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Factoring in the forgotten role of renewables in CO_2 emission trends using decomposition analysis

Kristina Mohlin[a,*], Jonathan R. Camuzeaux[a], Adrian Muller[b], Marius Schneider[c], Gernot Wagner[d]

[a] Environmental Defense Fund (EDF), 257 Park Avenue South, New York, NY 10010, USA
[b] Department of Environmental Systems Science, Institute for Environmental Decisions IED, Swiss Federal Institute of Technology Zurich (ETHZ), SOL F 7, Sonneggstrasse 33, 8092 Zurich, Switzerland
[c] South Pole, Technoparkstrasse 1, 8005 Zurich, Switzerland
[d] Harvard University Center for the Environment, 26 Oxford Street, Cambridge, MA 02138, USA

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ABSTRACT

This paper introduces an approach for separately quantifying the contributions from renewables in decomposition analysis. So far, decomposition analyses of the drivers of national CO_2 emissions have typically considered the combined energy mix as an explanatory factor without an explicit consideration or separation of renewables. As the cost of renewables continues to decrease, it becomes increasingly relevant to track their role in CO_2 emission trends. Index decomposition analysis, in particular, provides a simple approach for doing so using publicly available data. We look to the U.S. as a case study, highlighting differences with the more detailed but also more complex structural decomposition analysis. Between 2007 and 2013, U.S. CO_2 emissions decreased by around 10%—a decline not seen since the oil crisis of 1979. Prior analyses have identified the shale gas boom and the economic recession as the main explanatory factors. However, by decomposing the fuel mix effect, we conclude that renewables played an equally important role as natural gas in reducing CO_2 emissions between 2007 and 2013: renewables decreased total emissions by 2.3–3.3%, roughly matching the 2.5–3.6% contribution from the shift to natural gas, compared with 0.6–1.5% for nuclear energy.

1. Introduction

Over the period of 1990–2007, U.S. energy-related CO_2 emissions showed an increasing trend and were projected to continue increasing (EIA, 2007). In 2007, however, emissions instead took a sharp turn downwards and by 2013, annual CO_2 emissions had decreased by 10% (600 million tonnes). Over the same period, renewable energy increased significantly. Most of the expansion in renewables came from wind energy, which increased from 0.360 terajoules (TJ) to 1.69 TJ over the period. There was also an increase of roughly equal magnitude in bioenergy from 3.68 TJ to 4.93 TJ. The increase in solar energy was modest in absolute terms (from 0.064 TJ to 0.45 TJ), though significant in relative terms, with close to a sevenfold increase in seven years (EIA, 2016). This increase in renewable energy was matched by a similarly unprecedented decline in costs (Wagner et al., 2015). Observing such trends, we want to be able to answer the question: what was the contribution from renewables to U.S. CO_2 emissions reductions?

Decomposition analysis provides a method for addressing that question. As Wang et al.'s (2017) review shows, index decomposition analysis (IDA) and structural decomposition analysis (SDA) are techniques that have been extensively used by researchers to analyze drivers of changes in energy-related emissions for energy and climate policy assessment. IDA in particular has proven useful for tracking improvements in economy-wide energy efficiency: as noted by Wang et al. (2017), the activity intensity effect, which captures changes in energy efficiency as part of the IDA, is used by energy agencies in numerous countries, including the U.S., Canada, Australia, New Zealand, and Europe (Belzer, 2014; OEE, 2013; Stanwix et al., 2015; Elliot et al., 2016; ODYSSEE, 2015). Similarly, we here demonstrate how IDA can be used to track the role of renewables in CO_2 emission trends by separately quantifying the impacts of renewables, nuclear energy, and natural gas.

We complement our IDA with an SDA for the same period. By doing so, we can compare differences between these two methods. We assess, in particular, whether it is legitimate to use the much simpler IDA to address the question of renewables' contribution or whether the complex SDA is needed. We find that IDA is adequate to address this question.

* Corresponding author.
E-mail addresses: kmohlin@edf.org (K. Mohlin), jcamuzeaux@edf.org (J.R. Camuzeaux), amueller@env.ethz.ch (A. Muller), m.schneider@southpole.com (M. Schneider), gwagner@fas.harvard.edu (G. Wagner).

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Furthermore, applying both IDA and SDA to the same case study provides new insights on the drivers behind recent U.S. CO_2 emission reductions with potentially important implications for policy. Specifically, it reveals problematic aspects with the data used in a recent SDA by Feng et al. (2015), which lead to questionable conclusions. Feng et al. (2015) quantified the contributions from the economic recession and changes in the fuel mix and found, consistent with Nelson et al. (2015), that the largest decrease in emissions over the period 2007–2013 was due to decreased consumption during the recession of 2007–2009, with changes in the fuel mix playing a comparatively smaller role. However, by only focusing on changes in the total fuel mix, Feng et al. (2015) could not separately quantify the impact of renewables and natural gas. In a response to Feng et al. (2015), Kotchen and Mansur (2016) also suggested that Feng et al. understated the impact of natural gas and that the shale gas boom alone had reduced total U.S. CO_2 emission by 2.1–4.3% between 2007 and 2013. This range for the contribution from natural gas, however, is wide, and neither of these previous analyses specifically considered the impact of renewables.[1]

By separately quantifying the impacts of renewables, nuclear energy, and natural gas, we find that changes in the composition of U.S. energy supply contributed 6.3% (SDA) to 7.5% (IDA) of the total emissions reduction of 10% between 2007 and 2013, out of which natural gas contributed 2.5% (SDA) to 3.6% (IDA) and renewables 2.3% (SDA) to 3.3% (IDA). These results are within the range for natural gas suggested by previous analyses such as Kotchen and Mansur (2016) but, unlike those prior analyses, also show that renewables have been as important as natural gas in reducing U.S. CO_2 emissions.

2. Using IDA and SDA to analyze the role of renewables in CO2 emission trends

As explained by Wang et al. (2017), results given by decomposition analyses can help researchers and policy makers understand the driving forces behind changes in energy use or emissions. The rationale of decomposition analysis is to decompose the change in a variable of interest, such as total CO_2 emissions, into a sum of changes in each of a number of key driver variables (such as total energy use, the share of renewables, and the composition of fossil fuel energy use). The approach is based on defining an identity where the variable of interest equals the product of all the driver variables. The different methods of decomposition analysis offer different approaches on how to decompose an overall change in this multiplication into a sum of changes in each driver variable. Formally, this is achieved by taking the derivative over time of the variable of interest and applying the product rule, thus resulting in the sum of the derivatives over time of the driver variables. The decomposition methods then offer different approaches on how to go from infinitesimal changes (derivatives) to changes between time periods such as years or longer periods, depending on data availability (cf. Löfgren and Muller, 2010; Muller, 2007). The effects identified in an IDA make it possible to draw conclusions regarding the impacts of improved energy efficiency (activity intensity effect), adjusting economy structure (structure effect) and decarbonizing energy mix (energy mix effect). The energy mix however is commonly introduced as one of the explanatory factors without an explicit consideration or separation of renewables and nuclear energy, as with the analyses done by Feng et al. (2015) and Steenhof and Weber (2011). However, with the rise of renewables and their expected continued cost decreases, it will become increasingly important to analyze the role of renewables in CO_2 emission trends. We here introduce an example for how to do so in both IDA and SDA. In particular, we decompose the changes in the energy mix into three components: changes in the energy supply from renewables, nuclear energy, and changes in the fossil fuel mix. This allows us to quantify what the rise of renewables and the recent sharp decrease in their costs have meant for U.S. CO_2 emissions, and also to separately quantify the contribution from changes in the fossil fuel mix triggered by the shale gas boom and lower natural gas prices.

We present results using both IDA and SDA and note just like Wang et al. (2017) and Hoekstra and van den Bergh (2003) that IDA offers insights on the impacts of energy composition, economic structure and economic output, while SDA sheds light on the effects of production technology and consumption patterns. The main advantage of SDA lies in a detailed coverage of a number of technological and final demand effects related to the sectoral structure and between-sector exchange as captured in input-output tables. These aspects are however not relevant for the identification of the role of renewables in IDA, as they do not specifically affect different energy types (IEA, 2016a). The main reason we also perform an SDA is to be able to compare our results to the SDA performed by Feng et al. (2015) which highlights some methodological pitfalls to consider when assessing the impacts of changes in the energy mix using SDA.

3. Data and methods

We here present the data used and the formulas for separating the renewables, nuclear and fossil fuels effects in IDA and SDA.

3.1. Data

In the IDA, we utilize energy statistics from the U.S. Energy Information Administration's (EIA) Monthly Energy Review for the residential, commercial, industrial, transportation and power sectors on CO_2 emissions (Tables 12.2–12.6, respectively), on primary energy use (Tables 2.2–2.6, respectively), and on net electricity generation from the power sector (Table 7.2b) (EIA, 2015). We use the coal, natural gas, petroleum, and renewable energy (for the transportation sector equivalent to biomass energy) categories as defined by the EIA. Detailed information about data definitions and sources can be found for the primary energy data in EIA (2017a), for the CO_2 emissions data in EIA (2017b), for the power sector net generation data in EIA (2017c), and for renewable energy data in EIA (2017d).

The SDA is instead based on energy accounts created to match with an input-output table for national accounts. The basis for the Input-Output tables are the Make and Use tables by the Bureau of Economic Analysis (BEA) (2016a, 2016b). We adjusted the obtained Input-Output tables from current prices to constant prices (base year 2009) using the Chain-Type Price Indexes for Gross Output by Industry, developed by the Bureau of Economic Analysis (BEA) (2016c). For the compilation of energy use data, we followed the technical report on the compilation of the World Input-Output Database (WIOD) environmental data by Genty et al. (2012), whenever it was applicable. The authors of this report demonstrate how to get from energy balances to energy accounts that correspond to the national accounting framework based on the extended world energy balances provided by the International Energy Agency (IEA) (2016b). Schneider (2016) provides a detailed explanation of this data compilation process for the SDA. The corresponding CO_2 emissions data was taken from IEA (2016a).

Due to the different data used, there are differences in the total U.S. CO_2 emission estimates used for the IDA and the SDA. The reason is that the energy statistics used for the IDA follow the territorial principle, meaning that all energy use and emissions that take place in a certain territory (e.g., a country) are accounted for, irrespective of the legal status of the emitting unit as a resident or not. In contrast, the national accounts used for the SDA follow the residence principle, i.e., all energy use and emissions by a resident of the country are included, whether they are taking place within or outside this territory (Genty et al., 2012). Important differences between the national accounts and the

[1] A previous version of this paper was shared with Feng et al. in September 2015. In their reply to Kotchen and Mansur (2016), Feng et al. (2016) subsequently made brief reference to the role of renewables.