BENCHMARKING CARBON SAVINGS AND ECONOMIC EFFECTIVENESS OF RENEWABLE ENERGY SOURCES: A METHODOLOGICAL COMPARATIVE STUDY

Saeed Alokkah, Imperial College Business School, +44(0)7472404259, saeed.alokkah12@imperial.ac.uk(1)

Overview

The expansion of renewable energy technologies is believed to be one of the key components of climate change mitigation strategies (IEA, 2015). In recent years, amid climate change concerns, the number of studies addressing the carbon emission savings attributable to expanding the use of renewables has substantially increased. More recently, literature has emerged that offers cautionary insights about overestimating or potentially underestimating the carbon reduction contributions of renewables and their role in achieving the deep decarbonisation of electric system (Hart and Jacobson, 2011, Strbac et al., 2015, Thomson et al., 2017). While much of the focus has been devoted to quantifying and projecting the renewable carbon emission savings, far too little attention has been dedicated to measuring and tracking the cost-effectiveness of the renewable decarbonisation process. This might partly be attributed to the lack of a generally accepted framework to measure and report the cost-effectiveness of the renewable decarbonisation process.

This paper proposes a new theoretical framework to measure and benchmark the cost-effectiveness of decarbonising electric systems using renewables. In addition, it presents a comparative study to demonstrate to what extent methodological variations across decarbonisation studies can affect the relative competitiveness of renewables to decarbonise energy systems.

The new framework is generic, technology-neutral, and enables consolidation of the economic results of decarbonisation studies that consider various renewable technologies. Equally, it allows the compilation of results from studies that use different modeling methodologies, assumptions, and data sets. It also enables measuring and tracking the cost-effectiveness of the renewable decarbonisation process at a country or a system level by directly linking the changes in the system's total cost with respect to the carbon reduction savings attributable to renewables. As a result, it also allows the direct comparison of the economic implications of different decarbonisation scenarios and various policy proposals in a very intuitive graphical way.

Framework Graphical Illustration

For demonstration purposes, we firstly introduce the framework using deep decarbonisation simulations for different renewable energy technologies as shown in Figure 1. We refer to each individual curve shown in the framework as the "carbon economic effectiveness curve". These curves clearly demonstrate the increasing difficulty of maintaining marginal carbon savings with increased renewable penetration. The pace of saving carbon emissions tends to be highest at relatively low renewable penetration rates and it tends to fall considerably afterwards. This explains the exponential pace of production cost escalation at relatively high penetration rates. This might be attributed to the increased incidence of curtailment and the inability of renewable generation to achieve more capacity savings at the system level.

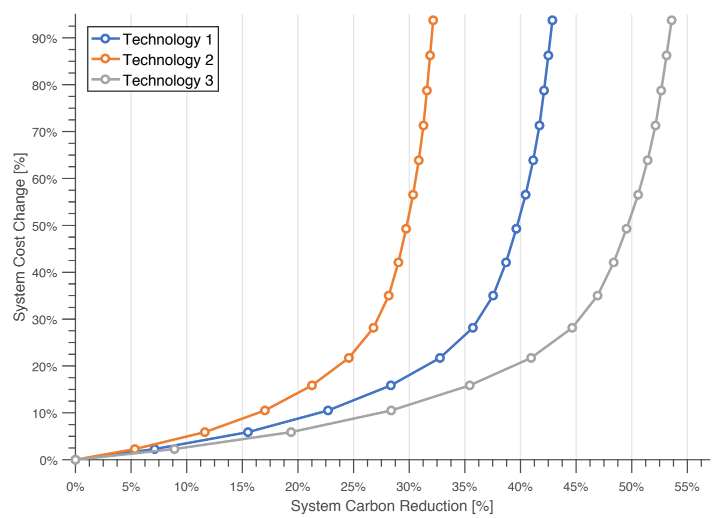

Figure 1: Proposed framework

As shown in Figure 1, the new framework gives a very handy tool to graphically estimate the economic implications of different policies scenarios. For instance, it could be estimated that Technology 3 has the edge compared to the other technologies in terms of its deep decarbonisation potential which could reach as high as 53%. On the other hand, it could be estimated that with a 50% increase in total system's cost, Technology 1, 2, and 3 can deliver about 30%, 40%, and 50% system decarbonisation respectively.

Method

Using historical load profiles, high-resolution solar radiation data, and long-term meteorological data for a Gulf country, we investigate deep decarbonisation of the electric system through the large-scale deployment of solar technologies. For consistency and demonstration purposes, we adopt a greenfield modeling approach for the system under study to help easily identify the underlying pattern and the scale of the methodological bias that might exist in the results. We compare the results of two well-established optimisation methodologies that have been used extensively in the literature to study decarbonisation of power systems:

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the screening curve (SC) method and the unit commitment (UC) method. Each modeling methodology requires building a bottom-up, techno-economic model intended to minimise the operation and investment costs of the electric system under study. We report the results of the research in a comparative analysis fashion to facilitate the dissemination of the research findings using the developed framework.

Results

The results suggest that the choice of the modeling methodology considerably influences the perceived economic effectiveness of the renewable decarbonisation process.

As shown in Figure 2, running a deep decarbonisation scenario using the Concentrated Solar Power (CSP) technology, we found that the SC approach systemically underestimates the carbon savings by up to 29% when compared to the carbon emissions savings obtained from the UC-based model under higher penetration scenarios. The underlying tendency of the SC method to favour cheap and carbon-intensive technologies (e.g., coal-fired plants) over cleaner, more expensive, yet more flexible generation technologies (e.g., OCGT and CCGT) can explain this. This could be attributed to the inability of the SC method to consider the flexibility requirement needed to accommodate the added renewable generation which, if considered, would make the more flexible, clean, and relatively expensive units the most cost-effective option for running the system rate.

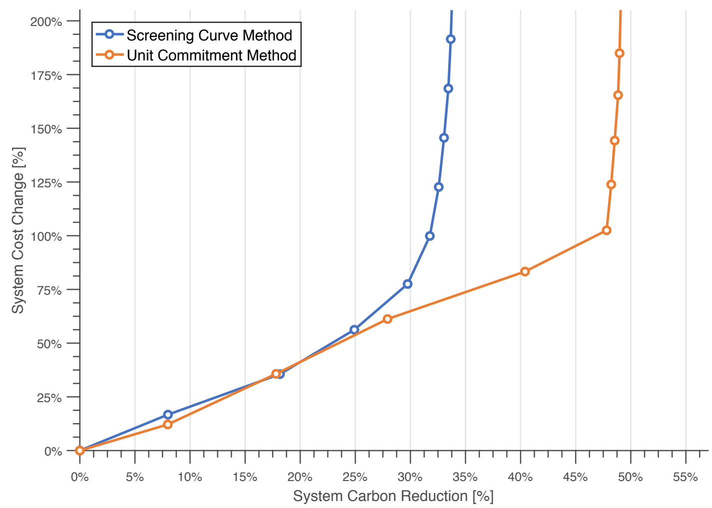

Figure 2: Carbon economic effectiveness curves of CSP technology using SC and UC modeling methodologies

In summary, we find that SC might systemically underestimate the decarbonisation potential of deep decarbonisation studies. We also find that the precision of estimating the system's total carbon emission has the greatest influence in accurately estimating the economic effectiveness of the decarbonisation process and hence the implied carbon abatement cost of renewables.

Conclusions

We present a new theoretical framework to measure and benchmark the cost-effectiveness of decarbonising electric systems using renewables. Due to its generic nature, one might use it to examine how sensitive the economics of the decarbonisation process is to variations of countless economic, technical, and methodological factors. Our framework helps evaluate the scale and the magnitude of the sensitivity levels to these variations.

In terms of our methodological comparative study, we find that SC might systemically underestimate the decarbonisation potential of deep decarbonisation studies. We also find that the precision of estimating the system's total carbon emission has the greatest influence in accurately estimating the economic effectiveness of the decarbonisation process and hence the implied carbon abatement cost of renewables. However, we find that the economics of the decarbonisation process hinges predominantly on the accuracy of the carbon emission saving estimates. Therefore, for policy evaluation purposes, we recommend policymakers to carefully consider the effect of modeling methodology bias in their analyses. We believe this would be of particular relevance and importance for climate change policy evaluation purposes. Ignoring this might lead to inaccurate estimates about the true cost of decarbonisation. Furthermore, it might lead to sub-optimal investment and policy design decisions. As the carbon saving potential of renewables is frequently cited as one of the primary drivers to expand their use and justify their capital-intensive investments and subsidies, there is a real need to ensure that renewables are capable of delivering the hoped carbon savings in a technically-efficient and cost-effective manner.

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