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Insights into wind sites: Critically assessing the innovation, cost, and performance dynamics of global wind energy development

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ABSTRACT

Reliable empirical data on the siting characteristics and operational performance of wind farms are scarce. Knowing more about the technical characteristics of wind farms provides insight into the business mindset of wind farm developers, which can be useful for policymakers or researchers who are intent on designing policy in a way to optimize wind farm investment by creating better alignment between the investment patterns sought by developers and government support designed to attract investment. This study draws on a unique dataset from 32 wind farms, 20 onshore and 12 in forested areas with a total of more than 2.5 GW installed wind capacity to explore development patterns. The paper examines four hypotheses related to characteristics of wind farms in emerging markets and investigating how project delays and progressive technological enhancements shape wind farm development. In this paper, we explain these results and conclude by extracting lessons from this analysis for creating wind power policy better aligned with developers' interests.

1. Introduction

Wind power has been recognized as one of the most promising technologies in the transition towards electricity generated by low-carbon resources (Masters, 2013; Valentine, 2014; Jacobson et al., 2017; Rand and Hoen, 2017). Even more than a decade ago, basing projections on technology that is now outdated, 20% of the world's realizable wind energy potential was considered to be enough to satisfy the world's energy needs (Archer and Jacobson, 2005).

More recently, the emergence of commercially viable wind energy systems have fueled a market boom (Sovacool and Enevoldsen, 2015). The world's installed wind power capacity has blossomed from 17.4 GW in 2000 to 486 GW in 2016 (GWEC, 2017). Moreover, wind power installations which were more or less limited to Western Europe, USA, India, and China just 10 years ago (GWEC, 2007) have now diffused to more than 100 countries (GWEC, 2017).

As a welcome side effect of this growth, the industry now employs more than 1 million workers (IRENA, 2015). In testament to the comparative rise of wind power as an important source of employment, in the United States, the wind power sector employed 88,000 workers in 2015, compared to just 67,929 employed in the coal mining sector (AWEA, 2016; Lovins, 2017).

Despite the allure of wind power, however, policymakers and even the research community in general know little about why wind farms develop in the manner that they do. In many economic sectors, understanding development patterns are important if policymakers are to create supportive policy measures (Jefferson, 2014; Kelsey and Meckling, 2018). For example, in agriculture, it would be imprudent to create policy which supports certain crops over others without understanding how and why farmers plant the crops they do. Similarly, in regard to wind farm development, successful diffusion is fortified by establishing conditions that are most conducive to attracting investment while ensuring that other aspects of social welfare are not undermined by the development (Enevoldsen and Sovacool, 2016). By extension, it is intuitively logical that as wind power markets evolve, land scarcity concerns rise and “Not in My Back Yard” (NIMBY) threats elevate, policies might need to be devised to nudge developers into developing projects that might not otherwise materialize under free market conditions (Valentine, 2014). In some markets the socio-political and cultural factors are becoming just as important as wind resources (Khan, 2003; Brinkman and Hirsh, 2017; Hirsh and Sovacool, 2013), as decades of innovative research has rendered it possible for wind turbine to operate in a wide range of wind conditions (Sovacool and Enevoldsen, 2015) including low – and extreme wind speeds. However, as stated by Jefferson (2018) wind project developers have to achieve certain capacity factors, in order to succeed with a business. It

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is therefore critical when lack of socio-political support push new developments to complex areas where wind resource assessments are more unsecure (Enevoldsen, 2016).

Previous research suggests that development patterns in the electricity sector might not be solely driven by technological or economic factors (Geels et al., 2017; Sovacool et al., 2017). Yet further empirical research is needed to support suppositions on how wind farms are designed and configured. Until the impacts of market and policy dynamics on wind farm developer behavior are better clarified through empirical research, it is difficult to optimize both technological design and policy in order to promote developments that serve the needs of communities while delivering much needed clean energy into the grid, which is an emerging challenge for all renewables (Jefferson, 2016).

In contributing to this challenge, this article critically examines operational data from 32 wind farms with a total of more than 2.5 GW installed wind capacity. It does so with the aim of better understanding wind power development patterns so that policymakers, community planners, engineers, and analysts can harness and optimize policies and development standards that will help them to encourage wind farm developments that best balance community expectations and economic performance. The purpose of the paper can therefore be articulated as the following four hypotheses or preconceptions which are sought to be tested through the operational data:

1. In nations that have low levels of installed wind power capacity, developers will be more risk averse causing initial projects to be smaller.

2. Due to elevated concerns over avian mortality and desires to minimize deforestation, wind farms in forested areas should have fewer turbines. However, these turbines should deliver more output per turbine.

3. Project development lags and delays in logistics and sales channels will result in wind farms that are developed with outdated technology.

4. New wind farm sites should produce more power in aggregate because developers can use turbines with enhanced power capture capabilities and improved designs.

2. Research design and methods

The primary source of data for this study is an original dataset concerning the configurations and 2015 performance characteristics of 32 globally situated wind farms, including 20 “conventional” onshore wind farms (onshore farms) spread across five continents and 12 wind farms in forested areas (forested-area farms) primarily located in Northern Europe. Due to confidentiality agreements with the data providers, the project names and specific locations have been anonymized. We have decided to separate the forested-area farms from the onshore farms because we thought that the relative immaturity of this emerging market pattern might yield different development patterns that would obscure our findings if treated together. The reason being that wind turbines operating in forested areas tends to have unique performance patterns (Enevoldsen and Valentine, 2016), which are caused by the changes in wind conditions in the roughness sub-layer above forest canopies (Arnqvist et al., 2015; Enevoldsen, 2016). The forest configurations can furthermore be considered a novel and emerging market pattern within well-established and mature wind markets, and also more or less the only onshore configuration in countries well covered by forest.

Figs. 1 and 2 illustrate the aggregated profiles of these wind farms, delineated by region and described in terms of average wind farm size (MW) (Fig. 1) and average annual energy production per wind farm (MWh) (Fig. 2).

The data encapsulated in these figures suggest that the onshore farms possess higher capacity (MW) than forested-area farms do. Evaluating the reason for this difference can help policymakers (and others) better understand the mindset of developers, the drivers which influence project development and the factors that might have to be managed to catalyze desirable patterns of wind power development. This insight inspired the creation of four hypotheses related to development patterns that could be empirically evaluated by digging further into the data set to investigate disparities at the individual wind farm level. The hypotheses analyzed in this study were largely chosen because the proprietary data we had access to could inform the analysis. Although research is typically driven by research questions, which then dictate methods to be used, in this study the approach was turned on its head to leverage our unique access to industry data – making it a data driven or grounded approach. Through meetings with developers and through our own set of experiences in the industry, we feel that the preconceptions we put forth in Table 1 are all of policy importance. To ensure industry relevance, aside from interpreting our statistical analysis, we met with nine wind power developers in order to get experiential assistance in interpreting the findings.

To evaluate the emerging market hypothesis (H1), we employed a comparison of means, medians and standard deviations. For each farm, we first ascertained the aggregate level of installed wind power capacity in the nation in question at the time the project was completed. When this level was under 1000 MW, we assigned a delineation variable of “0” to the wind farm under analysis, indicating that the wind farm was being developed when the nation was still considered to be an emerging nation when it came to wind power development. When the level in the nation was 1000 MW or over, we assigned a delineation variable of “1” to the wind farm under analysis, indicating that the wind farm was developed in a nation where wind power had diffused to a level of installed capacity that was deemed to be sufficient to consider the nation as a mature wind market. The intension of applying delineation variables was to allow us to separate mature from immature wind markets, despite including no mathematical function.

Our preconception was considered supported if to a high degree of statistical certainty, the average aggregate output of wind farms in emerging wind power nations was lower than the average aggregate output of wind farms in mature wind power nations. The 1000 MW figure was an admittedly arbitrary description but the rationale of this

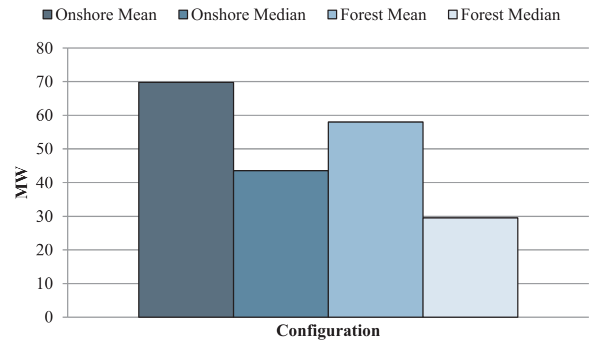

Fig. 1. Average wind farm size within the dataset (MW).

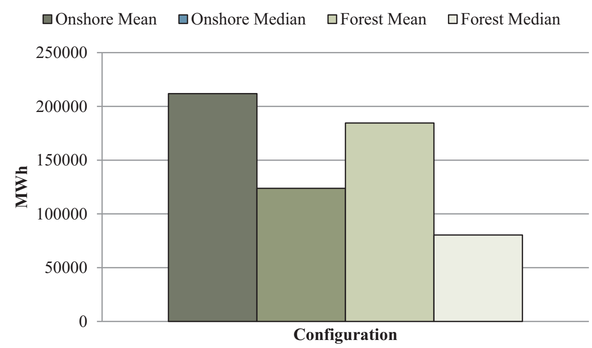

Fig. 2. Annual wind farm energy production within the dataset (MWh).