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# A global stocktake of the Paris pledges: Implications for energy systems and economy

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ABSTRACT

The United Nations-led international climate change negotiations in Paris in December 2015 (COP21) trigger and enhance climate action across the globe. This paper presents a model-based assessment of the Paris Agreement. In particular, we assess the mitigation policies implied by the Intended Nationally Determined Contributions (INDCs) put forward in the run-up to COP21 by individual member states and a policy that is likely to limit global warming to 2 °C above pre-industrial levels. We combine a technology-rich bottom-up energy system model with an economy-wide top-down CGE model to analyse the impact on greenhouse gas emissions, energy demand and supply, and the wider economic effects, including the implications for trade flows and employment levels. In addition, we illustrate how the gap between the Paris mitigation pledges and a pathway that is likely to restrict global warming to 2 °C can be bridged. Results indicate that energy demand reduction and a decarbonisation of the power sector are important contributors to overall emission reductions up to 2050. Further, the analysis shows that the Paris pledges lead to relatively small losses in GDP, indicating that global action to cut emissions is consistent with robust economic growth. The results for employment indicate a potential transition of jobs from energy-intensive to low-carbon, service oriented sectors.


## 1. Introduction

The twenty-first edition of the annual United Nations-led conference on climate change (Conference of the Parties, COP21) was held in Paris in December 2015. The Paris Agreement is an important step forward in international climate change negotiations. Its main merits include a legally binding 2 °C target, the introduction of a five-yearly review process from 2018 onwards with a first global stocktake scheduled for 2023 and an agreement on international climate financing. Compared to previous editions such as COP3 in Kyoto and COP15 in Copenhagen, the bottom-up approach to climate change mitigation (introduced in Durban, COP17 in 2011) was a fundamental shift in the nature of the policy process. In the run-up to COP21, most countries submitted climate action pledges labelled 'Intended Nationally Determined Contributions' (INDCs). The greenhouse gas emissions of the countries that have communicated INDCs represent over 95% of global emissions in 2010 (UNFCCC, 2016). Hence, in contrast to the Kyoto protocol, the Paris pledges have a broad coverage in terms of emissions. Although unprecedented, this is by no means a sufficient condition to avoid global warming of more than 2 °C above pre-industrial levels by the end of the century, a target included in the Copenhagen Accord (COP15) in 2009 and in the Cancun Agreement (COP16) in 2010. Pre-COP analyses indicate that the INDCs imply an increase in global temperatures in the range of 2.6–3.1 °C by 2100 (Fawcett et al., 2015; Gütschow et al., 2015; Rogelj et al., 2016). Another outstanding challenge is the voluntary nature of individual countries' emission reductions. Once ratified, the Paris Agreement will be legally binding, but the INDCs of individual countries will not. Moreover, whereas the Paris Agreement mentions the economy-wide scope of the emission reduction, it does not include any explicit reference to the aviation and shipping sector.

The outcomes of previous rounds of international climate change negotiations have been assessed by various studies. For instance, Weyant and Hill (1999) summarize that the Kyoto Protocol does not imply a cost-effective climate change mitigation policy and highlight the cost-reducing potential of emission trading, while Böhringer and Vogt (2003) point out that the combination of permit trade and the presence of 'hot air' (due to emission targets well above the projected business as usual) may

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strongly reduce the environmental effectiveness of the Kyoto Protocol. The analyses of the pledges of the Copenhagen Accord based on integrated assessment models (den Elzen et al., 2011a,b; van Vliet et al., 2012; Riahi et al., 2015) and computable general equilibrium (CGE) models (Dellink et al., 2011; McKibbin et al., 2011; Peterson et al., 2011; Saveyn et al., 2011; Tianyu et al., 2016) typically find a policy cost between 0 and 3% of GDP compared to a baseline in 2020 for different cost metrics (abatement cost, GDP, welfare). Pre-COP21 assessments of the INDCs can be found in Fawcett et al. (2015) and IEA (2015).

This paper assesses the energy-related and economic implications of the climate mitigation policies embedded in the INDCs. The main contribution to the literature is twofold. First, we present a timely, policy-relevant, global stocktake of the Paris mitigation pledges that translates the outcome of the latest international climate negotiations into quantifiable changes in a range of variables including energy demand, the composition of energy and electricity production, economic activity, trade and employment. The second contribution lies in the methodological framework, presented in the following section. The combination of a bottom-up, detailed energy system model and a top-down global economic model exploits the complementarities between both and enables an extensive study of climate change mitigation policies.

The remainder of the paper is organised as follows. After presenting the methodology, we describe the scenarios studied: the Reference scenario, the INDC scenario covering the mitigation component of the Paris pledges and a scenario that is likely to put the world on track to meet the 2 °C target. Results are presented in Section 4. We highlight the impact on energy production, demand and investments and the economic effects. Furthermore, we present how the gap between the INDCs and the 2 °C pathway can be bridged. The final section concludes.

## 2. Methodology

The assessment of climate change mitigation policies presented in this paper builds on the combined modelling effort of a detailed, technology-rich energy system model (JRC-POLES, https://ec.europa.eu/jrc/en/poles) and an economy-wide Computable General Equilibrium (CGE) model (JRC-GEM-E3, https://ec.europa.eu/jrc/en/gem-e3/). The models are harmonized along a common Reference scenario and are soft-linked to exploit complementarities of a detailed representation of energy production, demand and markets on the one hand, and economy-wide feedback mechanisms including international trade, intermediate input links between industries, and recycling of taxation revenue on the other hand. As such, this paper addresses part of the critique on standard modelling practices put forward by Rosen (2016) and Rosen and Guenther (2016), particularly on the high degree of aggregation in most integrated assessment models. In contrast to exercises using numerous models in order to provide a range of results for a common set of output variables (Kriegler et al., 2013, 2015; Riahi et al., 2015), this paper emphasizes that different model types can contribute complementary parts to a complex puzzle. The scenarios analysed here build on the analyses by Labat et al. (2015), Kitous and Keramidas (2015) and Kitous et al. (2016), whereas the methodology further develops the framework adopted by Russ et al. (2009) and Saveyn et al. (2011). The approach of linking an energy model with a CGE model with a bottom-up representation of the power sector contributes to but is distinct from the literature reconciling top-down and bottom-up information while building a high degree of energy system detail into a CGE model (e.g. McFarland et al., 2004; Hourcade et al., 2006; Sue Wing, 2008; Böhringer and Rutherford, 2008; Abrell and Rausch, 2016; Li and Zhang, 2016).The following paragraphs briefly describe the JRC-POLES model, the JRC-GEM-E3 model and the way in which the two models are combined. For more detailed model descriptions we refer to Appendices A and B, the above-mentioned model websites and the mathematical description of JRC-GEM-E3 in Capros et al. (2013).

The JRC-POLES model is a global partial equilibrium simulation model of the energy sector, covering 38 regions world-wide plus the EU. The model covers 15 fuel supply branches, 30 technologies in power production, 6 in transformation, 15 final demand sectors and corresponding greenhouse gas emissions. GDP is an exogenous input into the model, while endogenous resource prices, endogenous global technological progress in electricity generation technologies and price-induced lagged adjustments of energy supply and demand are important features of the model. The mitigation policies discussed in the next section and listed in Appendix C are implemented by introducing carbon prices up to the level where emission reduction targets are met. Carbon prices affect the average energy prices, inducing energy efficiency responses on the demand side, and the relative prices of different fuels and technologies, leading to adjustments on both the demand side (e.g. fuel switch) and the supply side (e.g. investments in renewables).

The JRC-GEM-E3 model is a global recursive-dynamic CGE model. The model describes the economic behaviour of welfare-maximizing households and cost-minimising firms, includes (exogenous) government policies, different types of energy use and greenhouse gas emissions and endogenously determines changes in international trade flows, unemployment and GDP. Inter-industry connections are explicitly represented via intermediate consumption. Climate policies are introduced in the model via emission constraints. The JRC-GEM-E3 model then endogenously derives the shadow prices to meet these constraints, raising the cost of emission-intensive inputs for firms and consumption of emission-intensive goods for households. Emission reductions occur via three mechanisms: a reduction in output and consumption, substitution towards low-carbon inputs and goods and end-of-pipe abatement technologies.

The analyses presented in this paper benefit from the combination of the two models in a way that allows for a broad assessment while preserving the details and particular strengths of each. First, a Reference shared by the two models is developed based on common assumptions for the (exogenous) evolution of two important factors with regards to climate change: region-specific economic (GDP) and population growth. The evolution of the sector composition of economic activity follows the same projection in both models, projecting structural changes in developing countries based on historical data. In addition, the emissions by greenhouse gas, economic sector and region are identical between the two models in the Reference. Second, scenario results of the disaggregated energy model feed into the economy-wide CGE model to make use of the in-depth treatment of the energy system in JRC-POLES. In particular, the totals of greenhouse gas emissions derived from the bottom-up analysis determine regional emission constraints for the economic assessment with JRC-GEM-E3. In addition, the shares of the different technologies in electricity generation in JRC-POLES are used as an input in the JRC-GEM-E3 analyses. This soft-link is enabled by the split of electricity generation into 10 technologies in the JRC-GEM-E3 model. As a result, the technology mix in electricity supply in the JRC-GEM-E3 model is consistent with an enhanced representation of the specific features that characterize real-world electricity markets, such as price-setting by the marginal technology, capacity investment decisions, intermittency, region-specific potentials of renewable energy sources (per technology) and endogenous technological progress. Changes in electricity trade between regions and the location of production of technologies (e.g. solar panels) are not considered explicitly in