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Wind Power and Externalities

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ABSTRACT

This paper provides a literature review on wind power and externalities from multiple perspectives. Specifically, the economic rationale behind world-wide wind power deployment is to mitigate negative externalities of conventional electricity technologies, notably emissions from fossil fuels. However, wind power entails externalities itself. Wind turbines can lower quality of human life through noise and visual impacts, and threaten wildlife. Variable wind electricity can impose additional costs within the electricity system. Locally and nationally, employment, output, and security of electricity supply can be affected. Assembling evidence from diverse strands of research, this literature review provides a structured account of external and indirect costs, both mitigated and imposed.

1. Introduction

Since the beginning of the 2000s, wind power has gained a considerable share in electricity generation portfolios around the world. In 2000, 17 gigawatt (GW) of onshore turbines were in operation; by 2014, capacity had increased to 361 GW (IRENA, 2015). In Germany, for example, wind power accounted for almost 10% of total electricity consumption in 2014 (BMWi, 2015). Wind power is also being driven by the US, where onshore capacities more than quintupled between 2007 and 2014, and China, the world's biggest market in 2014 (IRENA, 2015).

Although costs of wind turbines have declined, there is still a wedge between the private and the public economics of wind power (Borenstein, 2012). While private costs can be greater than for conventional alternatives, social costs are presumed to be lower. This is due to external costs inherent to many conventional technologies, which are avoided with wind power. Specifically, fossil fuel combustion releases emissions, unfolding detrimental impacts both regionally and globally. Wind power, on the other hand, is also not inherently free of externalities. To play an effective role, wind turbines must be constructed in large numbers. Such land use may incur local external effects and meet resistance from affected individuals. Wind electricity, due to its variability, poses new challenges for the short- and long-term operations of power systems.

Thus, the public economics of wind power can be understood through the lens of the externality concept. In case of negative externalities, agents do not fully account for social costs, and social welfare can be reduced. Research or policy concerned with internalization must be informed about the categories and scope of externalities as well as the state of knowledge. However, as the application of a narrow externality concept can be quickly stretched to its limits, this literature review pursues a more encompassing and pragmatic approach. Providing a qualitative map of the public economics of wind power, this paper surveys the literature to identify external effects, whether triggered or mitigated, as well as further unintended consequences. Evidence is structured according to scope and effect, with central findings synthesized. To the best of my knowledge, there is no existing comprehensive literature review, consolidating evidence from otherwise disparate sources: economics, ecology, geography, public health, as well as economics and engineering; a gap this paper addresses.

The remainder of this paper proceeds as follows: Section 2 operationalizes the externality concept. Sections 3 and 4 provide an account of external and indirect costs related to wind electricity, and wind turbines, respectively. Section 5 discusses economic and security-related effects outside the electricity system; Section 6 concludes and outlines avenues for future research.

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2. Operationalization of the Externality Concept

2.1. Scope of the Externality Concept

At first, the application of the externality concept to the public economics of wind power needs some clarification. While there is no single acknowledged definition, in principle, a negative externality is an effect, external to market mechanisms, that influences an individual or a firm beyond her control, by reducing her utility or feasible production set, respectively. In neoclassical theory, it constitutes a market failure and reduces social welfare by putting a wedge between the private and the social costs of an alternative. A wider externality concept can also be understood outside a neoclassical setting from a system perspective, as long as some agent's well-being is affected as a side effect beyond market-based transactions (van den Bergh, 2010).

Welfare policies aim at internalizing externalities, guided by quantifications. When quantifying, several valuation methods exist, rooted in an individual utility framework. For externalities related to wind turbines, numerous papers derive a monetary valuation. However, environmental externalities arising in electricity generation can be subject to wide spatial and temporal boundaries. The consequences of emissions, like climate change, affect individuals far from their origins. Likewise, detrimental impacts unfold over time and affect future generations. Cause and effect can be spatially and temporally detached, rendering quantification and comparison to narrower external effects difficult (Bithas, 2011).

Conceptually, one can argue that the behavioral and ethical foundations of externality valuation can be too restrictive a basis for social choice (Söderholm and Sundqvist, 2003). Beyond use values, intrinsic values, for instance of human health or the environment, or existence values can be affected (Davidson, 2013). Such valuation is not unanimous and subject to considerable discretion (Laes et al., 2011). This is particularly important when there is little experience but much complexity. With far-reaching externalities of emissions (and nuclear power), valuation and aggregation of preferences based on an individual utility concept can be stretched to its limits (Freeman III, 1996).

While externalities are, as such, a descriptive concept, their implications are normative. Questions regarding which effects to include, to what extent, and the trade-offs between efficiency and distribution – be it spatial, inter-personal, or intergenerational (Fouquet, 2011) – imply a choice of goals (Baumgärtner and Quaas, 2010; Stirling, 1997). A comparison would also imply statements about commodification (Spash, 2013), distributional issues, and the aggregation of preferences across space and time (Chambers and Melkonyan, 2017).

2.2. Methodology

Thus, generalizations and aggregations are not instructive (Borenstein, 2012; Stirling, 2010). When discussing externalities of wind power, both imposed and mitigated, I abstain from full-cost valuations and cost–benefit analyses. Instead, I synthesize evidence and qualitatively elaborate on relevant dimensions.

To this end, I conducted a systematic literature search of the leading peer-reviewed journals in ecological, environmental, and energy economics. It is complemented with papers from general-interest economic outlets, and non-economic literature from geography, ecology, environmental psychology as well as economics and engineering. Whenever possible, I draw on existing aggregated knowledge from systematic review and survey articles. A complete list of journals and key words can be found in Appendix B.

On this basis, I distil common and diverging findings on the relationships under scrutiny. Necessarily, the breadth of the approach must be traded off against its depth. While I highlight selective significant cases, I do not provide a comprehensive discussion of idiosyncrasies of particular energy systems or case studies. Instead, I synthesize findings on an abstract level.

2.3. A Taxonomy

Wind power entails peculiarities distinct from conventional electricity generation technologies. In this paper, I distinguish three categories: (i) externalities and indirect costs of *wind electricity*; (ii) externalities of *wind turbines*; and (iii) *economic and security-related side effects*. Table 1 provides an overview of the taxonomy.

For *wind electricity*, pivotal characteristics are the variability of supply and the virtually zero marginal costs. As electricity is, as such, not storable, supply and demand must be continuously balanced. Wind electricity may require sufficient flexibility to level out short-term variability. In the long-term, power systems can be re-shaped to accommodate variable wind supply. Due to its zero marginal costs, wind electricity displaces conventional generation and, thus, helps to avoid its negative externalities, including not only regional health and environmental impacts from emissions, but also world-wide climate change due to greenhouse gases.

For *wind turbines*, a pivotal characteristic is the greater number of single installations, rendering energy supply more salient (Wüstenhagen et al., 2007), and increasing awareness of intrusions in the environment and personal space (Pasqualetti, 2000). Direct negative external impacts of wind turbines include threats to wildlife, noise emissions, and a deterioration of the aesthetic quality of landscapes. These externalities can affect nearby residents, thus lowering the quality of life. Against this background, the siting process negotiates potential conflicts of interest. Several studies quantify these externalities, either in a revealed or a stated preference framework.

Beyond the electricity system, wind power can trigger *economic and security-related side effects*. These indirect costs and benefits materialize both on a local scale, in areas where wind turbines are installed, and on a macroeconomic scale. Security of electricity supply can be affected, in a narrower view due to variability, or, in a broader view, due to lower dependency on depletable resources.

2.4. Preferences for Wind Power

An extensive literature explores preferences for green electricity, in general, and wind power, in particular (Oerlemans et al., 2016; Zoric and Hrovatin, 2012). Studies evaluate an entire bundle of external effects, including direct monetary costs. Thus, they shed light on socio-political trade-offs between multiple relevant factors from an individual perspective.

On average, meta-analyses generally find a positive willingness to pay (WTP) for renewable electricity (Soon and Ahmad, 2015; Sundt and Rehdanz, 2015) and, in particular, wind power (Ma et al., 2015). It is especially driven by information about displaced conventional generation (Sundt and Rehdanz, 2015), pointing at a high weight of climate-change considerations. Evidence for Germany, as a country with developed wind power, underlines this relationship (Bertsch et al., 2016; Grösche and Schröder, 2011). In particular, among socio-economic correlates, education, environmental concern, and a younger age are consistently identified as drivers for a higher WTP (Akcura, 2015; Conte and Jacobsen, 2016; Oerlemans et al., 2016; Tabi et al., 2014). Likewise, Welsch and Biermann (2014a) find a positive association between higher renewables shares and subjective well-being across over 25 European countries. Thus, such implicit cost–benefit accountings evaluate wind power as a favorable alternative.