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Greening the power generation sector: Understanding the role of uncertainty

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ABSTRACT

The transition to low-carbon technologies is essential to meet international climate change agreements. While market dynamics are contributing to make technologies increasingly affordable, experience has shown that other factors as well play a role in investment decisions. Uncertainty is one of them. Focusing on the power generation sector, this paper reviews the most recent literature on the subject, under the specific conditions that at least one adoption driver is uncertain and that a technology and/or environmental policy is in place. To understand how uncertainty affects adoption decisions, the survey considers economic parameters (e.g., investment costs or electricity prices) first and then focuses on the role of policy. While the deterring effect of uncertainty over investments is largely confirmed, several mitigating and underexplored issues are also identified, such as the role of heterogeneous investors' characteristics or the welfare implications of different policy designs. Moreover, by explicitly considering policy uncertainty, this survey provides a clearer understanding of the effects of a lack of government commitment on the adoption of environmentally friendly technologies in the energy sector. Related challenges for policymakers and investors are carefully delineated, together with directions for further research.

1. Introduction

The transition to a low-carbon energy system is one of the great societal challenges of the coming years. Electricity and heat production accounts for 25% of total greenhouse gases emissions, and reducing this contribution is fundamental to meet the Paris Agreement goals [1]. In this respect, the electricity sector has been experiencing a transformation for quite some time, and the large majority of investments in power generation are currently forecasted to involve renewable energy sources (over 70% in the period 2017–2040, [2]). Although market dynamics, with the decreasing costs for wind and solar installations, represent an important driver, they are still not expected to deliver by themselves the level of investment necessary to meet the 2 °C temperature target [2]. Policy interventions will continue playing a key role in reconciling climate change mitigation and sustainable economic growth.

Yet, geographical differences remain large. In the European Union, where the share of electricity produced by Renewable Energy Sources (RES) has already reached 29% in 2015 and is expected to grow up to 50% in 2030, policies are evolving at a fast pace. The latest package of measures launched by the European Commission in late 2016 comprehensively addresses the transformation of power systems, by focusing on market rules that will favor investments in renewables and in other fast-advancing technologies (e.g., storage), as well as on consumer empowerment. Indeed, the Commission places active consumers at the center of the policy agenda, as new technologies enable them (individually or in aggregation) to produce their own electricity and to respond to market signals, thus facilitating the integration of intermittent, renewable generation [3]. In the US, despite the initiatives to address climate change are rather significant at the state level, the adoption of a more incisive federal policy continues to be unlikely, at least in the short term [4]. China is expected to remain a large coal consumer for the next two decades, and achieving universal access to modern and sustainable energy in emerging economies is proving rather challenging [2,5].

Against this background, numerous studies have addressed the question of the adoption of environmentally beneficial technologies, that is, technologies capable to reduce negative environmental externalities (not only in the energy sector). These contributions mainly confirm the findings of the broader literature on technology diffusion: relevant drivers include investment costs and revenues, the flow of information, as well as firms' or individual investors' characteristics.

Abbreviations: CCGT, Combine Cycle Gas Turbine; CCS, Carbon Capture and Storage; CDM, Clean Development Mechanism; ETS, Emission Trading Scheme; FIP, Feed-In Premium; FIT, Feed-In Tariff; IGCC, Integrated Gasification Combined Cycle; MILP, Mixed Integer Linear Programming; PTC, Production Tax Credit; PV, Photovoltaic; RES, Renewable Energy Source; RO, Real Options; RPS, Renewable Portfolio Standard; VPP, Virtual Power Plant

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There are, moreover, two distinctive factors that affect the adoption decision in less carbon intensive technologies specifically: attitude and knowledge about the environment and policy instruments [6].

The main contribution of this paper is to address one missing piece in the above description. Experience has shown that in the adoption of a green technology, as in any investment decision, uncertainty about future returns plays a crucial role in determining the timing and the size of the investment [7]. In presence of irreversibilities (such as sunk costs), uncertainty over any of the factors affecting the profitability of an investment has, most of the times, the effect of delaying it. Yet, investors' attributes, the pace of technological change or policy design features have the ability to mitigate or worsen this result. Hence, taken collectively, the way firms and individuals respond to the challenges posed by uncertainty will contribute to defining the ability to meet international climate change agreements as well as local environmental targets. For this reason, uncertainty is the common denominator of the contributions selected for this work, and the understanding of its effects on the adoption of less carbon intensive technologies is the main purpose of this survey.

The focus is on the power generation sector, as a main global source of energy-related CO_2 emissions. The main question in this domain regards the profitability of a new technology, not only per se but also with respect to that of more traditional ones. Differently, analyses of electricity production costs are less relevant [8]. Accordingly, the studies included in this review are designed either to compare the profitability of two or more technological choices that entail different levels of emissions, or to assess the profitability of an investment in a new, cleaner technology (renewable or not) for power generation.

Moreover, all studies assume the presence of government intervention, either through an environmental policy (e.g., carbon policy) or through a technology one (e.g., renewable energy policy). This choice is justified not only by the role of policy as a driver of adoption, but also because, looking forward, government support for generation technologies is still expected to change, as policy makers strive to redesign market rules and create a level-playing field for all technologies.

A few surveys analyzing the relationship between uncertainty and investments in energy systems already exist but, in most cases, they are methodologically oriented. Soroudi and Amraee [9] and Aien et al. [10] provide an overview of the methodologies that can be used to model operational and planning problems under uncertainty. Similarly, the reviews by Fernandes et al. [11], Martínez Ceseña et al. [12], and Schachter and Mancarella [13] have a strong methodological characterization and only analyze real options applications.

The present work is more comprehensive than these surveys in terms of empirical approaches and, distinctively, also strongly oriented towards results and policy implications rather than methodologies. Specifically, the review is conducted along two lines: uncertainty over economic parameters, such as investment costs or electricity prices, is considered first, together with its effect on the adoption decision; then, the role of policy is addressed. By explicitly considering contributions where the policy regime is itself uncertain, this work provides, to the best of authors' knowledge, a first summary of the effects of policy uncertainty on the adoption of less-carbon intensive technologies for power generation.

The remainder of the paper is organized as follows. A general conceptual framework motivating the analysis is presented in Section 2, while Section 3 illustrates the inclusion criteria for the selected studies. Relevant outcomes that derive from uncertainties in revenues, input prices, and investment costs are discussed in Section 4. The results regarding the effect of policy and, in particular, of an uncertain policy are the focus of Section 5. Both sections also include policy recommendations and/or directions for further research. Section 6 concludes.

2. Conceptual framework

A fundamental step in understanding the effect of uncertainty on the diffusion of green technologies in power generation is to identify its sources. Soroudi and Amraee [9] make a distinction between technical and economic uncertainties, to discern between factors under control of the decision maker (or internal to the project) and purely exogenous ones. Because adopting a new technology is a planning decision (not a project design one), the scope of this review mainly covers uncertainties of economical/external nature (e.g., input prices) and relatively less technical/internal ones (e.g., wind availability).

Accordingly, among the economic/external factors that might create uncertainties over the profitability of a green investment in power generation, the present work considers, first of all, the elements that are common to any technological investment, namely *revenue-* and *cost-related* factors. The former are represented by electricity price and demand, while the latter comprise *investment costs* and variable costs in the form of *input prices* (fuel and CO_2 prices). The effect of a few *technical factors*, such as the rate of technical change (linked to investment costs) or renewable resources' availability (affecting the revenue stream) is consistently included in the previous categories.

The relative magnitude of revenues and costs is clearly crucial in the decision to invest [6]. Nevertheless, the unpredictability of one or more of these factors makes the optimal investment response more complex. Moreover, there might be potential behavioral biases in the investment decision. In this regard, this survey summarizes the findings of the literature on the relationship between revenue- and/or costs-related uncertainty and investment timing (and size), and discusses the related implications for the current technological transition. The survey also highlights the role of other potentially relevant factors, such as investors' characteristics and capabilities, and draws attention to under-researched areas.

Then, because of its importance for less carbon-intensive investments, particular attention is directed at the role of the *policy regime*, which can take the form of carbon and/or renewable policies. In fact, the presence of such policies is not always reducing uncertainty in the power sector. On the contrary, given the frequent policy revisions, investors are likely to be exposed to a further element of (hardly removable) uncertainty in their adoption decision.

Allan et al. [6] summarize the evidence concerning the effect of different, albeit stable, policy instruments on investors' technology choices in the adoption of green technologies in any sector. The present review adds to this work in two ways: by looking at the effect of a stable policy framework on the adoption of green technologies in the power sector specifically; and by explicitly addressing the issue of policy uncertainty. In this regard, it is essential to note that policy-related and other revenue- or cost-related uncertainties tend to overlap in many contributions. Specifically, some authors identify policy uncertainty with CO_2 price volatility or with green certificates' price variance. This review departs from this definition by introducing a clear distinction between the uncertainty generated by the kind of policy in place and the uncertainty on the policy itself. As for the former, the uncertainty derives, for instance, from a green certificates system making the unit revenue from the sale of renewable power variable (such an uncertainty is included, in this survey, in the "electricity price" or revenue class), or from a variable CO_2 price generating uncertain input prices for conventional power plants (included in the "CO_2 price" or input price uncertainty class). Hence, the category "policy uncertainty" only includes contributions where the uncertainty is on the policy itself, that is, on its introduction/termination, as well as on changes in its implementation details. This approach leads to a clear summary of the evidence regarding the relationship between policy uncertainty and adoption of less-carbon intensive technologies, as well as to the identification of issues that deserve further research.

3. Selection of the studies included in the review

The articles included in this survey were retrieved through electronic searches in bibliographic databases, as well as backward and