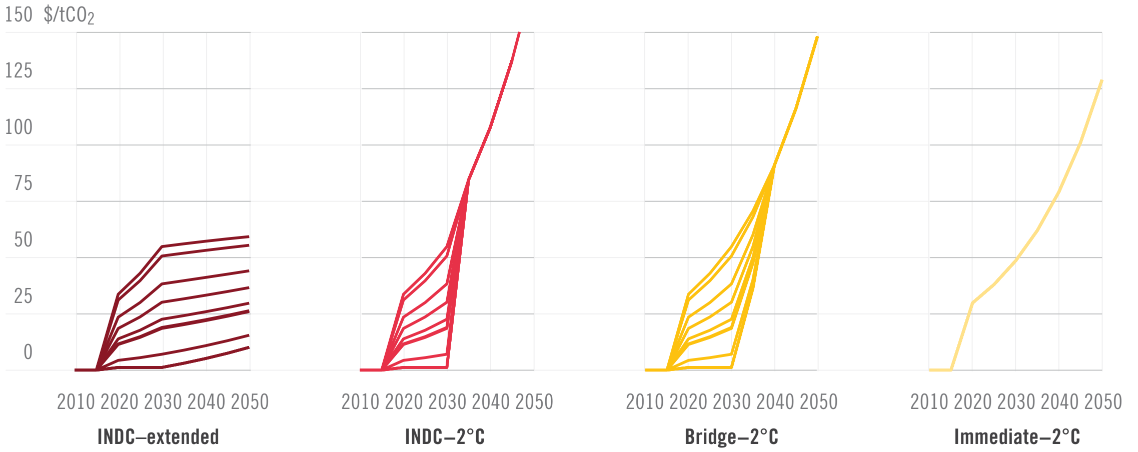
Most so far enacted climate policies don’t take the form of comprehensive carbon pricing but are rather targeted sectoral or technology policies to foster low-carbon technologies and to limit emission intensive technologies. Therefore, we additionally represent in a stylized way a number of these policies in the regions which have announced such policies or associated targets in their INDC or national climate and energy plans (see second column of Table A).

The REMIND model captures the full basket of greenhouse gases from fossil fuel use, industry and land use. For the implementation of the INDCs, land-use change emissions are constrained to exogenous trajectories. These have been derived with the land use model MAgPIE (Lotze-Campen et al. 2008, Popp et al. 2014), taking into account targets to limit deforestation and enhancing natural sinks, e.g. through afforestation, as announced in INDCs of various countries. We consider land-related INDCs from Brazil, Argentina and China For Latin America (largely based on the land-use related INDCs of Brazil and Argentina), we assume a reduction of annual deforestation by 80% until the year 2030 compared to the baseline year 2005. After 2030, we assume that the deforestation rate of Latin America remains constant. Based on China’s INDC announcement, we assume that historical

Table A: Overview of * "INDC emissions 2030 - Conditional PBL best estimate" values. regional policies represented in the INDC scenarios of Chapter 4

Region	Emission target for 2030 (2025 for USA), implemented in the model via increasing carbon prices over the period 2020-2030	Additional energy sector policies for regions
AFR (Subsahara Africa without South Africa)	Target calculated based on INDC statistics: 1. Countries without INDC (representing 28% of 2012 emissions of the AFR region) are assumed to follow their baseline. 2. For bigger countries with quantified 2030 targets (28% of 2012 emissions), the sum of their absolute 2030 targets (calculated from the specified reductions of national BAU projections) is used. 3. Countries with INDC referring to emission reduction relative to BAU, but without specifying their BAU assumption (44% of 2012 emissions) are assumed to have half the relative reduction than those with quantified INDC (measured against the REMIND BAU). For the allocation of 2030 BAU emissions onto these three country groups, it is assumed that their emission share in 2012 remains roughly unchanged until 2030.	
CHN (China)	Emission intensity of GDP -65% in 2030 vs. 2005	100(200) GW solar in 2020 (2030), 200(400) GW wind in 2020 (2030); Low carbon PE share increasing linearly from 16% in 2020 to 20% in 2030 and beyond (accounting for renewable and nuclear electricity with assumed 45% efficiency); 10% gas share in 2020
EUR (EU-28)	-40% GHG below 1990	Renewable secondary energy share (in gross final energy as defined by EU) of 20% in 2020, 27% in 2030 and increasing with 0.5pp per year beyond
IND (India)	Emission intensity of GDP -34% in 2030 vs. 2005	100(180) GW solar in 2022(2030), 65(110) GW wind in 2022(2030). 40% non-fossil based electricity capacity share in 2030.
JPN (Japan)	-25.4% GHG below 2005	Bound on fossil fuels in transport, increasing in ambition over time from -13% below BAU in 2020 to -70% in 2100.
MEA (North Africa, Middle East, and Asian Countries of the Former Soviet Union)	Countries without INDC (representing 80% of 2012 emission of the MEA region) are assumed to follow their baseline, for countries assessed by PBL* (10% of 2012 emissions), the abatement relative to BAU is taken from the PBL analysis, and half of that is assumed for further countries with INDC (10% of 2012 emissions). For the allocation of 2030 BAU emissions onto these three country groups, it is assumed that their emission share in 2012 remains roughly unchanged until 2030.	
LAM (Latin America)	Countries without INDC (representing 29% of 2012 emission of the LAM region) are assumed to follow their baseline, for countries assessed by PBL* (57% of 2012 emissions) the abatement relative to BAU is taken from the PBL analysis, and half of that is assumed for further countries with INDC (14% of 2012 emissions). For the allocation of 2030 BAU emissions onto these three country groups, it is assumed that their emission share in 2012 remains roughly unchanged until 2030.	
OAS (Other Asia, excluding China, India, Japan Middle Eastern and Former Soviet Union Countries)	Countries without INDC (representing 15% of 2012 emission of the OAS region) are assumed to follow their baseline, for countries assessed by PBL* (57% of 2012 emissions) the abatement relative to BAU is taken from the PBL analysis, and half of that is assumed for further countries with INDC (29% of 2012 emissions). For the allocation of 2030 BAU emissions onto these three country groups, it is assumed that their emission share in 2012 remains roughly unchanged until 2030.	
ROW (Australia, New Zealand, Canada, South Africa, Other Europe excluding EU-28 and Russia)	PBL database* contains INDC emission levels for 12 countries that have submitted INDCs, mostly with absolute 2030 emission targets, representing close to 100% of emissions of the ROW region in 2012; we use the sum of the 2030 value for those 12 countries scaled with $\text{Emissions}_{\text{REMIND,ROW}}$ (2005)/$\text{Emissions}_{\text{PBL,12countries}}$ (2005), in order to reflect the trend of the PBL analysis for this region.	
RUS (Russia)	-35% GHG below 1990	
USA	-27% GHG below 2005 (in 2025)	No new freely emitting coal power plants from 2020 onwards, bound on fossil fuels in transport, increasing in ambition over time from -13% below BAU in 2020 to -70% in 2100.

Figure A.1. CO_2 prices in the scenarios of this study



Note: The implicit carbon prices shown here do not reflect the stringency level of the overall INDC of a region, as for some regions, additional policies are represented in the modelling that depress the prices shown here (see table 1 in the annex). As all countries are likely to implement dedicated technology policies, actual carbon prices in a trading scheme or a carbon tax scheme will be lower for regions for which the complementary policies are not yet represented. Monetary values are given in

(2005) afforestation trends in China continue until 2020, resulting in 40 Mha additional forest area. For the time after 2020, we assume that afforestation rates in China decline by 2%/yr.

The REMIND model features perfect foresight, so that the level of policies assumed post-2030 has an impact on the way mitigation targets until 2030 are met. Therefore, we assume a continuation of a steady but moderate increase of ambition level in both the pricing and technology policies. For the carbon pricing, an exponential increase with 1.25% p.a., overlaid with a convergence of regional prices towards a medium trajectory is assumed, so that all regions experience a price increase and the spread between them narrows over time. For the technology targets as well, a moderate increase of stringency over time is assumed.

An overview of the REMIND model used for the analysis of global INDC scenarios in this report can be found in the supplementary material of this paper: http://www.nature.com/nclimate/journal/v5/n3/full/nclimate2514.html.

A detailed documentation of REMIND can be found here:

http://www.pik-potsdam.de/research/sustainable-solutions/models/remind/description-of-remind-v1.5

Carbon Price Representation in the REMIND Model under INDC Scenario and 2 ° C scenarios

The figure below shows the CO_2 prices in the four 2°C scenarios. Note that they do not reflect the stringency level of the overall INDC of a region, as for some regions, additional policies are represented in the modelling that depress the prices shown here (see Table A in the annex). As all countries are likely to implement dedicated technology policies, actual carbon prices in an emissions trading scheme or a carbon tax scheme will be lower for regions for which the complementary policies are not yet represented.

Co-benefit calculations

For the air pollution analysis, we used scenarios from the LIMITS modelling framework to establish the relationship between the greenhouse gas emission reductions and air pollutant changes using a delayed climate stabilization scenario and a business-as-usual projection in five different models (AIM, GCAM, IMAGE, MESSAGE, and WITCH) in 2030. To establish this relationship for each model, we assumed that for a given time slice, air-pollution co-benefits scale linearly with CO_2 emission reductions relative to a baseline without climate policy. For each model, the linear relationships were then used to project what the air pollutant changes would be under that model's assumptions and the INDC and reference levels resulting from the country-level analysis by the national modelling teams. This results in a range of air pollutant emission reductions from the INDC greenhouse gas emission reduction relative to the reference pathways. Because of known limitations, the co-benefits in 2030 can be overestimated relative to what global models would have simulated. All scenarios model a continuation and successful implementation of current air quality policies.

To estimate the net-energy import dependence implications of INDCs, we used scenarios from LIMITS, AMPERE, and EMF27 under different climate and technology policy assumptions. For each region-model combination, a linear regression was run on the full scenario set for 2030 to estimate the relationship between emissions and net-energy trade. This relationship was then used in conjunction with the country-level results from national teams to project the range of change in net-energy imports under that region's INDCs. The linear regression relationships were established for energy importing regions using six models for the EU (DNE, IMAGE, MESSAGE, POLES, REMIND, and WITCH), five models for China (DNE, IMAGE, POLES, REMIND, and WITCH) and four models for Japan (DNE, IMAGE, POLES, and REMIND). MESSAGE was excluded from the analysis because it depicts China as becoming an energy exporter in the 21st century whereas all the other models depict the country as an energy exporter.

XXX

XXX

IDDRI'S PUBLICATIONS

Publications available online at: www.iddri.org

The Institute for Sustainable Development and International Relations (IDDRI) is a non-profit policy research institute based in Paris. Its objective is to determine and share the keys for analyzing and understanding strategic issues linked to sustainable development from a global perspective. IDDRI helps stakeholders in deliberating on global governance of the major issues of common interest: action to attenuate climate change, to protect biodiversity, to enhance food security and to manage urbanisation. IDDRI also takes part in efforts to reframe development pathways. A special effort has been made to develop a partnership network with emerging countries to better understand and share various perspectives on sustainable development issues and governance.

For more effective action, IDDRI operates with a network of partners from the private sector, academia, civil society and the public sector, not only in France and Europe but also internationally. As an independent institute, IDDRI mobilises resources and expertise to disseminate the most relevant scientific ideas and research ahead of negotiations and decision-making processes. It applies a cross-cutting approach to its work, which focuses on seven themes: Global Governance, Climate and Energy, Biodiversity, Oceans and Coastal Zones, Urban Fabric, Agriculture, and New Prosperity.

IDDRI organises its publications policy around its own collections, books in partnership (such as *Planet for Life*, the result of a scientific collaboration with the French Development Agency and The Energy and Resource Institute, and an editorial partnership with Armand Colin for its French edition, *Regards sur la Terre*) and papers in scientific journals. IDDRI also publishes studies within the framework of the Club d'ingénierie prospective énergie et environnement [CLIP]: *Les Cahiers du CLIP*. IDDRI's own collections are made up of short texts (*Issue Briefs* and *Policy Briefs*), working papers (*Working Papers*) and studies or reports (*Studies*).

To learn more on IDDRI's publications and activities, visit www.iddri.org

IDDRI

www.iddri.org