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Quantifying CO_2 emission reductions from renewables and nuclear energy – Some paradoxes

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ABSTRACT

As countries seek to adopt cleaner energy sources, a key question that is often asked is what the avoided emissions from the switch to non-fossil based energy sources are. There is no standard approach to tackle this problem. The most common approach, which is known as the primary energy equivalent (PEE) approach, estimates emission reductions by computing the amount of CO_2 emissions that would have been emitted from fossil fuels had renewables or nuclear energy not been used. Another approach, the Equal Share (ES) approach, estimates emission reductions based on the change in the share of non-fossil based energy. As the two approaches have some limitations, a more comprehensive approach based on index decomposition analysis (IDA) is proposed as an alternative, together with an extension to quantify substitution amongst non-fossil based sources. A comparison of the assumptions and features of all three approaches is presented. The study finds that IDA is favoured for its ability to identify policy intervention areas beyond a switch to cleaner energy and is well-suited for tracking of progress towards emission reduction targets and analysing future scenarios.

1. Introduction

Emission reductions are a common type of performance indicator used to track the success of climate mitigation efforts. Countries seek to measure emission reductions to assess performance towards climate mitigation targets and success of energy policies. Since the Paris Agreement entered into force in 2016, there has been greater impetus to estimate emission reductions. Many countries have quantified their contributions to global climate mitigation efforts, more formally known as nationally determined contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC), in terms of greenhouse gas (GHG) emission reductions.[1]

CO_2 emissions from energy consumption make up a large share of total GHG emissions. Improvements to the energy system can alter CO_2 emission levels and lead to emission reductions. The ability to separate the effects of different changes to the energy system, such as improvements to energy efficiency and a switch to cleaner energy sources, provides governments with more information on the drivers of change in emissions.

Improving energy efficiency and switching to cleaner energy sources are two key options for climate mitigation. In this study, the focus is on quantifying emission reductions from the latter option. This is because the quantification of emission reductions from energy efficiency improvements can be easily extended from a more well-established concept of energy savings (Ang et al., 2010; IEA, 2015). However, a direct extension to the estimation of emission reductions from a switch to non-fossil based energy sources (i.e. renewables and nuclear energy) is not possible.

Most countries compute emission reductions from non-fossil based energy sources as the emissions that would have been emitted had fossil fuels been used to generate the same amount of electricity. For example, an additional 1 TWh of renewable energy output will result in emission savings equivalent to 0.7 million tonnes of CO_2 ($MtCO_2$) if the emission intensity of fossil generation is 700 gCO_2/kWh.[2] The focus so far is the electricity generation sector and the commonly used approach is known as the primary energy equivalent (PEE) approach (Clancy et al., 2015). The approach is simple and intuitive but encounters some problems in two situations - when energy demand decreases over time and in countries with low fossil fuel shares in the energy mix.

Although most countries may not have encountered these situations

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[1] For example, the European Union pledged to reduce GHG emissions by at least 40% below 1990 levels by 2030, while Indonesia pledged to reduce GHG emissions by 26% below BAU levels by 2020.

[2] The emission intensity of fossil generation of 700 gCO_2/kWh is approximately the current global average.

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to date, in the future, countries are more likely to experience changes in their energy systems that will result in a decreasing energy demand and low fossil share. In the short term, this will be driven by energy efficiency improvements while in the long term, decarbonisation will drive this change, especially in the electricity sector (Förster et al., 2013; IEA, 2014). Studies have acknowledged the need for deep decarbonisation if the world is to maintain a temperature increase below 2 °C according to the Paris Agreement (DDPP, 2015; IEA, 2014). By 2050, the world should collectively achieve emission reductions from 41% to 72% below 2010 levels in order to achieve the 2 °C target (IPCC, 2014). Energy efficiency improvements alone will be insufficient to achieve this and countries have to embark on deep decarbonisation pathways that include a switch to cleaner energy and greater use of electricity in end-use sectors (Bataille et al., 2016a). Drastic changes in energy systems, especially electricity generation, to facilitate the rapid adoption of cleaner energy sources such as renewables and nuclear power will be necessary.

As the energy systems of countries transform and move away from traditional fossil-fuel based systems, a more universal approach, independent of the type of energy system, is needed to quantify emission reductions. The Equal Share (ES) approach is a more universal approach that estimates emission reductions based on the change in the share of non-fossil based energy in the electricity mix. However, while it can handle energy systems with decreasing energy demand and low fossil fuel shares, it also has its limitations – it is biased towards the target year and is not ideal for the tracking of progress towards national emission reduction targets. As the ES approach cannot quantify emission reductions from other climate mitigation actions such as improvements to energy efficiency and changes in the fuel mix, it is also not ideal for analysing future emission scenarios which incorporate many different mitigation measures to achieve deep decarbonisation.

Index decomposition analysis (IDA)[3] is proposed as an alternative approach that overcomes the problems faced by the PEE and ES approaches. It can be obtained via a simple extension of the ES approach. As the three approaches present different pictures of progress, affect future targets set and impact policy options, this study seeks to compare them by dissecting their underlying assumptions, premises and features so that policymakers can be better informed when deciding on the approach to use. Implications for performance tracking and target setting are also examined.

This study begins with a description and comparison of the traditional PEE and ES approaches in Section 2. Next, in Section 3, in response to the limitations of the PEE and ES approaches, IDA is introduced as a more comprehensive alternative approach. A new technique to attribute emission reductions to various non-fossil based energy sources via IDA so as to quantify the substitution across energy sources is also proposed. A comparison across all three approaches is presented in Section 4 and illustrated via a case study of Canada. Lastly, the policy implications of the choice of approach are discussed in Section 5. The study focuses on the electricity generation sector, although the concept and proposed procedures are applicable to other sectors of the energy system.

2. Approaches

Non-fossil based energy sources, namely renewables and nuclear energy, do not produce CO_2 emissions. The introduction of these energy sources into the electricity mix can help a country to achieve its emission reduction targets while meeting electricity demand. However, the question is, how much CO_2 emissions were avoided? If electricity demand remains constant, then the introduction of non-fossil based energy has to displace fossil fuels. In this case, the CO_2 emissions avoided are the emissions originally arising from fossil fuels. However, a constant electricity demand is rare. Renewables and nuclear power can also be used to fulfil new electricity demand. In this case, what are the emission reductions achieved?

In fact, most of the time an exact value cannot be placed on emission reductions arising from non-fossil based energy sources. These avoided emissions are hypothetical and there are a variety of ways to estimate them. The quantification of emission reductions provides an estimate of what the emission level would have been had the switch to a cleaner energy source not taken place. A concrete value is assigned to the change, making the impact of the change visible.

2.1. Primary energy equivalent approach

The most straightforward and commonly used approach to quantify emission reductions from a switch to non-fossil based energy sources is by computing the emission reductions based on the amount of electricity generated from newly installed capacity. This electricity from newly installed renewable or nuclear plants is multiplied by the emissions arising from fossil fuels that would have been required to generate the same amount of electricity. Clancy et al. (2015) term this the primary energy equivalent (PEE) approach.

In the PEE approach, assume that a country installs a new hydroelectric power plant that generated 1 TWh of electricity in the year of interest (i.e. target year T). To obtain the emission reductions due to this installation, -1 TWh is multiplied by the electricity emission factor had the electricity been produced only from fossil fuels in the country in that year (target year) to obtain the emission reductions achieved $\Delta C_{p(PEE)}$, i.e.

$$\Delta C_{p(PEE)} = I^T (R^0 - R^T) \tag{1}$$

where I^T denotes the electricity intensity of fossil generation in the target year T, while R^0 and R^T represent the non-fossil based electricity produced in the base year 0 and target year T respectively in kWh.[4] Under normal circumstances, we expect R^T to be greater than R^0, i.e. an increase in non-fossil based generation over time. The term $(R^0 - R^T)$ in Eq. (1) is then the corresponding reduction in fossil fuel based electricity generation in year T as compared to year *0*.

As an example, assume an emission intensity of fossil generation in the target year of 700 gCO_2/kWh. An increase in the non-fossil based electricity produced from 3 TWh in the base year to 5 TWh in the target year gives an emission change of -1.40 $MtCO_2$ in the target year.[5] These avoided emissions are then added to the emissions in the target year to obtain the business-as-usual (BAU) emission level as shown in Fig. 1.

The PEE approach is based on the premise that a country will naturally be more inclined to use fossil fuels, or has a predominantly fossil fuel based economy, as has been the case in the past 100 years or so. Hence, any new renewable energy installation results in “avoided emissions”, CO_2 emissions that would have been emitted had fossil fuels been used.[6] The European Environment Agency (2015) uses this method and considers additional use of renewable energy as “avoided fossil fuel use”. The fossil fuels avoided are analysed by sector and therefore the exact emission intensities used differs across sectors. For

[3] IDA is a decomposition technique that has been used by countries to decompose changes in CO_2 emissions. See, for example, Xu and Ang (2013).

[4] The emission intensity of fossil generation I^T is generally a weighted value and is dependent on the fossil generation mix and the emission factors of individual fossil fuels used in year T in the country.

[5] A negative sign in emission change denotes emission reductions.

[6] The PEE approach is consistent with the commonly used approach in energy supply accounting to measure the primary energy supply equivalent of nuclear energy and/or renewable energy in electricity production in energy statistical publications (e.g. BP and IEA energy balance), where the primary energy supply equivalent is computed by dividing the electricity generated by a conversion factor representing the average thermal efficiency of fossil generation.