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D6.4 REPORT CONTAINING AN ECONOMIC ANALYSIS OF A SET OF SECTORAL IMPACTS

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[1] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission

Contents

Tables

Figures

6.4.1. – Introduction

Pre-COP21 international climate framework

Climate change is a critical challenge that affects all aspects of our planetary life. The United Nations Framework Convention on Climate Change (UNFCCC) Treaty initiated in Rio in 1992 in order to achieve a collective agreement for global action against climate change. Although the first Conference of the Parties (COP) was held in 1995, progress towards global action has been slow and the results mixed for the following two decades. Various integrated analyses of the costs of climate change and the cost of inaction highlighted profoundly the need to find common solutions among the global community in order to combat climate change (e.g. Ciscar et al. (2014), Stern (2006), OECD (2015), Burke et al. (2015), IPCC (2007), World Bank (2012)).

Article 2 of the (UNFCCC 1992) states the objective of "*stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*". This level was for the first time included in a political declaration by the European Council of environment ministers in 1996, stating that 2°C is the target ceiling for the EU, as the risk of severe climate change impacts would increase markedly beyond a global average temperature rise of 2°C above pre-industrial levels. Although the origins of this long-term target are under debate (for example see Cointe et al. (2011), Tol (2007), Knutti et al. (2016), Smith et al. (2009), Jaeger and Jaeger (2010), Knopf et al. (2012)), the target being linked with the scientific consensus stated in the second Assessment Report from the IPCC (1995), has been conceived for decades as the common direction of climate policy. However, UNFCCC parties achieved agreement on goal only years later in 2009 in Copenhagen.

The first international climate treaty was agreed in COP3 in December 1997 in Kyoto, while COP7 in 2001 resulted in the Marrakesh Accords and put the foundations for the ratification of the Kyoto protocol in 2005. Efforts to include all major emitters in an intensified global mitigation action were unsuccessful in 2009 in COP15, Copenhagen, despite the submission of the Copenhagen Accords for 2020. Later in COP17, Durban 2011, and in COP18, Doha 2012, governments relaunched efforts for a new climate change agreement for the post-2020 period by 2015. While COP19 and COP20 did not make substantial progress, in December 2015, COP21 in Paris produced the next climate treaty that will be ratified once 55 parties have signed it.

The COP21 Paris Agreement

The Paris Agreement is generally considered to be a milestone in international climate policy. Compared to previous climate agreements, such as the Kyoto Protocol, the bottom-up approach to climate change mitigation through the submission of Intended Nationally Determined Contributions (INDC) marked a fundamental shift in the nature of the international climate policy regime. The greenhouse gas emissions of the countries that have communicated INDCs represent over 98.8% of global emissions in 2010, a much broader coverage compared to the Kyoto Protocol. Similarly, the emitting sectors covered are economy-wide and broad, including also emissions attributed to Land Use, Land Use Change and Forestry.

Important elements of the Paris Agreement include the transparent and common framework for monitoring, reporting and verifying GHG emissions and the confirmation of the goal for mobilizing at least USD 100 billion per year from developed to developing countries for mitigation and adaptation actions. A facilitative dialogue, foreseen to start in 2018 and to repeat every 5 years, shall take stock of the collective efforts of the parties in relation to the long-term goal and report to the COP accordingly. Of high importance is also the outcome of COP21 that supersedes the long-term target agreed in Copenhagen and Cancun and sets it to levels well below 2°C, referring to a maximum global average increase of temperature of 1.5°C by the end of the century while the 2°C target is acknowledged as the minimum safety goal for planetary stability. This achievement poses new challenges for the scientific community and the society as a whole.

However, the Paris Agreement fails to introduce concrete steps towards a low-carbon economy with a zero-carbon energy system. Concrete measures are foreseen only to the extent that they are included in the submitted INDCs; hence an early assessment of the effectiveness of the INDCs is a key scientific contribution to the global mitigation effort. Among other factors, the range of emission trajectories resulting from the INDCs depends highly on the attainment of adequate financing flows to low-income countries. The implementation of INDCs is not mandated by the Paris Agreement but by national policies, as although the Paris Agreement sets the legal requirement to the Parties to legislate sufficient national measures, the INDCs are not themselves legally binding as international law. As is stated in Averchenkova and Bassi (2016), the Paris Agreement does not foresee penalties or sanctions for non-compliance, "without credible policy implementation, the collective trust needed to support the Paris Agreement's system of reporting and review will not be built".

6.4.2. - Methodology

Literature Review

A first comprehensive analysis on the impacts of a COP agreement was published in the Energy Journal (Weyant et al. (1999)). Focusing on the impacts of the Kyoto protocol, the special issue included a set of stand-alone, single-model papers, each following different methodologies and assumptions. Similarly the pledges of the Copenhagen Accords have been assessed for their environmental effectiveness in many reports and academic papers. Examples of single model analyses that assess the Copenhagen emission trajectories in relation to a 2°C path include UNEP (2010), UNFCCC (2010) and Stern and Taylor (2010). Economic and energy-system impacts have also been considered. Ricci and Selosse (2013) use a partial equilibrium energy model, Van Vliet et al. (2012) and den Elzen et al. (2010) utilize an integrated assessment model while Saveyn et al. (2011), Peterson et al. (2011) and Dellink et al. (2011) use a general equilibrium model. Examples of multi-model analyses include Kriegler et al. (2013), where a number of integrated assessment models explore cost-effective 2°C emission paths starting including Copenhagen targets. Their key model assumptions are not harmonized but instead “a spread in GDP and population assumptions of participating models” is used “to explore the effect of uncertainty about those assumptions”, although different assumptions are not introduced in one model but in each participating model. In another example, Riahi et al. (2015), all participating models share common key macroeconomic assumptions (GDP, population) as well as global energy intensity growth rates.

Prior to COP21, a number of analyses have been published in order to facilitate an informative dialogue among the parties. Labat et al. (2015) provide an early scientific input on costs of 2°C and INDC-related mitigation action with the combined use of a CGE and an energy system model, Spencer et al. (2015) provide a country-level assessment of the implementation of INDCs for major emitters presenting results of single-model regional analysis for major emitters and IEA (2015) provides suggestions on how to bridge the gap between the INDC trajectory and the 2°C one. UNEP (2015) also assesses the emission gap to a cost-efficient 2°C scenario, while the UNFCCC (2015) published a Synthesis Report a few months prior COP21 presenting the emission trajectories of the submitted INDCs and concluding that the commitments are not sufficient for the achievement of the 2°C target. This report was updated in May 2016 (UNFCCC 2016) in order to include all submitted INDCs and concludes to the need for more ambitious commitments.

In the aftermath of the Paris Agreement, we find a small number of research publications that have evaluated the implications of the INDCs, of which few are peer-reviewed. Rogelj et al. (2016) summarize and assesses the information provided by a number of publications, reporting results either from single-model analysis (e.g. Fawcett et al. 2015) or from simpler accounting of INDC emission reductions (e.g. UNFCCC, 2015). Den Elzen et al. (2016) analyze in depth the emission trajectories not only on a global but also on a regional level, while Vandyck et al. (2016) also report global and regional policy costs.

Novel contributions of study

This paper presents a first multi-model assessment of the impacts of the Paris Agreement by deploying state-of-the-art models. More specifically, by utilizing different model types we conduct an analysis of the implications of INDCs on emission trajectories, the energy system and the economy, focusing in year 2030[2]. We further examine the efficiency of the INDCs towards the long-term 2°C and 1.5°C targets by comparing the outcome of the Paris Agreement with cost-efficient, early, global mitigation action. Comparability and equity considerations are out of the scope of this analysis, as well as the legal implications of the agreement.

A distinctive feature of this paper is the assessment of the emissions gap not only in relation to the 2°C long-term target but also to the 1.5°C one, providing a timely response to this current scientific challenge that emerged following the Paris Agreement. Further, in the paper we present a first combined estimation of mitigation costs for implementing the INDCs, the 2°C and the 1.5°C emissions trajectories.

The methodology followed in this paper features a harmonization of scenario assumptions so as to provide a common ground for assessing policy impacts with different model structures. Assumptions are harmonized not only for the main socio-economic indicators (GDP, population) but also for a set of energy policies and for the long-term trajectory of emission intensities. This demanding harmonization process among such a large group of different models goes beyond the practice followed in previous literature. This process is pivotal in order to allow for a consistent discussion and comparison of different model results while depicting the underlying uncertainties that are both inherent to modelling methods and to a real-world implementation of policies. Nevertheless, harmonization of historical years is beyond the scope of this paper, although similarly important for a robust multi-model analysis.

[2] 2030 is reported as the most commonly shared target year in the INDCs. The USA, Brazil, Ecuador and other small emitters (e.g. Grenada, Marshall Islands) have indicated year 2025 as a target year for their emission reductions in the corresponding INDC.

Description of models

The models that participate in this analysis are well established in the fields of climate and energy policy analysis. They have participated in many EU-funded research projects and other policy relevant analyses like IPCC reports and European Commission Impact Assessments. The models are briefly described in Table 6.4.1.

Table 6.4.1: Brief description of participating models

Model	Model type	Disaggregated economic sectors	Land use emissions	GHG coverage
POLES	Energy system-PE [3] model	No	Yes	All
MESSAGE	Energy system – GE growth model	No	Yes	All
GEM-E3-ICCS	Computable GE model	Yes	No	All
IMACLIM	Computable GE model	Yes	No	Only CO2
REMIND	Energy system – GE growth model	No	Yes	All
IMAGE	Energy-Land PE model	No	Yes	All
WITCH	Energy system – GE growth model	No	Yes	All
AIM/CGE	Computable GE model	Yes	Yes	All

[3] PE: Partial equilibrium, GE: General equilibrium

Scenario design

A consolidated set of policy scenarios enables the assessment of the Paris Agreement in terms of mitigation effectiveness and system transition. A brief description of the 4 scenarios presented in this analysis is found in Table 6.4.2[4] and the sections below.

Table 6.4.2: Brief description of scenarios

Scenario name	Description	Long-term temperature target
Reference	2020 Cancun pledges / low ambition post-2020 reductions	No
INDC	2020 Cancun pledges / 2030 INDCs / post-2030 fragmented emission reductions of the 2020-2030 intensity	No
2020_2°C	2020 Cancun pledges / post-2020 global action to a 1000 Gt CO_2 carbon budget	2°C
2020_1.5°C	2020 Cancun pledges / post-2020 global action to a 400 Gt CO_2 carbon budget	1.5°C

Reference scenario

The Reference scenario describes the trajectory of key economic, environmental and energy figures under the existing, pre-COP21 climate policies. It follows a low ambition mitigation effort that is highly diverse and fragmented across countries. In the post-2020 period it further assumes a continuation of low ambition climate policies, taking stock of the Reference trajectories in Labat et al. (2015).

The building process of a current policies Reference scenario is based on deriving data from many different sources (e.g. UN, OECD, EIA, European Commission, and UNFCCC) and aims for maximum consistency with related projections of international and national institutions. The socioeconomic assumptions of this scenario build upon two main sources in terms of economic growth rates and population assumptions, namely the global Reference scenario as described in Labat et al. (2015) and the SSP2[5] scenario. Harmonization with the above assumptions ensures consistency with the EU28's energy and GHG emissions trends as described in EC (2013) and with international publications like the UN (2013).

[4] The top of the rectangle indicates the third quartile, the horizontal line near the middle of the rectangle indicates the median, while the bottom of the rectangle indicates the first quartile. Error bars indicate the maximum and minimum values. All boxplot figures are constructed as described above.
[5] http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/SSP_Scenario_Database

INDC scenario

The **INDC** scenario increases efforts after 2020 so as to achieve full implementation of the conditional (high) pledges. This scenario further assumes that the regional mitigation effort in the period beyond the Paris Agreement time-frame, i.e. post-2030, will continue equal to that of moving from the Cancun to the Paris reductions, i.e. sustains the emission intensity reduction rate of the 2020-2030 period. In line with the assumed fragmented mitigation action, it is further ensured that carbon prices of low/lower-middle income[6] countries do not exceed 25%/40% of the average OECD carbon price. This model restriction warrants that emission reductions will come as a result of plausible policy instruments, but also restricts the cost-efficiency of results by taking into account the development policy angle. INDCs include different types of pledges, i.e. in relation to different base years, in relation to a baseline scenario or as carbon intensity improvements. A key feature of our analysis is the quantification of INDCs as emission reductions relative to 2010 levels so as to enables a harmonized approach by all models.

2°C and 1.5°C scenarios

A set of stylized carbon-budget scenarios enables the comparison of the INDC and climate stabilization scenarios. These result in emission pathways that ensure a probability above 66% of achieving maximum global average temperature increase of 2°C (**2020_2°C**) and 1.5°C (**2020_1.5°C**) by 2100. This deep-decarbonization action is enabled as early as 2020 and assumes a cost-efficient, common global action that limits the concentration of CO_2 emissions in the period 2011-2100 to 1000 $GtCO_2$ and 400 $GtCO_2$ respectively.

[6] According to the World Bank for the current 2016 fiscal year, low-income economies are defined as those with a GNI per capita, calculated using the *World Bank Atlas* method, of $1,045 or less in 2014; middle-income economies are those with a GNI per capita of more than $1,045 but less than $12,736; high-income economies are those with a GNI per capita of $12,736 or more. Lower-middle-income and upper-middle-income economies are separated at a GNI per capita of $4,125. No change of this classification is assumed until 2050.

6.4.3. – Results

Global mitigation impacts of the Paris Agreement are presented in this chapter with a focus on emission levels, energy system transformation and economy-wide costs. In parallel, the Agreement is assessed in comparison to stylized 1.5˚C and 2˚C pathways. Results from 8 participating models are discussed, identifying global trends and the contribution of aggregate sectors to a low-carbon transition. The focus year of the analysis is 2030, in line with the most common target year in the INDCs, but model runs are for the 2010-2100 period.

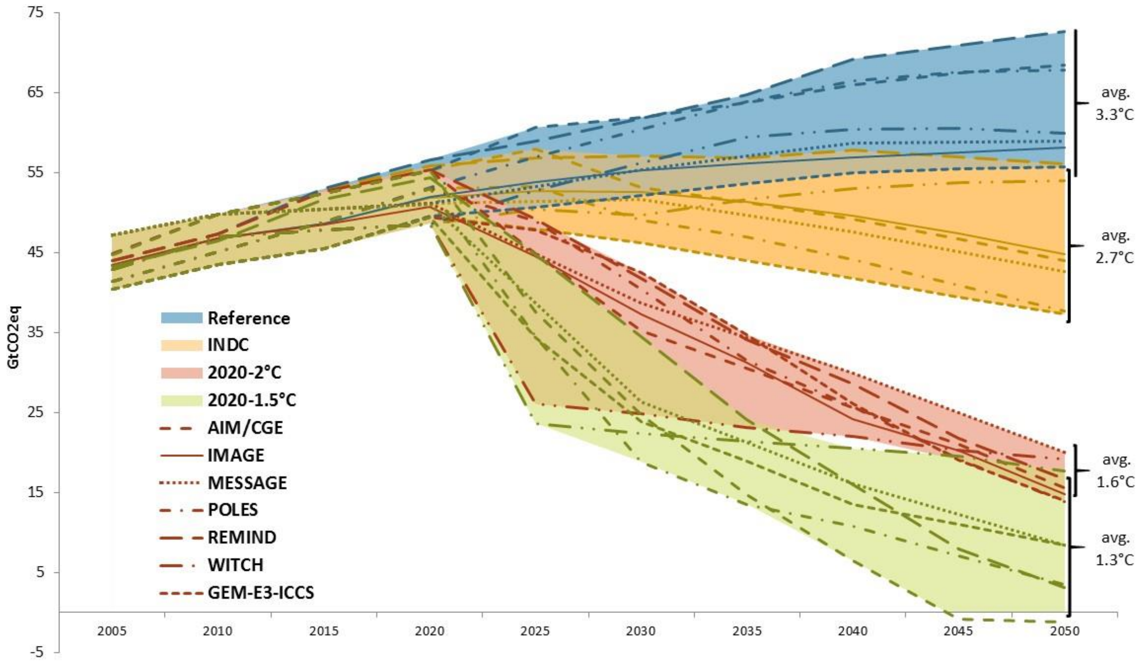

Figure 6.4.1: Global emission trajectories for 2010-2050

The “emissions gap” to 1.5-2˚C

The Reference scenario projects a world where economic and GHG emissions growth have not decoupled. A yearly increase of global emissions at 0.7%[7] [0.4-1.1%] annual rate continues for the 2010-2050 period, reaching 56 [52-62] $GtCO_2eq$ in 2030, 20% [11-34%] above 2010 levels. Along such trajectories, the projected global mean temperature increase is 3.3˚C [3.0˚-3.6˚] putting global livelihoods at risk of experiencing sizeable impacts and jeopardizing the overall sustainability of future development.

The INDC scenario leads to global emission levels equal to 52 [46-57] $GtCO_2eq$ in 2030. This corresponds to an emission level which is 11% [5-19%] lower than the Reference one. These findings are in line with UNFCCC (2016), which finds a global emission level equal to 54 [51-56] $GtCO_2eq$ in 2030 and with Rogelj et al. (2016), who assess 10 earlier-published single-model studies, and find a global level of 53 [51-53] $GtCO_2eq$ in 2030.

Emission levels in 2030 for the 2020_2°C and 2020_1.5°C scenarios are found equal to 39 [25-43] $GtCO_2eq$ and 24 [19-34] $GtCO_2eq$ or 33% [19-56%] and 57% [44-69%] below the Reference scenario levels. Comparing our results with the literature, we find that our 2050 emission levels in the 2020_2°C scenario (65% [59-69%] below 2010 levels) are consistent with the IPCC(2014) range of 41-72% below 2010 levels and our 2030 levels are consistent with the UNEP(2015) findings of 42[31-44] $GtCO_2eq$. Similarly, and although IPCC (2014) states that only a limited number of model studies have explored emission trajectories that are consistent with a high probability of achieving the 1.5°C target, our 2020_1.5°C scenario emission levels are consistent with the findings in the literature. In particular, 2050 emissions are equal to 88% [62-102%] of 2010 levels, showing that our median is well within the IPCC (2014) range (70-95% below 2010 levels) despite our range being wider. However, 2030 emission levels are substantially lower than the UNEP(2015) 39 [37-40] $GtCO_2eq$ range.

The resulting “emissions gap”[8] in 2030 is equal to 14[4-25] $GtCO_2eq$ and 25 [13-30] $GtCO_2eq$ for the 2 °C and 1.5°C targets respectively. Both the latest UNEP Gap Report (2015) and Rogelj et al. (2016) reach similar conclusions with an emissions gap from the 2°C trajectory of 12 [10-15] $GtCO_2eq$ and 11 [10.5-16] $GtCO_2eq$ in 2030 respectively.

Figure 6.4.1 shows the global GHG emission trajectories from 2005 to 2050 along with the average global mean temperature of each scenario, while Figure 6.4.2 zooms in year 2030 depicting also the emissions gap. Apart from an intrinsic uncertainty found in GHG emission projections, the uncertainty in historical emissions[9] is a key factor of the 2030 INDC emission levels, as the latter are linked to emission reduction targets expressed in relation to historical base years.

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[7] Results are expressed in terms of Median [minimum-maximum] values of all model results.

[8] According to the UNEP definition, an emissions gap is “the difference between the GHG emission levels consistent with having a likely chance (>66 per cent) of limiting the mean global temperature rise to below 2°C or 1.5°C in 2100 above pre-industrial levels and the GHG emission levels consistent with the global effect of the INDCs, assuming full implementation from 2020”.

[9] Modelling teams use different databases for their analysis (e.g. EDGAR, UNFCCC, National statistic, CAIT, EUROSTAT) and a harmonization of these sources is beyond the scope of this analysis hence remains a challenge for future model ensemble analyses.

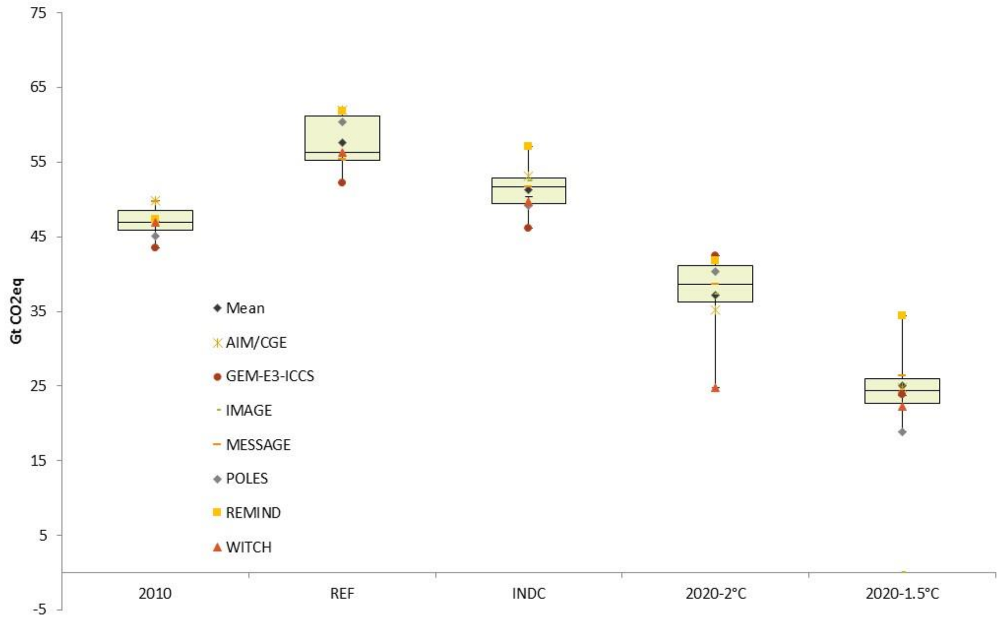

Figure 6.4.2: Global GHG emissions in 2030

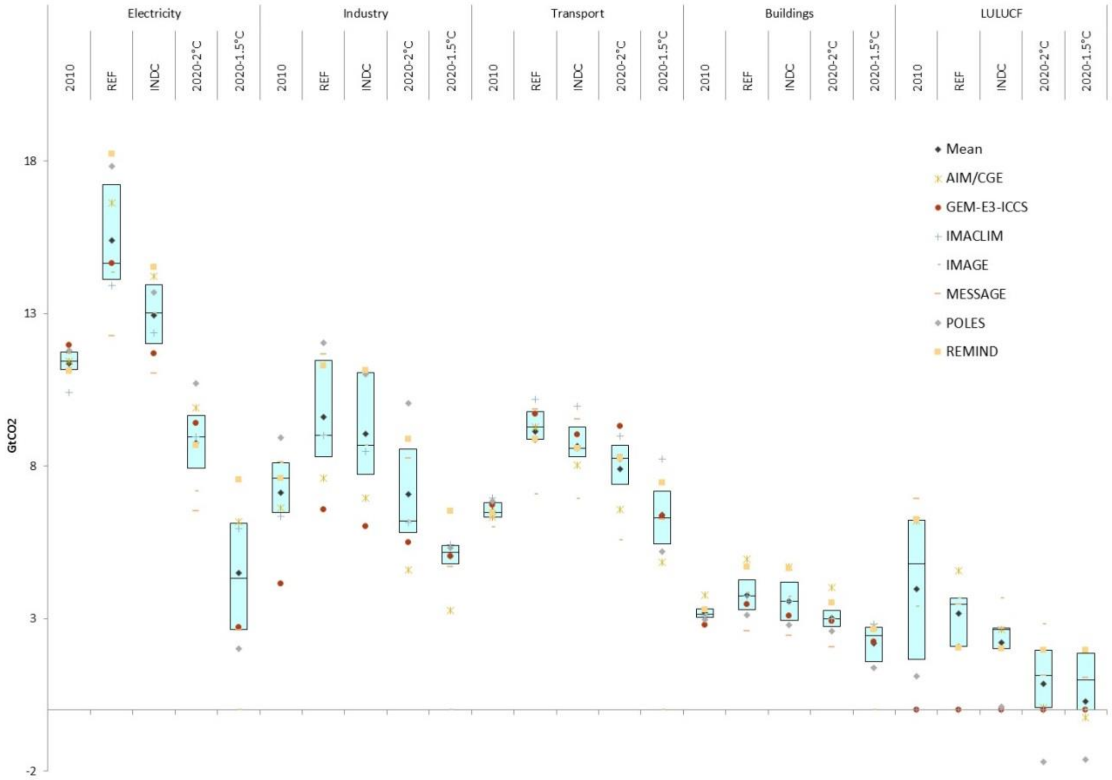

Figure 6.4.3: Direct CO_2 Emissions per sector in 2030

Sectoral contributions to emission reductions

In the INDC scenario, CO_2 emission reductions contribute an average of 83% [74-92%] in total GHG reductions from Reference, followed by an 11% [0-18%] contribution of CH_4, 4% [0-9%] of F-gases, and 2% [1-4%] of N_2O emissions. The same contributions are found in the mitigation effort to get from the INDC to the 2020_1.5C trajectory, while to get to the 2020_2C emission levels, CO_2 contribution is losing 5 percentage points from the increase of CH_4 and F-gases.

The power sector accounts for more than half of CO2 emission reductions in the INDC scenario (56% [33-84%]), but also holds the greatest potential for further reductions to put the world on track for the 1.5-2°C limits, contributing by 49% [35-75%] in reductions from INDC to 2020_2C scenario levels and by 45% [37-59%] to 2020_1.5C levels. As can be seen in Figure 6.4.3, the demand side[10] has a lower effect on near-term abatement but its share is increasing with increasing abatement efforts. In particular, in 2030 its share is 26% [6-47%] of CO2 emission reductions of the INDC scenario and increases to 36% [6-54%] and 40% [17-58%] when going from INDC to 2020_2C and 2020_1.5C trajectories. Within the demand sector, industry achieves almost half of the reductions, followed by the transport sector while buildings contribute less, depicting also their lowest share in total demand side CO2 emissions. Emission reductions in the LULUCF sector are important in all scenarios, and as its share in total reductions is decreasing with the increasing abatement efforts, we conclude that the abatement potential of the sector is utilized already in the INDC scenario due to cost-efficient marginal abatement costs.

[10] The term “demand side” refers to direct emissions from the industrial, transport and building sectors.

Transformation of the global energy system

The abatement effort entailed by the INDCs implies a rather moderate change from current trends in the energy system. The transformation of the energy system is limited even when considering the energy-related targets provided in the INDCs, thus it remains a challenge that needs to be addressed with more ambitious climate policies in order to achieve climate stabilization.

Energy is used more efficiently than today economy-wide already in the Reference scenario, with energy intensity in 2030 falling by 21% [17-43%] below 2010 levels. The implementation of INDCs brings only marginal improvements in the energy efficiency of the global economy, getting energy intensity in 2030 only 25% [19-44%] below 2010 levels. On the contrary, to achieve the 1.5-2°C targets, the economy changes the way it uses energy, as already in 2030 energy intensity levels fall by 33% [25-50%] and 39% [30-57%] below 2010 levels in the 2020_2C and 2020_1.5C scenarios respectively.

In the INDC scenario final energy demand is reduced by only 3% [1-5%] in 2030 compared to the Reference, while in the 2020_2C and 2020_1.5C scenarios it is reduced by 13% [6-24%] and 21% [9-31%] respectively. Figure 6.4.4 shows the global final energy demand per sector for each model[11], giving an insight on which sectors contribute the most in the drop of demand, either due to efficiency measures or due to a fall in sectoral activity. In the INDC scenario Buildings have the biggest reduction in demand (3% [1-4%] relative to Reference), followed by Transportation (2% [1-13%]) and Industry (2% [0-6%]). However, Industry is found as the most important sector in closing the emissions gap, reducing its final energy demand from INDC levels by 13% [3-21%] and by 24% [7-31%] in the 2020_2C and 2020_1.5C scenarios respectively.

[11] Excluding WITCH model that does not provide results in this sectoral detail.

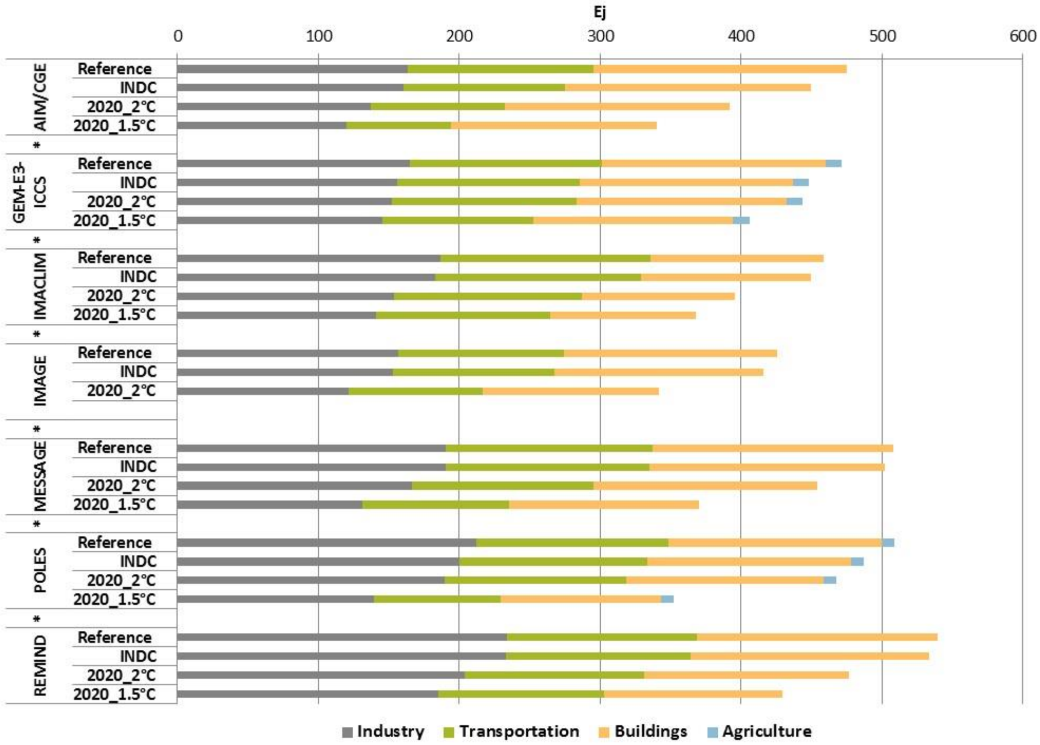

Figure 6.4.4: Global final energy demand per sector in 2030

In 2030, the decarbonization of the power sector is dominant in the transformation of the energy system and in the mitigation effort in all scenarios.

Figure 6.4.5 shows the shares of zero-carbon production in the global power system in 2030. The implementation of the INDCs results in a zero-carbon production share equal to 48% [40-66%], 7% [1-12%] higher than in the Reference, while 2020_2°C and 2020_1.5°C scenarios have respective shares of 57% [50-90%] and 73% [57-93%]respectively. Figure 6.4.6 provides an insight on specific zero-carbon technologies that enter the system for all different scenarios. Although nuclear power maintains a share close to that of 2010 in all scenarios, solar power increases from an almost zero share in 2010 to 4% [1-13%] in 2030 in the INDC scenario, 1% [0-8%] higher than Reference levels, and even reaches 7% [5-225] in 2020_1.5°C. Wind has an even deeper penetration, with a sevenfold increase from 2010 levels in 2030 INDC scenario, 3% [0-9%] higher than in the Reference. Wind penetration in 2020_2°C and 2020_1.5°C scenarios reaches 16% [8-42%] and 25% [17-43%] respectively, indicating the key role of the technology in the decarbonization of the sector.

The importance of zero-carbon power technologies differs widely across models. This can be explained, among others, by differences in the abatement effort and emission gap in 2030, by differences in the costs of each technology but also by the size of the cost-effective contribution of other sectors and gases, which in turn is determined by different abatement options and costs and by the sector responsiveness of each model.

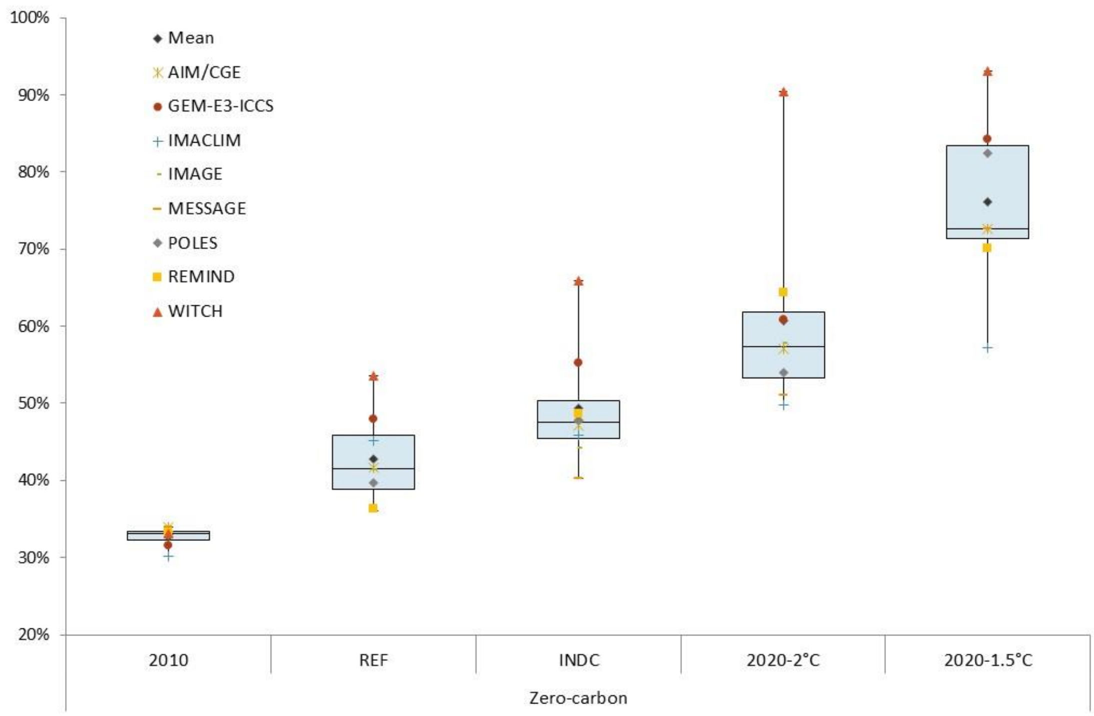

Figure 6.4.5: Share of zero-carbon power production in the global power system in 2030

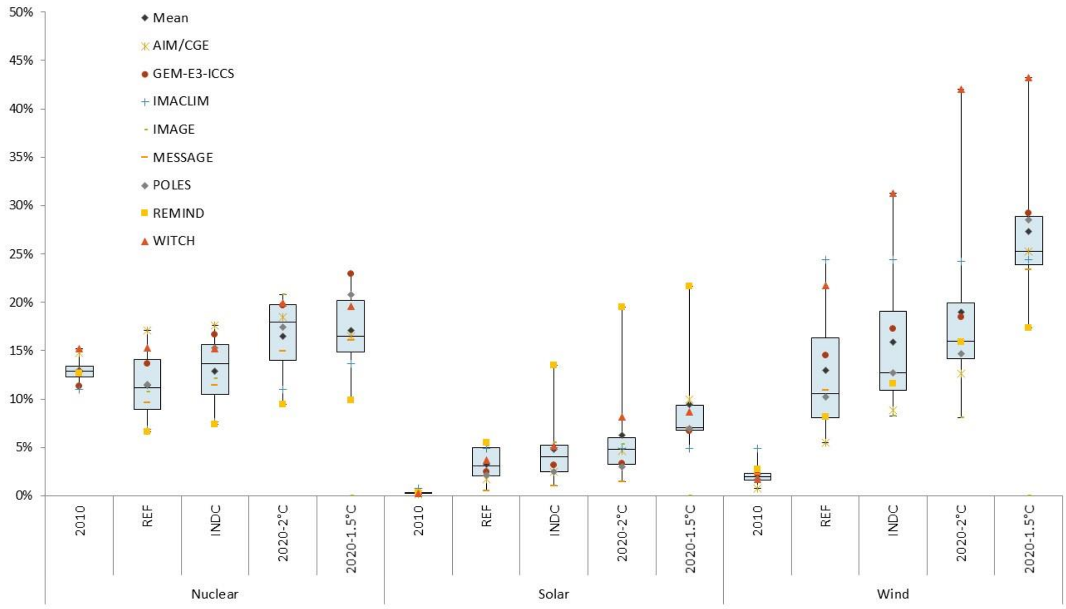

Figure 6.4.6: Share of nuclear, solar and wind production in the global power system in 2030

The decarbonization of the transport sector remains a key challenge in the effort towards climate stabilization. Results indicate (see Figure 6.4.3) that transport is the only sector whose 2030 emissions are higher than 2010 levels in the 2020_2C scenario, while even in the deep-decarbonization 2020_1.5C scenario, transport emissions reduce only marginally from 2010 levels. This is mainly due to increasing activity levels, especially in developing parts of the world, as results show that the sector undergoes a gradual low-carbon transition (see Figure 6.4.7).

In 2030 the share of electricity in total final energy use of transport is already 2% [1-6%] in the Reference, remaining low in the INDC scenario, and increasing only by 1% [0-7%] in the 2020_2C and 20_1.5C scenarios. Similarly, the share of biofuels exceeds only marginally the Reference levels (5% [1-10%]) by reaching 6% [1-10%] in the INDC, 5% [1-12%] in the 2020_2C and 8% [2-14%] in the 2020_1.5C scenarios.

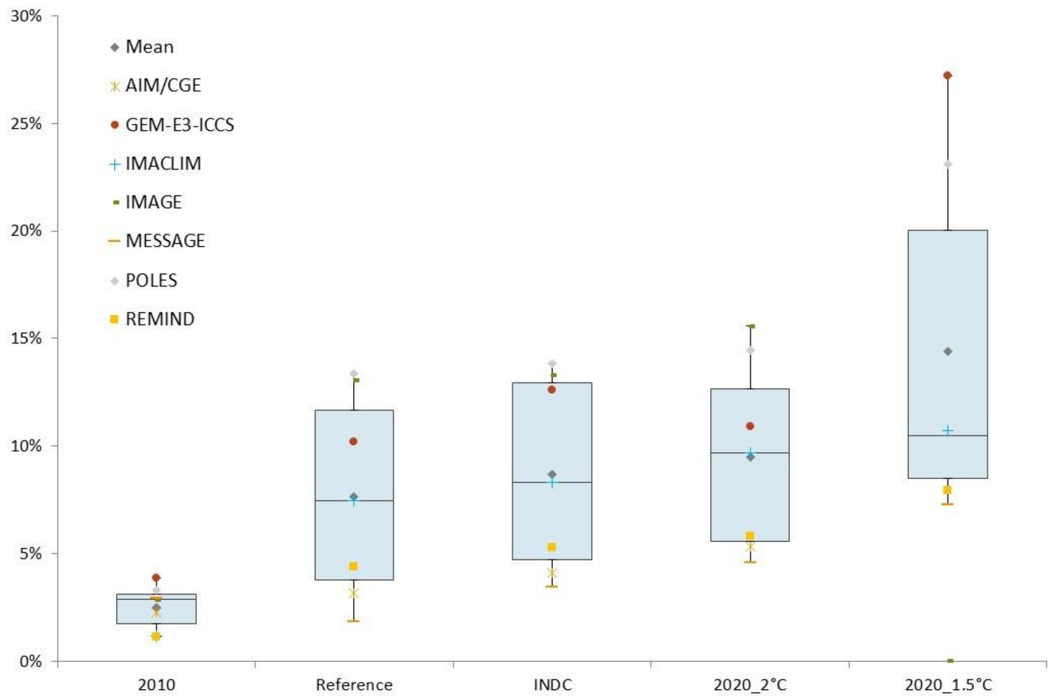

Figure 6.4.7: Share of non-fossils in final energy demand for transportation in 2030;

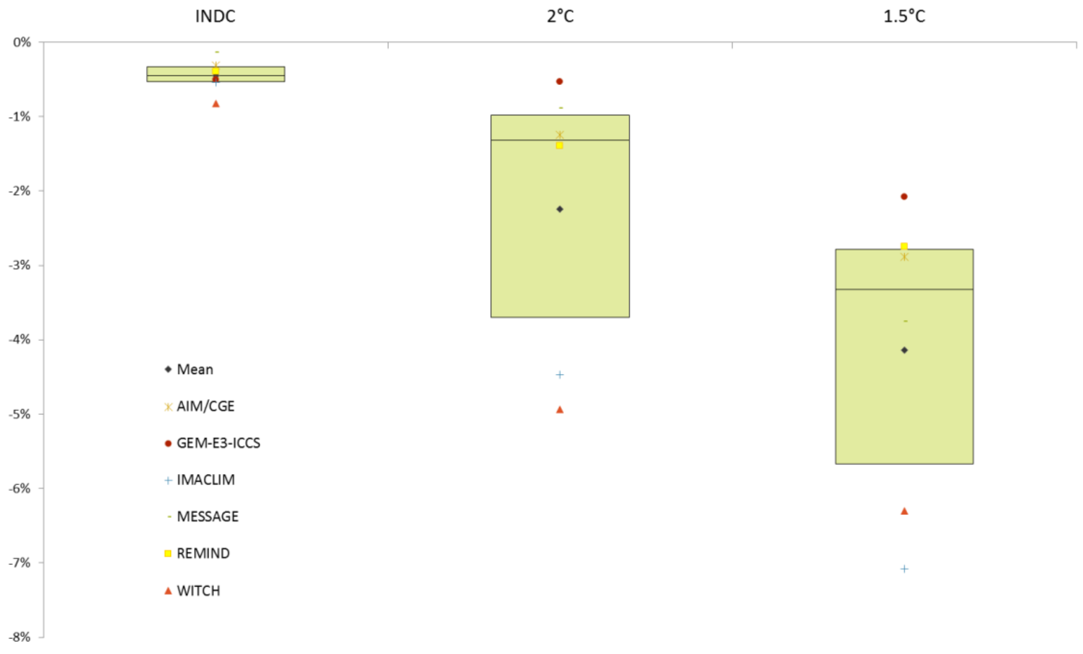

Figure 6.4.8: Total costs of mitigation in 2030: GDP loss as % change from Reference.

Policy costs and investments

Hybrid general equilibrium models are used to assess the INDC, 2C and 1.5C scenarios. Moving to a low carbon system is capital intensive and requires a reallocation of resources that is likely to result in economy-wide policy costs. In general, costs rise with more ambitious climate mitigation policies. However, the allocation of efforts is also an important driver of costs, as those are minimized in a global mitigation framework where reductions are undertaken by sectors and countries with the lowest marginal abatement cost. On the contrary, a fragmented action, like under the INDC scenario, may results in sub-optimal burden sharing. We assess the costs of implementing the INDCs and find a global policy cost in 2030 in terms of loss of GDP equal to 0.4% [0.1-0.8%] of Reference GDP. Closing the "emissions gap", i.e. moving from INDC to deep-decarbonization pathways, reduces further GDP by 1% [0-4%] and 3% [2-7%] from INDC levels for the 2°C and 1.5°C scenarios respectively. This analysis does not take into account the eventual avoided damage costs from pollution (e.g. air quality) and climate change impacts, or other positive feedback effects of the mitigation policies. Hence, the (negative) GDP impacts are high-end estimates and can be considered as conservative.

To put these numbers into context, we note that in the 2°C and 1.5°C scenarios, the global annual GDP growth rate for the 2010-2030 period remains in sustainable levels (around 3%), showing a reduction from Reference levels of only 0.08% [0.03-0.26%] and 0.19% [0.11-0.38%] respectively, while in the INDC scenario the GDP growth rates are almost unchanged from Reference, reducing only by 0.03% [0.01-0.04%]. In Figure 6.4.8 we provide the GDP costs illustrating that, among else, costs also differ due the different abatement efforts in 2030 in relation to the Reference, as both Reference emission trajectories and cost-efficient pathways for the 1.5-2°C targets differ across models. We find that the average abatement cost, i.e. the ratio of GDP losses to GHG reductions relative to Reference, differs across models and across scenarios but most models stay within the range of 0.07 bl$2005/Mt$CO_2$eq. Results indicate that in all models marginal costs increase with the intensity of reductions, showing that average costs in the 1.5°C scenario are higher than in the 2°C scenario. However, average abatement costs of the fragmented action in INDC scenario may be higher than those of common deep-decarbonization action.

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Appendix 6.3.5 – Diverse Strategies to Encourage Uptake of Alternative Fuel Vehicles are Essential for Decarbonising Transport.

Authors: David McCollum and Charlie Wilson

Introduction

Decarbonising transport is a major challenge for climate change mitigation [Creutzig et al. 2016]. In recent years, emissions from the sector have grown faster and more persistently than any other, including power generation, buildings and industry.

Private vehicles account for around half of all transport energy use and emissions [IEA 2015a]. Oil products burnt in the internal combustion engine (ICE) vehicles account dominate the sub-sector (>90%).

Although 'peak car' may have been reached in developed countries [Goodwin and Van Dender 2013], exponential growth in car ownership and use still characterises much of the world. As a result, widespread substitution of conventional (fossil fuel) vehicles with alternative fuel vehicles (AFVs) – such as ICEs running on biofuels as well as battery-electric (BEVs), plug-in hybrid-electric (PHEVs) and hydrogen fuel cell vehicles (FCVs) – is an essential feature of a 2 ^{o}C-consistent future [Clarke et al. 2014]. While all of these AFVs are commercially available today, they nevertheless comprise far less than 1% of the global private vehicle fleet. Sales of new vehicles are growing quickly, however, particularly in places like Norway, California, and the Netherlands. For example, more than a quarter of all new cars sold in early 2015 in Norway were BEVs [Kane 2015].

Consumer Preferences for Alternative Fuel Vehicles

Widespread adoption of AFVs implies consumers actively choosing to purchase them over conventional vehicles. Yet, outside of ICE vehicles capable of running on biofuels, most AFVs are still not cost-competitive with conventional rivals, although technological advances, learning effects, and manufacturing economies of scale continue to drive down upfront (capital) costs and increase efficiency [Nykvist et al., 2015].

Upfront costs and uncertain expectations about future fuel savings are but one part of a more complex picture. Consumer behaviour is not narrowly financial: vehicle purchasers express strong preferences over a wide range of non-financial performance attributes. Moreover, these preferences vary widely between different types of vehicle purchasers.

In a major review carried out for the ADVANCE project of over 80 empirical studies, we found strong evidence that heterogeneous consumers have measurably different non-financial preferences for vehicle choices [Wilson et al. 2014]. Consumers can be differentiated, for example, according to their propensity to adopt new technologies (e.g., early vs. late adopters), their location (e.g., urban vs. rural), and their vehicle usage intensity (e.g., modest vs. frequent).

Across these different consumer segments, the non-financial preferences that may vary include: (1) aversion to the risk of new vehicles, or its converse, attraction to the novelty of new vehicles; (2) consideration of the range of vehicle makes or models on offer; (3) concern for the availability (or lack thereof) of refuelling stations; and (4) anxiety about limited driving range.

These non-financial preferences have a strong influence on vehicle choices, particularly for AFVs which are still relatively novel, limited in the range of models available, and have a less dense network of refuelling stations [Mattauch et al. 2015]. The fourth non-financial preference, range anxiety, applies specifically to electric vehicles using current battery technologies.

To add one final layer of complexity, these non-financial preferences within different consumer segments vary from country to country, according to our empirical analysis. As an example, one study finds that range anxiety concerns are twice as strong in the US as they are in Western European countries, while in China they are four times higher [Dimitropoulos et al. 2013]. Our own analysis showed that nationally-specific cultural characteristics can help predict this variation in consumers' non-financial preferences [Pettifor et al. in review].

Challenges for Global Modelling of Vehicle Choices

These empirical findings represent a major challenge for the analytical and modelling tools currently used to understand the transitional dynamics of global climate change mitigation, including the class of integrated assessment models (IAMs) that informed the 5th Assessment Report of the Intergovernmental Panel on Climate Change [Clarke et al. 2014]. With respect to modelling vehicle choice, global IAMs are limited in three important ways. First, for the most part, they implicitly capture only a single 'representative' consumer, with no heterogeneity between different types of individuals. Second, they tend to represent vehicle purchase decisions purely as a function of capital, fuel, and maintenance costs, with no representation of non-financial preferences. Third, in only a limited way are model assumptions regarding vehicle choices differentiated by countries or regions.

ADVANCE project researchers have tackled each of these limitations in a pioneering initiative to make global modelling tools more behaviourally realistic in the area of private vehicle choice. For the first time, a large number of teams with integrated modelling frameworks now have the capability to represent heterogeneous consumer groups expressing both financial *and* non-financial preferences for AFVs. Consumer heterogeneity means that vehicle choices in models can now explicitly distinguish up to 27 different types of individuals (e.g., urban or rural, frequent or less frequent, risk averse or novelty-seeking). Non-financial preferences means that attributes including novelty, range, and refueling availability can explicitly influence vehicle choices. Preferences for these attributes are monetized and included alongside financial costs as additional terms in model equations capturing vehicle choice. These terms vary uniquely by consumer type for each vehicle technology within each world region. This approach allows consumer heterogeneity and non-financial preferences to be linked to (or derived from) specific scenarios so that narrative storylines, model set-up, and model assumptions are all consistent.

These enhancements have improved the modelers' ability to explore and understand the challenge of mitigating emissions in the transport sector (see later section for examples), while at the same time taking into account developments in other sectors of the energy system, such as fluctuations in oil prices or economy-wide carbon pricing.

Crucially, these model developments have also improved our capacity to provide policy-relevant insights by enabling modellers - for the first time - to simulate the effects of a wide-range of sectoral policies and strategies for encouraging the uptake of AFVs.

Strategies and Policies for Encouraging the Uptake of AFVs

Global modelling analyses of the mid-to-long-term typically use economy-wide carbon pricing as the principal policy lever to promote energy efficiency and low-carbon energy; in the transport sector, this results in consumer preferences shifting towards AFVs because of their lower relative fuel costs. In the real world, however, sectoral policies dominate regulatory influences on vehicle choices. Such policies are both financial (e.g., fuel taxes, subsidies, fee-bates) and non-financial (e.g., efficiency standards, vehicle mandates, refuelling infrastructure investments, exclusive access to parking spaces or roads). Moreover, a wider range of strategies involving not just policymakers but also businesses and civil society, can effectively support the adoption and use of AFVs. Examples include car clubs or car-sharing networks and social marketing campaigns using celebrity endorsements.

In Table 1 below, we illustrate some examples of sectoral strategies and policies for encouraging the uptake of AFVs around the world. Many are drawn from studies of electric vehicles, but apply more generally to other AFVs. We also indicate the types of consumer preferences, both financial and non-financial, that each strategy or policy is likely to influence, especially in the near term when recharging or refuelling infrastructure for AFVs will be limited. Between the years 2008 and 2014, government spending on a subset of these policies targeting electric vehicles (specifically, RD&D subsidies, public investments in recharging/refuelling infrastructure, and vehicle sales incentives) totalled around 14 billion US$ globally [IEA 2015b], representing some 0.002 to 0.018% of national GDP in leading electric vehicle countries in 2014 [Wesseling 2016].

Table 1. Examples of strategies and policies in selected countries for encouraging the uptake of AFVs by acting on consumer preferences (both financial and non-financial). Source: Strategies and policies based primarily on Lutsey et al. [2015] and Nilsson and Nykvist [2016]. Notes: ++ strongly or directly affects consumer preference; + weakly or indirectly affects consumer preference (as assessed by the ADVANCE project team).

		Consumer Preferences					
		Financial		***Nonfinancial***			
Strategy or policy	**Selection of Countries of Where Strategy or Policy has been Implemented** [a]	***Upfront capital cost***	***Fuel cost***	***Risk aversion***	***Model availability***	***Refuelling availability***	***Range anxiety***
Targets for cumulative vehicle sales, sales quotas, vehicle mandates	Norway, Netherlands, UK, USA (10 states with California mandates), China, France, Germany	+		+	++	+	
Vehicle efficiency or emission standards	Norway, Netherlands, UK, USA, Japan, China, France, Germany		+	+			
Vehicle sales incentives (purchase subsidies, tax credits, fee-bates, reduced registration fees)	Norway, Netherlands, UK, USA, Japan, China, France	++		+			
Vehicle manufacturer support (RD&D, production subsidies)	Norway, Netherlands, UK, USA, Japan, China, France, Germany	++			+		+
High transport fuel taxes (also carbon taxes or pricing)	Norway, Netherlands, UK, France, Germany		++			+	
Government and company vehicle procurement policies, other demonstration & test fleets	UK, USA, Japan, China, France	+		++	+	++	+
Trialling in car clubs or car-sharing networks	France, Germany, Netherlands, USA			++	+	++	+
Recharging and refuelling public infrastructure investments	Norway, Netherlands, UK, USA, Japan, China, France, Germany		+			++	++
Workplace or home charging incentives	USA, France		+			++	++
Preferential parking or roadway access; reduced congestion charges or tolls	Norway, Netherlands, UK, USA, Japan, France, Germany			+			
Promotions, social marketing, outreach, information campaigns	Norway, Netherlands, UK, USA, Japan, China, France, Germany			++	+	+	++

[a] Only a selection of countries listed, representing >90% of global electric vehicle sales in 2014 [Lutsey et al. 2015].

Global Modelling Analysis of Strategies and Policies for Encouraging Uptake of AFVs by Acting on Non-Financial as well as Financial Consumer Preferences

Using the model developments described earlier, modelling teams tested the effect of strategies and policies to encourage non-financial preferences (e.g., via declining risk aversions) and financial preferences (e.g., via carbon pricing). We show these effects by comparing a scenario that assumes strong sectoral actions are applied ubiquitously throughout the world by governments, businesses and civil society ('**AFV Push**') against a counterfactual scenario in which such policies are non-existent ('**No AFV Action**').

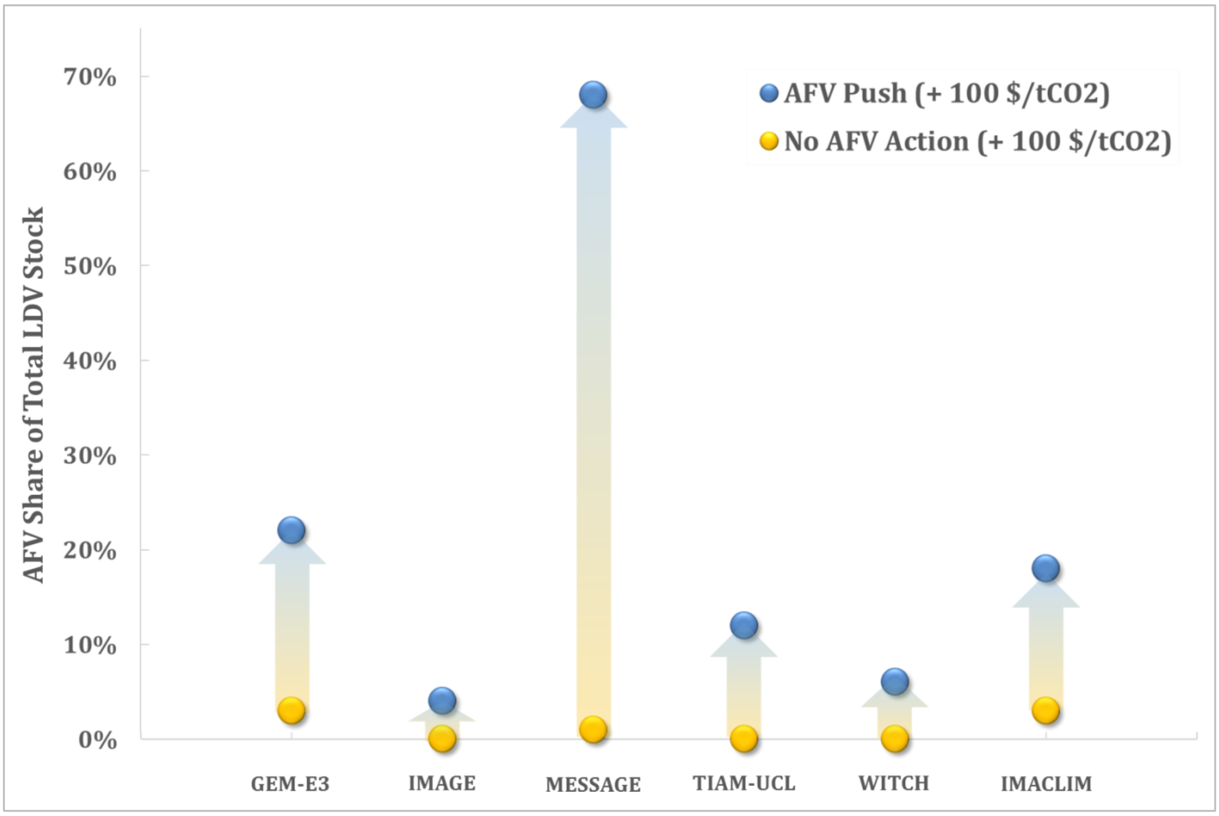
In the 'AFV Push' scenario, non-financial preferences representing aversion to AFVs decline as (i) the share of AFVs increases over time, (ii) more makes and models become available, (iii) refueling and recharging infrastructure is built out, and (iv) battery technology continues to improve. While the models do not attempt to explicitly represent each and every strategy or policy listed in Table 1, the scenario narrative rests upon a package of best-in-class actions being implemented. In the 'No AFV Policy scenario', current risk aversion and other non-financial concerns over AFV range and refueling remain constant, unaffected by future developments.

Figure 1 presents a snapshot of results from six global integrated assessment models. Using and comparing multiple models reflects the uncertainties in future socio-economic and technological developments which models represent differently (e.g., related to GDP growth, fossil and renewable resource availabilities, energy prices, technology costs and performance attributes across all energy sectors). As Figure 1 clearly shows, concerted near-to-mid-term action on the part of governments, businesses and civil society to address the non-financial considerations of consumers when making vehicle purchases is critical to the mid-to-long-term success of AFVs. With a mixture of strong strategies and policies in place, the models estimate that AFV shares (as a percentage of total light-duty vehicle stock) could be as high as 68% by 2050 ('AFV Push' scenario). Lacking such concerted action, AFV shares are found to reach only 0 to 3% by 2050 ('No AFV Action' scenario). Considering the high, economy-wide carbon price assumed in both scenarios, in line with stringent climate policy, the results for low AFV penetration in the 'No AFV Action' case are especially stark.

Our analysis clearly shows that <u>*both*</u> *carbon pricing* <u>*and*</u> *sectoral strategies and policies targetting consumers' non-financial preferences are important for driving widespread adoption of AFVs in the transport sector and to ensure that the electricity and hydrogen used to power these advanced vehicles is derived from low-carbon sources*. In other words, the two classes of policies are found to act synergistically to accelerate the transition to low-carbon AFVs.

However, models vary in their estimations of how rapid and pervasive this transition will be. An important condition to our main finding is, therefore, that implementing sectoral strategies or policies is no guarantee of AFV success, even if their costs and performance continue to improve over time.

Figure 1. Shares of electric and fuel cell vehicles in 2050 assuming strong sectoral strategies ('AFV Push') or no sectoral strategies ('No AFV Action') across six global integrated assessment models. Global, economy-wide carbon pricing is assumed as climate policy in both scenarios from 2020 onward (100 US$2010/t$CO_2$ held constant over time), which raises fuel costs of conventional vehicles and induces a shift away from upstream fossil energy production.



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