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Optimal location of renewable power[☆]

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ABSTRACT

A decarbonization of the energy sector calls for large new investments in renewable energy production, and several countries stimulate renewable energy production through economic instruments, such as feed-in premiums or other kinds of subsidies. When choosing the location for increased production capacity, the producer has typically limited incentives to take fully into account the investments costs of the subsequent need for increased grid capacity. This may lead to inefficient choices of location. We explore analytically the design of feed-in premiums that secure an optimal coordinated development of the entire electricity system. We show that with binding electricity transmission constraints, feed-in premiums should differ across locations. By the use of a numerical energy system model (TIMES), we investigate the potential welfare cost of a non-coordinated development of grids and wind power production capacity in the Norwegian energy system. Our result indicates that grid investment costs can be substantially higher when the location decision is based on uniform feed-in premiums compared with geographically differentiated premiums However, the difference in the sum of grid investment cost and production cost is much more modest, as location based on uniform feed-in premiums leads to capacity increase in areas with better wind conditions.

1. Introduction

A starting point for our analysis is that increased renewable energy production is one important pillar for reaching a low-carbon society. Increased renewable electricity production demands investments in grid infrastructure, especially because sources for renewable energy, like wind power and hydro power, may be located far from consumer sites. The necessary investment in infrastructure does not only depend on the amount of new production capacity, but also on the geographical location of this capacity. Within a market based system it is to a large extent up to the electricity producers to determine which generation projects they believe may be profitable. The regulatory authorities typically decide whether to grant a license for a specific project, but they have a limited role in determining which areas market participants choose to locate their projects. In this paper we analyze analytically the conditions for an optimal geographical distribution of renewable production capacity, and we discuss how this can be implemented in a market economy with a support scheme for renewable energy production. Furthermore, we conduct a numerical analysis of the Norwegian energy system to illustrate the social cost of ignoring the investments in the grid infrastructure when designing policy instruments to induce more renewable energy production.

Several countries have specific targets for renewable energy production, including all EU Member States [1]. The European Union seeks to establish an Energy Union with an ambitious climate policy and an integrated EU electricity market open to cross-border trade. [1] Moreover, environmental acts such as the Renewables

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[1] Legislation at both primary Treaty level (Treaty on the Functioning of the European Union (TFEU)) and secondary legislation level are key instruments to achieve these goals. This EU energy acquis is also, as a point of departure, EEA (European Economic Area) relevant, and is or will become part of the EEA Agreement. The energy specific secondary legislation includes a comprehensive set of substantive and institutional requirements aimed at promoting a sustainable, secure and competitive EU Internal Electricity Market. These provisions are included, inter alia, in the Third Energy Package comprising (for electricity) the Electricity Directive 2009/72/EC, the Electricity Regulation (EC) No. 714/2009 and the Regulation (EC) No. 713/2009 establishing the Agency for the Cooperation of Energy Regulators (ACER).

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Directive 2009/28/EC are of large significance for the electricity market, requiring new renewables investments through the setting of binding national renewables targets. However, the choice of instruments to achieve the binding national targets have not been harmonised at EU level. Moreover, EU law does not at present include harmonised rules for the setting of connection tariffs for new electricity generation plants. Member States are therefore free to choose different kinds of renewables incentives – such as feed-in premiums, green certificates, tax- or tariff schemes – provided the schemes are designed in accordance with the more general EU legislation. The designated policy instrument varies across countries, see, among others, Kitzing et al. [2].

Furthermore, according to Kitzing et al. [2]; the support for new renewable energy production among EU member states is, in general, not site specific (but does vary across technologies and size). Capacity location may matter significantly for the social cost of the transformation of the energy sector. Location matters for both emission reductions, impact on landscape and transmission congestions, see Hitaj [3] and Zografos and Martinez-Alier [6]. In this paper we concentrate attention on the impact on grid costs. A radical increase in renewable energy production may demand substantial investments in increased transmission and distribution capacity. Whether the market system leads to a socially efficient geographical distribution of production capacity depends inter alia on the design of grid connection charges. The literature distinguishes between so-called deep and shallow connection charges, see, i.e., Turvey [48]. Deep connection charges reflect all of the estimated cost of accommodating additional generation. With shallow connection charges the producers only pay for the local investment required to connect capacity to the grid, and not the incremental investment that has to be made in the wider transportation system. Shallow connection charges lead to inefficient location. Although deep connection charges can ensure optimal location of energy production capacity, it raises new question concerning how the cost of reinforcement of the wider energy system is to be shared among new and existing users. This is especially relevant for lumpy connection investments; see discussion in Turvey [48]. Although the discussion on shallow versus deep connection charges is not new, the problem of inefficient location may become increasingly severe due to the greening of the energy sector and the subsequent need for grid enforcements.

In the next section, we present an analytical model to derive the conditions for an optimal geographical distribution of new renewable energy production, taking into account the warranted grid investments. The model is very simple, but rich enough to capture some of the main characteristics of an electricity market with price zones (bidding areas). [2] We show how a market-based solution with shallow connection charges and uniform feed-in premiums (subsidies) to green energy production leads to socially inefficient location and grid investments. Furthermore, we show how differentiated (non-uniform) feed-in premiums can yield socially optimal location.

Several authors have analysed the effect of different renewable subsides schemes on spatial distribution of wind power [8,9] [10]; [11], but none of these studies analyze the impact on grid investment costs. Grimm et al. [12] studies how private suboptimal locational decisions for generation capacity may imply excessive network expansion. However, they do not derive how an optimal design of subsidies alleviates the inefficiencies.

We restrict our analysis to the potential inefficiency following from the geographical distribution of new production capacity, ignoring any potential inefficiencies following from the behavior of the regulated grid owners; see discussion in Brunekreeft [15]. For analyses of merchant transmission investment as an alternative to investment by regulated transmission system operators, see, i.e., Chao and Peck [16]; Bushnell and Stoft [17] and Joskow and Tirole [18].

[2] Zonal pricing has a uniform market price inside a price zone and is adopted by most European countries. See Bjørndal and Jørnsten [46] for a critical analysis of zonal pricing.

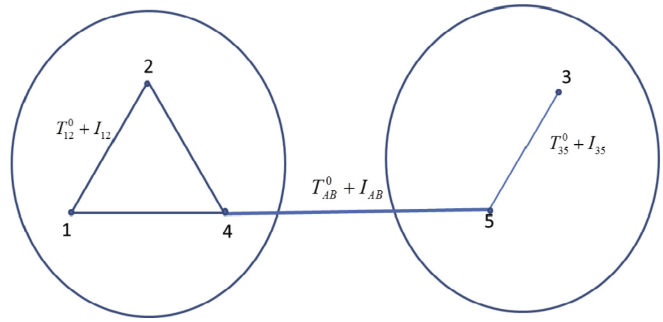

Fig. 1. Electric power network.

In Section 3 we present results from a numerical model for the Norwegian energy system to illustrate the potential social cost of a socially non-optimal location of wind power capacities. Our starting point for the numerical exercise is a political goal to increase the production of wind power (a renewable target). We compare the outcome of market based incentive system with uniform feed-in premiums (subsidies) with a first-best outcome, that is, a geographical distribution of wind production capacities that minimizes the energy system cost (given the renewable target). Our result indicate that the total energy system cost of a 5 TWh increase in wind power production following from uniform feed in premiums was modestly (6%) more costly than a first-best outcome. However, the location of capacities deviates substantially between the two regimes, leading to around 50% higher grid investment costs under a market-based incentive mechanism with uniform feed-in premiums compared with the socially optimal distribution.

2. Analytical model

The purpose of the analytical model is to highlight some important characteristics of an optimal spatial distribution of wind power, and show how feed-in premiums can be designed to achieve that solution in a competitive electricity market. We therefore have constructed an analytical model which is very simple, but still rich enough to capture some of the main characteristics of an electricity market with price zones. For the sake of simplicity, we make several assumptions. All of them are presented successively below, and the implications of the simplifying assumptions are briefly discussed in section 2.4. The assumptions are also listed in Table 2. From the model, we derive some general qualitative results, which, due to their generality, will also hold for more sophisticated models. In section 3.2, we present our numerical model which has a detailed description of the entire energy system, and without the simplifying assumption made in the analytical model. We use this model to derive quantitative results regarding the social cost of an inefficient geographical distribution wind power in Norway.

We consider a simple electric power network with two price zones, A and B. There are three production nodes and two consumption nodes, as shown in Fig. 1. Nodes 1, 2 and 3 are potential supply nodes for new wind parks, whereas nodes 4 and 5 are consumption nodes. A notation list is provided in Table 1.