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Analysis

Wind power externalities: A meta-analysis

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ABSTRACT

This study presents the first quantitative meta-analysis of the non-market valuation literature on the external effects associated with wind power production. A data set of 60 observations drawn from 32 studies is constructed. The relative economic values of different types of externalities as well as the impact of various methodological and sample characteristics on welfare estimates are examined. The results indicate a significant effect of visual externalities on welfare estimates in both directions, i.e., a positive effect of visual improvements and a negative effect of deteriorations. This finding corresponds to predictions of the importance of visual impacts in the social science literature. External effects of wind power on biodiversity (mainly birds) do not affect welfare estimates. Indirect externalities caused by conventional sources of electricity that can be avoided by wind power, such as a the reduction of air pollution, do neither have a significant impact on welfare measures. Methodologically, we find substantial but inelastic income effects and, for choice experiments, clear evidence of sensitivity to scope. From a policy point of view, our results suggest that a policy mix combining a promotion of wind turbines with another green policy facilitates expansion of wind energy.

1. Introduction

There is a growing consensus on the need to decarbonize the world economy (Fay et al., 2015; G7, 2015). This is reflected in most industrialized economies emitting less CO_2 than 5 or 10 years ago (PBL, 2014). The process of decarbonization has a profound impact on the electricity production sector. Conventional carbon-intense electricity production technologies are replaced with renewable sources of electricity in many developed countries (see e.g., ECN, 2011, for an overview of renewable energy expansion projections for the EU-27). In Europe, some signs can be found of a similar replacement process that takes place for nuclear power, where Germany and Switzerland both decided to phase-out nuclear power following the 2011 nuclear accident in Fukushima, Japan. This development is restricted to Europe so far. However, with the exception of China, the often heralded "renaissance of nuclear power" does not seem to manifest itself in other parts of the world either (Mez, 2012).

Among the various available renewable sources of energy, wind power is the second most important one after hydroelectricity as measured by its share in global renewable electricity generation. In 2012, wind power had a worldwide market share of 11% (EIA, 2012). Roughly 40% of worldwide wind energy is produced within the EU-27, where wind power has a share in renewable electricity production of 27.1% (EIA, 2012). Wind power has seen high and continuous growth rates that are likely to continue. The worldwide installed capacity in 2012 was roughly nine times as high as it was in 2002 with an average yearly growth rate of 25.2% (GWEC, 2012). Predictions for future capacity growth seem equally promising. The European Wind Energy Association predicts an increase of 64% in installed wind capacity in Europe between 2013 and 2020 (EWEA, 2014). China's roadmap foresees an even more extensive expansion in order to reach its goal of supplying 17% of electricity demand by wind power by 2050. Achieving this goal requires the installed capacity to expand by a factor 25 and an investment of USD 2'000 billion (IEA International Energy Agency, 2011).

Although there is an evident benefit of wind power production in terms of low greenhouse gas emissions, there are also negative effects associated with it. These effects are in general caused by renewable energy sources operating with lower energy densities than non-renewable energy carriers, which results in spatially larger production facilities (Wüstenhagen et al., 2007). This characteristic is often at the core of the observed limited community acceptance of renewable sources of energy. Wind power specifically results in a variety of uncompensated side effects. Such externalities include visual impacts (e.g., Pasqualetti et al., 2002), noise pollution (e.g., Harrison, 2011), and negative effects on animals, in particular birds (e.g., Drewitt and Langston, 2006; Leung and Yang, 2012; Mathew, 2006). Offshore wind farms may have additional negative effects on marine animals caused by underwater noise (e.g., Bergström et al., 2014; Wahlberg and Westerberg, 2005) and electromagnetic fields (e.g., Gill et al., 2012;

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Ohman et al., 2007; Petersen and Malm, 2006). They also provide positive externalities, such as creating new habitats and recreational benefits by serving as artificial reefs (e.g., Petersen and Malm, 2006; Westerberg et al., 2013; Wilson and Elliott, 2009) and improving fishery management by facilitating the control of fish harvest surrounding wind turbines (e.g., Fayram and de Risi, 2007). Except for these direct external effects of wind power facilities, there are also indirect effects, which refer to the negative effects caused by conventional energy sources that are mitigated or avoided by wind power. Such indirect effects include the avoidance of greenhouse gas emissions – although there are some emissions during construction and decommissioning of wind power plants (Weisser, 2007) – and the reduction or elimination of risks associated with nuclear power.

Apart from the valuation studies that are analyzed in this paper, there exists a number of empirical non-economic social science studies that investigate the impact of wind power characteristics on its public acceptance. These latter studies also provide an indication of relevant factors that influence public preferences and economic values of wind power externalities. They focus predominantly on visual impacts, noise, and effects on birds caused by wind power turbines and link these effects to the acceptance of wind energy. A consistent result reported in this literature is the identification of visual impacts as a key externality determining public acceptance of wind power. Devine-Wright (2005), for example, conclude in a literature review that negative visual impacts on the landscape and noise are the most frequent reasons for the public to oppose wind power development. Similar evidence is provided by Wolsink (2000, 2007) and Warren et al. (2005). Wolsink (2000) also identifies noise pollution and dangers to birds as important predictors of public attitudes toward wind power. However, their impact is much smaller than the impact caused by visual effects. Johansson and Laike (2007) specifically focus on the determinants of individuals to oppose local wind turbines. Their results support the importance of aesthetic effects and the "perceived unity of the environment" on local opposition. As commented by Pasqualetti (2011), there are few other artifacts that change landscapes as profoundly as wind turbines. Pedersen and Larsman (2008); Pedersen and Persson Waye (2007) and Pedersen (2011) study individuals' perception of wind turbines from a medical perspective and conclude that visual and audio effects have a significant impact on annoyance levels. They also find that the annoyance levels due to noise increase with visual annoyance.

This paper synthesizes the empirical evidence on the economic non-market valuation of the external effects of wind power in a meta-analysis. This is to our knowledge the first meta-analysis on the economic valuation of wind power externalities. Meta-analysis is a technique frequently used in environmental and resource economics (Nelson and Kennedy, 2008; van den Bergh et al., 1997). The usual procedure for conducting a meta-analysis in a non-market valuation context is to regress economic values (e.g., willingness to pay (WTP)) on regressors that are expected to explain data heterogeneity of economic values within and between studies. There are several possible objectives of a meta-analysis such as providing combined estimates of the dependent variable, explaining the variation of economic values within or between studies and estimating within-sample and out-of-sample predictions based on specific conditions (Nelson and Kennedy, 2008). This last objective makes meta-analysis a valuable tool in benefit-transfer applications since it allows the construction of a value function than can be used to transform values from one site to another (Bergstrom and Taylor, 2006; Brouwer, 2000).

The purpose of the meta-analysis conducted in this study is to review the existing literature and explain the observed variation in the non-market values of various types of wind power externalities whilst controlling for key methodological and sample characteristics. The main objectives are thereby to identify, disentangle, and classify the external effects of wind power production valued in the literature. In a further step, welfare estimates for the non-market effects of wind power production and their drivers are quantitatively assessed in a meta-regression model. The quantitative analysis aims to answer our main research question: What is the relative importance of various external effects, methodological features, and sample characteristics in explaining the economic values of wind power externalities? With respect to the types of external effects valued, the quantitative analysis distinguishes between the externalities caused by wind power directly (direct effects) and the external effects caused by other sources of electricity that are replaced by wind power (indirect effects). From a methodological perspective, this meta-analysis tests for sensitivity to scope by constructing a quantitative variable that represents the size of change valued across studies and types of externalities.

The remainder of this paper is structured as follows. Section 2 explains the search and selection procedure of studies included in the meta-analysis. Section 3 describes the meta-regression models and the main explanatory variables. Section 4 presents the results of the meta-regression models, which is followed by discussion and conclusions in Section 5.

2. Study selection

The non-market valuation of wind power externalities constituted the main criterion for a study to be included in the meta-analysis. More specifically, studies that generated primary valuation data, in terms of public WTP or willingness to accept compensation (WTA), of the non-market impacts of electricity produced by wind power were considered for inclusion. We thereby included only those studies in which wind power production was identified as the source of externalities. Applying this selection criterion ensured that individuals specifically focused on wind power when valuing its external effects. Studies were included that value externalities of wind power exclusively (roughly half of all observations in the meta-analysis) and studies which value external effects of renewable energy in general but explicitly mention wind power as one of them. Some studies valued external effects directly, whereas others focused on the WTP for electricity generated by wind power compared to the electricity generated from other sources. Based on Lancaster's theory of demand (Lancaster, 1966), the latter approach usually explicitly defines the positive and negative externalities of wind power in order to elicit the economic values of the external effects of wind power more so than of its standard market good (electricity). This approach ensures that survey respondents focus on the externalities of wind power production when valuing a certain scenario. The economic values elicited in these studies are therefore comparable to the values obtained by studies valuing wind power externalities directly.

A total of 32 studies were identified. Two reports that satisfied the criteria above could not be obtained despite an extensive search procedure (in addition to being written in Nordic languages). Other studies that were excluded to avoid double counting analyzed data that had already been used in one or more other relevant publication. Six papers valued the effects of wind power without clearly defining the specific effects of wind power, and thus the economic values could not be ascribed to wind electricity production. Furthermore, only two studies elicited WTA compensation (du Preez et al., 2012; Groothuis et al., 2008) and six studies provided only marginal welfare estimates elicited by choice experiments (CE) that are not directly comparable with the values obtained from contingent valuation studies (CV) (Aravena et al., 2014; Dimitropoulos and Kontoleon, 2009; Ek, 2006; Meyerhoff et al., 2010; Roe et al., 2001; Strazzera et al., 2012). We excluded all WTA values from the analysis. For the case of CE, we only used values of policy scenarios, i.e., values that control for the levels of change in attributes. These values are better comparable to values obtained by CV studies than marginal estimates valuing marginal changes in an attribute without considering the scope of change. Including WTA values and marginal values of CE in the meta-analysis would have expanded the number of observations but at the same time increase the heterogeneity in the