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Drivers of regional decarbonization through 2100: A multi-model decomposition analysis

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ABSTRACT

This study explores short and long-term drivers of alternative decarbonization pathways in four major economies (China, India, Europe and USA), using a multi-model decomposition analysis. The paper focuses on determining the energy system transformations that drive the changes in carbon emissions and identifying the model characteristics that lead to differences in the decarbonization strategies. First, we compare the decomposition over time of near-past carbon emissions and near-future model projections as a methodology to validate baseline scenarios. We show that a no-policy baseline scenario is in line with historical trends for all regions except China, where all models project higher improvements in energy and carbon intensity than the near-past historical development. Second, we compare regional decarbonization drivers across models in a scenario with moderate policy targets that represent the current fragmented international climate policy landscape. The results from the different models show that energy efficiency improvements represent the main strategy in achieving the moderate climate targets. Finally, we develop an LMDI decomposition analysis to determine the additional energy system changes needed to achieve a global GHG concentration target of 450 ppm compared to the moderate policy case. In all models, reducing regional carbon intensity of energy is the major decarbonization strategy after 2030. In the long-term (after 2050), most of the models find that negative carbon emissions are critical in such scenario, emphasizing the key role of biomass with CCS. However, the level of contribution of the decarbonization factor varies significantly across models, due to the large uncertainty in the availability of renewables and the development of CCS technologies. Overall, we find that the main differences in the decomposition results across models are due to assumptions concerning availability of natural resources and variety of backstop technologies.

1. Introduction

Climate change mitigation is one of the major global policy challenges, as it is increasingly recognized that unabated climate change can lead to large environmental, social and economic impacts on human societies. Limiting greenhouse gas (GHG) emissions has been the subject of international negotiations for more than two decades. Due to the persistent lack of a comprehensive global agreement on GHG emissions reduction, several studies based on individual or multi-model results have analysed the effect of delayed and unilateral climate change mitigation policy action. For instance, the 22nd Energy Modeling Forum (EMF-22) analysed the consequences of delayed action (Bosetti et al., 2009; Krey and Riahi, 2009; van Vliet et al., 2009); unilateral climate change mitigation policies have been studied concerning policy effectiveness, carbon leakage and border carbon adjustment (Böhringer et al., 2012, 2014; Bosetti and De Cian, 2013). Moreover, the role of the European Union, which has taken the lead in climate change mitigation policy, has been investigated (For instance in the EMF-28, see De Cian et al. (2013) and Knopf et al. (2013)). Recently, the AMPERE modelling comparison project[1] analysed three different aspects of climate change mitigation: (1) The consequences of following the Copenhagen Accord and the Cancun Agreement until 2030 for the achievement of long-term global stringent mitigation objectives (Eom et al., 2015; Riahi et al., 2015); (2) the implications of moderate regional climate policies and the consequences of unilateral first-mover action in the EU and China (Bauer et al., 2015; Kriegler et al., 2015b; Marcucci and Turton, 2015; Paroussos et al., 2015; Schwanitz et al., 2015); and (3) European decarbonization pathways under alternative technological choices to achieve the climate targets of the EU Roadmap 2050 (Capros et al., 2014). We develop in this paper a multi-model decomposition analysis of a subset of the global AMPERE scenarios. This

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[1] The AMPERE project is a collaborative effort among 22 institutions in Europe, Asia and North America, funded by the European Commission, FP7 (http://ampere-project.eu/web/). AMPERE aims for a broad exploration of mitigation pathways and associated mitigation costs under real-world limitations while offering insights into the differences across models and the relation to historical trends.

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decomposition analysis helps identifying the contribution of different drivers, such as energy efficiency of GDP and carbon intensity of energy, to changes in CO_2 emissions from the combustion of fossil fuels and industrial applications.

The objective of decomposition analysis is to quantify the relative contribution of different pre-defined factors to the change of one explained variable. The decomposition methods used in the 1970s and 1980s were based on the Laspeyres index, which measures percentage change of a factor while holding the other decomposition factors constant (Ang, 2004). At the end of the 1980s, Boyd et al. (1987, 1988) proposed the use of the Divisia index to decompose energy intensity as an alternative to the Laspeyres index. The Divisia index is a “weighted sum of logarithmic growth rates, where the weights are components' shares in total value” (Ang, 2004). One frequently used method is the Log-mean Divisia index (LMDI), introduced by Ang and Liu (2001). The LMDI can be used to decompose energy demand or emissions between two end points into separate sectoral contributions (Ang, 2005). The LMDI method has been further developed to analyse energy intensity (Choi and Ang, 2012) and both energy and emissions (Su and Ang, 2012).

After being introduced in 1970, decomposition analysis has become a well-known analytical tool for supporting policy making in energy and environmental issues, as shown in Ang and Zhang (2000) where more than 100 decomposition studies are presented. In 1990, Kaya (1990) introduced a method to decompose emissions into key drivers, like population, GDP per capita, energy intensity of GDP and carbon intensity of energy. Kawase et al. (2006) expanded the Kaya identity in order to incorporate more drivers for carbon emissions and applied the extended method to a set of national emission scenarios for Japan, Germany, the U.K. and France. Many studies have evaluated the role of key drivers for historical changes in emissions or energy intensity, for example Baldwin and Sue Wing (2013) decompose the evolution CO_2 emissions in the period 1963–2008 in the US in five driving factors: the emission intensity of energy use, the energy intensity of economic activity, the composition of states' output, per capita income and population; Alves and Moutinho (2013) use the complete decomposition technique originally developed by Sun (1998) to examine the evolution of CO_2 emissions intensity in 16 industrial sectors in Portugal in the period 1996 to 2009; Voigt et al. (2014) analysed energy intensity trends between 1995 and 2007 in 40 major economies using the LMDI method to attribute efficiency changes to either changes in technology or changes in the structure of the economy.

Decomposition analysis has also been used to analyse future model-based energy scenarios, including analyses from the IEA (Ang and Liu, 2007a; IEA, 2004, 2012) and the assessments prepared for use by the IPCC[2] (Hanaoka et al., 2006, 2009; Nakicenovic et al., 1998). Moreover, Riahi et al. (2007) project the evolution of global energy intensity of GDP and carbon intensity of energy until 2100; Agnolucci et al. (2009) decompose future energy scenarios for the UK; Kesicki and Anandarajah (2011) decompose global and regional future energy-emissions scenarios using the Times Integrated assessment model; and Fisher-Vanden et al. (2012) apply a new decomposition technique to the results of a multi-region, multi-sector CGE model. While all these studies are based on a single model, more recently, the decomposition analyses have been focused on the comparison of the results from different models to determine robust patterns across them. For instance, Bellevrat (2012) analyses the Chinese future energy and carbon emissions scenarios using results from different models; Blanford et al. (2012) developed a decomposition analysis of baseline scenarios for Asia comparing different models; Förster et al. (2013), as part of the EMF-28, and Capros et al. (2014), as part of AMPERE, developed multi-model decomposition analyses of alternative European climate policy scenarios by 2050; and van Sluisveld et al. (2013) present a multi-model decomposition analysis of the emissions in five major economies using the Kaya identity in the period 2020–2050.

[2] Intergovernmental Panel on Climate Change.

Following the approach used in Bellevrat (2012) and Förster et al. (2013), in this paper we develop the first multi-model decomposition analysis of short- and long-term regional carbon emissions, which allows the analysis of differences and synergies in regional decarbonization strategies. We analyse four major economies, including both developed (USA, EU-27) and developing regions (China, India), all of which are projected to play a critical role in global climate policies in the long term. The analysis compares the results of a subset scenarios from ten well-established global energy-economy integrated assessment models (IAMs) that participated in the AMPERE project. The analysis focuses on the regional energy system transformations required to mitigate energy-related CO_2 emissions[3] including reductions in energy intensity of GDP and carbon intensity of final energy. This paper contributes to the literature by means of: (1) the decomposition of near-past historical carbon emissions and near-term modelling projections as an alternative to validate baseline scenarios; (2) the identification of regional decarbonization strategies to achieve moderate and stringent climate change mitigation objectives; and (3) determining the main assumptions and model characteristics that drive significant deviation from the average results in the carbon decomposition analyses.

First, integrated assessment modelling of climate change aims to analyse the behaviour of the future energy-economy-climate system by evaluating alternative scenarios of the system's future development. IAMs commonly use a (no climate policy) baseline scenario that provides the benchmark for the evaluation of the impacts of alternative climate policies on the evolution of the energy system and economic development. We propose the comparison of the decomposition of the historical carbon emissions of the period 1990–2010 with the near-term model results to validate the assumptions of the baseline scenario.

Second, we study a scenario with moderate climate change mitigation policies, where the impacts of regional pledges from the Copenhagen COP are analysed. This moderate climate policy scenario aims to conceptualize the current regionally fragmented climate policies providing important insights to the climate policy discussion concerning the required regional changes in energy efficiency and carbon intensity of energy to achieve the Copenhagen–Cancun pledges. Moreover, we analyse a strong mitigation scenario that results in negative carbon emissions by the end of the century. We present an LMDI decomposition analysis of the changes in emissions in this case compared to the moderate policy scenario to identify the additional efforts needed to realize a stringent mitigation target by 2100 and especially the important role of negative carbon emissions in the second half of the century.

Furthermore, the third contribution of the paper is the identification of the assumptions and model characteristics that lead to different decomposition results in both the moderate and the stringent climate policy scenarios.

The rest of the paper is organized as follows: in the next section we describe the integrated assessments models used in the multi-model decomposition analysis, the analysed scenarios and the decomposition methodologies used in the paper; in Section 3 we present the index decomposition analyses of both the no-policy baseline and the moderate reference policy scenario; Section 4 discusses the regional LMDI decomposition analysis in the case with a global ambitious climate change mitigation target; and finally we discuss the main conclusions and policy implications of the analysis.

2. Methodology

In this paper, we develop a multi-model decomposition analysis of CO_2 emissions to determine the main regional energy system

[3] The IAMs use in this paper have different sectoral resolution, from a very aggregate economy in the optimal growth models (1–3 sectors) to a detailed sectoral disaggregation (up to 23 sectors) in the computable general equilibrium models. Therefore, we focus on the analysis of energy-related CO_2 emissions at the aggregate level of economy.