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Bridging the gap: Do fast-reacting fossil technologies facilitate renewable energy diffusion?☆

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ABSTRACT

The diffusion of renewable energy in the power system implies high supply variability. Lacking economically viable storage options, renewable energy integration is possible thanks to the presence of modern mid-merit fossil-based technologies, which act as back-up capacity. This paper discusses the role of modern fossil-based power generation technologies in supporting renewable energy investments. We study the deployment of these two technologies conditional on all other drivers in 26 OECD countries between 1990 and 2013. We show that moving from the first to the third quartile of the distribution of modern fossil technologies is associated with an increase in yearly renewable energy investment of between 6 and 14 kW per thousand people, on average and ceteris paribus. This is a sizeable effect, considering that average yearly renewable capacity addition in our sample are around 12 kW per thousand people. These findings are robust to different econometric specifications, various definitions of modern fossil technologies and are stronger for wind, which is more intermittent and for which the mismatch between supply and demand is more marked. Our analysis points to the substantial indirect costs of renewable energy integration and highlights the complementarity of investments in different generation technologies for a successful decarbonization process.

1. Introduction

Electricity generation is one of the key sectors for decarbonization. In 2014, electricity production satisfied 18% of final energy demand, but contributed to more than 40% of energy-related CO_2 emissions. Indeed, the IEA estimates that this sector alone could contribute to more than two thirds the energy-related emission reductions in a "Two Degree Scenario", mostly through the deployment of renewable technologies (IEA, 2017).[1] One of the major barriers to the large scale deployment of the most renewables is that they are variable and non dispatchable, with peaks in generation not fully coinciding with peaks in demand.[2]

Historically, the variability of renewable generation has been accommodated within the energy system by relying on fossil-based technologies as back-up capacity, since cheap, large-scale storage options do not currently exist (see discussion in Section 3). Importantly, there are different categories of fossil-based technologies. Traditional fossil generation, which comprises coal-based and low efficiency generation technologies, cannot easily compensate for renewable variability due to slow reacting times, high capital costs and little modularity (meaning that the efficiency of smaller units is significantly lower than that of larger units). Modern fossil technologies, which include most gas generation technologies, Combined Heat and Power and Integrated Gasification Combined Cycle to name a few, are characterized by mid-

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[1] Generally speaking, renewable energy technologies include hydro, wind, solar, geothermal, ocean and wave technologies and biomass. See Section 4.1 for the specific definition of renewable energy technologies in the context of our analysis.

[2] Additional important barriers to the large scale deployment of renewable energy sources are that (1) renewables are not yet fully cost-competitive with fossil-based power generation, even though they recently witnessed significant decreases in costs and that (2) the energy sector is sticky and modifying the paradigm of electricity production implies multiple challenges: the need to upgrade infrastructure (i.e. the electricity grid) and the considerable sunk costs in existing, less efficient and more polluting power plants.

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merit order,[3] quick(er) ramp-up times, lower capital costs and modularity. These latter technologies are particularly suitable to meet peak demand and mitigate the variability of renewables.

We contribute to the debate on the determinants of renewable generation capacity by extending the analysis of Popp et al. (2011) and discussing the role of traditional and modern fossil-based technologies as back-up capacity to compensate renewable energy variability. We focus on a sample of 26 OECD countries, which account for the majority of renewable capacity additions between 1990 and 2013.

Controlling for country-level fixed effects and a host of factors affecting renewable energy investments, we show that the deployment of renewable energy sources did not decouple from that of fossil-based technologies in our sample, and specifically from a modern sub-set of these technologies using gas as primary input. Moving from the first to the third quartile of the distribution of modern fossil technologies capacity is associated with an increase in yearly renewable energy investments of roughly 6–14 kW per thousand people, on average and ceteris paribus. This is a sizeable effect, given that the average yearly renewable capacity addition in our sample is just below 12 kW per thousand people. These findings are robust to different econometric specifications, and two definitions of modern fossil technologies. Moreover, they are stronger for wind, which is more intermittent and for which the mismatch between supply and demand is more marked.

Our contribution suggests that overlooking the complementarity between renewable and modern fossil technologies leads to an underestimation of the costs of the energy transition. Given the large uncertainty regarding the availability of cost-competitive storage options in the immediate future, increasing the penetration of renewable energy as implied by global targets will most likely result in significantly higher system costs because it will require a parallel expansion of back-up resources, which are capital-intensive and will be largely underutilized. This gives rise to important policy implications related to (1) the need to account for such complementarity when making investment decisions; (2) the fact that system costs of renewables may be underestimated, especially as renewable penetration increase and (3) that investment in other non-fossil back-up technologies (i.e. storage) is a crucial component of the effort to decarbonize the energy system.

The rest of the paper is organized as follows. Section 2 discusses the related literature and highlights our contribution to the debate, while Section 3 details some of the challenges of the integration of renewable energy generation in the power system. Section 4 presents our data sources, the definition of our variables and provides descriptive statistics. Section 5 details the empirical strategy. Section 6 presents our results and quantifies them. Section 7 concludes with a discussion of the policy implications of our analysis.

2. Related literature

This paper focuses on the relationship between renewable energy generation and the presence of fossil-based back-up capacity. The core of the paper is devoted to the empirical investigation of whether the successful integration of renewable was possible partly due to the availability of modern, fast reacting fossil-based units. This topic has received little attention in the literature on the development and diffusion of renewable energy technologies.

A first set of contributions focuses on the role of energy and environmental policies in promoting renewable investment and deployment, which is proxied using information on installed capacity. Shrimali and Jenner (2013) explore the impact of different policy instruments on solar photovoltaics (PV) development in the US commercial and residential sectors over the years 1998–2009, but their analysis does not touch upon the possible role of other generation technologies. Jenner et al. (2013) extend the analysis to the EU and show that solar PV deployment has been driven by feed-in tariffs (FITs). They partially recognize the role of other generation technologies in affecting renewable investments (i.e. yearly capacity additions) by conditioning their empirical analysis on the share of power generation from traditional energy sources (nuclear, coal and gas), but they do not distinguish between the roles of different fossil-based technologies (modern vs. traditional) nor do they discuss the implication of their findings in this respect. Popp et al. (2011) show that technological improvements have a small positive impact on investments in renewable generation in OECD countries, but find that the effect of renewable energy policies is often not significant. Also in this case, the empirical analysis does not account for the possible complementarity between investments in renewable energy and (modern) fossil generation technologies. Generally speaking, the role of fossil-based generation is overlooked in these studies under the implicit assumption of high substitutability between clean and dirty technologies. This assumption is shared by the theoretical contributions on directed technical change, which assume a relatively high degree of substitutability between the two technologies (Acemoglu et al., 2012). We contribute to this strand of literature by providing the first macro-level empirical analysis of the diffusion of renewable generation while accounting for the interaction with investments in other generation capacity, and specifically modern and traditional fossil.

A second set of analyses uses data on power production (rather than capacity) as a proxy for renewable energy deployment. Aguirre and Ibikunle (2014) investigate the drivers of country-level renewable growth in a broad sample of countries, including Brazil, Russia, India, China and South Africa. They show that coal, oil and gas contribution to electricity generation is negatively associated with renewable growth (see also Pfeiffer and Mulder, 2013). Narbel (2013) finds that fossil-fuel reserves (proxied by the quantity of electricity generated per capita from domestic fossil fuel reserves) are a barrier to the diffusion of renewable technologies in a sample of 107 countries over the years 2007–2009. Overall, these contributions seem to suggest that renewable and fossil electricity generation technologies are substitutes. However, this conclusion is reached by focusing on electricity generation rather than on the amount of installed capacity. This is a relevant distinction, because, as argued in Jenner et al. (2013) "generation determines the actual return on investment while capacity reflects the expected return on investment." Moreover, for a given unobservable distribution of capacities in different technologies, it is purely mechanical to observe a negative correlation between the share of renewable and fossil electricity generation, as demand is met with either one or the other input. However, it may be indeed the case that to support a given level of renewable energy generation, a country needs to install back-up capacity in other (fossil) technologies on top of the capacity installed in renewable generation. This is due to the high variability of the most promising renewable energy sources (see discussion in the next Section). By choosing to focus on the amount of electricity produced one cannot provide any insights on the sunk costs associated with back-up capacity.[4] Our analysis contributes to this strand of literature by exploring the relationship between renewable and fossil generation technologies using capacity rather than production data. In this way, we are able to capture the investment decision as

[3] The merit order is a ranking criterion whereby, in a centralized system generation, capacity should be brought online in increasing order of marginal costs (considerations are also given to the amount of energy that can be generated and the speed at which each system can be brought online). Implementing the merit order ensures that electricity dispatch is done minimizing the cost of production. Generally speaking and focusing on fossil-fuel generation, coal power plants are characterized by high-merit order, as they have low marginal costs of production (in addition to slow reacting times). Gas-fired power plants, on the other hand, are characterized by mid-merit order as they have higher marginal costs than coal power plants (in addition to faster reacting times). Note that renewable energy sources are generally characterized by high merit order since their marginal cost of production is (close to) zero (Sensfuss and Ragwitz, 2008).

[4] Note also that the contributions just discussed pay no specific attention to the role of energy and environmental policies.