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Title

Market entry for wind energy: strategic approaches for the Original Equipment Manufacturer

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Abstract

Wind energy is a valuable resource, but many developing and emerging economies (DEEs) are not utilizing the tremendous wind capacity available to them. This means there is a potential for wind turbines Original Equipment Manufacturers (OEMs) to penetrate new markets to increase profits, and to contribute to Sustainable Development Goals.

This paper explores the potential triggers for wind energy diffusion and provides the basis for inclusive market entry strategies for wind power OEMs. Indications are that early wind energy path creation is driven by climate adaptation, vested interests in fossil fuels and hydropower, and the business case potential. A negative business case potential in many DEEs formed a substantial barrier.

A shift to increased local value creation, collaboration with traditional power producers, and promoting wind for climate adaptation are key novel inclusive market entry strategies to open and develop new markets.

Keywords

wind energy, inclusive, market entry, strategy, original equipment manufacturer, developing and emerging economies, diffusion

1. Introduction

The wind business has reached a substantial size: the total value of wind energy investment in 2020 equalled 143 billion USD (Henze, 2021). The Original Equipment Manufacturers (OEMs) capture the largest share of the investment volume. Close to 70% of the capital investment in wind energy is allocated to wind turbines, the remaining 30% covers the balance of plant and financial costs (Stehly & Beiter, 2019). The manufacturing of wind turbines is dominated by a handful of multinational OEMs, who compete intensively to service mature and nascent markets: the largest four accounted for 55% of all new turbine installations in 2019 (Henze, 2020). While these companies have been notably successful in developing markets, there is scope to penetrate new markets to increase profits and strive for competitive advantage.

In a recent review and meta-analysis, Zwarteveen et al (2021) define 68 high wind potential countries. Notably, only nine of these countries had installed more than 10 GW of wind energy by the end of 2017, 33% of which were Developing and Emerging Economies (DEEs), 67% were Advanced Economies (AEs)(country group definition by International Monetary Fund (2018)). Moreover, 34 of these high wind potential countries had installed less than 0.1 GW of wind energy, 94% of which were DEEs, 6% AEs. Wind energy is a valuable resource and it appears that it is being under-utilized by many DEEs.

The diffusion of wind energy into these 34 high wind potential countries has the potential to increase profits into the large OEMs, but also deliver an array of economic, environmental, and social benefits to these countries, for instance, foreign direct investments (Curran, Lv, & Spigarelli, 2017; Keeley & Matsumoto, 2018; Tan, 2013) and increasing access to clean and affordable energy, which is Sustainable Development Goal (SDG) number 7 (United Nations, 2015)). Through interlinked effects (Mantlana & Maoela, 2020), the contribution to the sustainable development agenda extends beyond SDG 7. With the majority of the global population living in DEEs, their development is key for achieving many SDGs (Pansera & Sarkar, 2016). However, the diffusion of wind energy into these high potential markets will require judicious corporate strategies, which will have to be based on an understanding of the drivers of early wind energy diffusion across these 34 countries.

In practical terms, wind energy diffusion can be measured in two different ways. The most common is to measure 'wind energy growth': the amount of newly installed capacity (MW) per year and the variables explaining this growth. Both quantitative (del Río & Tarancón, 2012; Mulder, 2008) and qualitative studies (Moe, 2012; Zhao, Chang, & Chen, 2016) have used this measurement. Zwarteveen et al (2021) identify 8 categories influencing wind energy growth: environmental, social, technical potential, economic, political, technological, regulatory, or a combination of those. For DEEs, they noted that economic factors form the most important driver. The second method to describe wind energy diffusion is through 'path creation': how wind energy arises (Simmie, Sternberg, & Carpenter, 2014)(Simmie et al., 2014). Compared to wind energy growth, far less is known about wind energy path creation. Factors influencing path creation are regulatory (Bento & Fontes, 2015), the business case (Inoue & Miyazaki, 2008; Wijayatunga, Siriwardena, Fernando, Shrestha, & Attalage, 2006), the environment (Jacobsson & Lauber, 2006), education (Bento & Fontes, 2015), spillover (Bento & Fontes, 2016; Steffen, Matsuo, Steinemann, & Schmidt, 2018), vested interests (Espinoza & Vredenburg, 2010; Steen & Hansen, 2018) and energy security (Cherp, Vinichenko, Jewell, Suzuki, & Antal, 2017). As wind diffusion in many DEEs is negligible, focused insights on path creation is needed. Path creation understanding enables the creation of successful market entry strategies. However, path creation has received little attention, and research on this topic is limited to primarily qualitative studies (Zwarteveen et al., 2021). This means, measurable, quantifiable, and repeatable analysis is largely absent. Since the field of path creation studies applied to wind energy is maturing, the available data now allows for quantitative research (Edmondson & Mcmanus, 2007).

Wind energy diffusion is also a multi-stakeholder process. Previous studies have considered the perspective of actors related to wind energy: policymakers (Friebe, Von Flotow, & Täube, 2014; Mulder, 2008; Nordensvärd & Urban, 2015) energy planners (Ioannou, Fuzuli, Brennan, Yudha, & Angus, 2019), financers and investors (Keeley & Ikeda, 2017; Steffen, 2018, 2020), developers (Lüthi & Prässler, 2011; Steffen et al., 2018) and utilities (Shah, Palacios, & Ruiz, 2013; Wijayatunga et al., 2006). Another notable gap in the literature is that, given the importance of wind technology in the process of path creation (Popp, Hascic, & Medhi, 2011), the role of OEMs has received little attention. Where policymakers stimulate the diffusion of wind energy: without the innovative and operational efforts of the wind power OEMs wind turbines would not be designed, installed, and maintained. Focussing on the purchasing side of green process innovation, Khan et al (2021) highlight that “management needs to respond to the changing demands of stakeholders and come up with a better strategic response, which includes ... clean technological adoption”. In addition to the purchaser, a strategic response of the supplier of the technology would promote the adoption even further. Given the vital role OEMs play, further research to support their business managers in strategic decision-making to stimulate wind energy diffusion is highly relevant.

Stimulating local jobs and creating local value are vital for improving the quality of life in low-income markets (Arnold, 2018). The most successful internationalized wind power OEMs are European (Yusta & Lacal-Arántegui, 2020). Despite their global reach, significant manufacturing, sales, and research activities are still largely based in Europe (Lacal-Arántegui, 2019). This means that the internationalization of wind into DEEs is resulting in a job increase in AEs, marginalizing the development impact in the DEEs. Inclusive development considers the empowerment of the marginalized (Gupta, Pouw, & Ros-Tonen, 2015). Multinational companies have an important role in achieving the SDGs (Arnold, 2018), however, according to Redman (2018), strategic and tactical business efforts need to be increased to achieve sustainability. For inclusive and sustainable development, the approach to wind energy growth in new markets need to be reconsidered.

In a recent automotive industry study, no evidence was found to support the idea that company climate strategies influenced financial performance (Damert & Baumgartner, 2018). Therefore, profit-driven organizations might have difficulties justifying a climate strategy without financial benefits. The topic of effective and efficient policies to stimulate wind energy is thoroughly addressed in the literature (Arent, Wise, & Gelman, 2011; Baudry & Bonnet, 2019; Blanford, 2009). However, policies will only be implemented if there is a desire for exploitation. In contrast to the frequently studied question of *how* to diffuse wind energy (e.g. with efficient policies), Zwarteveen et al (2021) propose a concept that explains *why* wind energy is diffused (for example, the need for energy security or cost savings). Change happens if first the ‘desire for change’ is in place followed by the ‘mechanism for change’. In the early stages of path creation, it is the initial interest that matters. Early path creation can even take place without regulatory support, Steffen et al (2018) confirm that “over two thirds of the projects were developed in absence of any deployment policy”. Once the desire is there, the mechanism for change will eventually follow, and combined with disturbances they shape the stages of path creation.

Therefore, the objective of this paper is to study path creation, using quantitative methods, taking the wind energy OEM perspective to improve the understanding of global diffusion differences of wind resources and to enable the design of effective diffusion strategies. Using a deterministic approach to explain path creation quantitatively, allows further exploration of if and how the explanatory variables can be influenced to further diffuse wind energy. The second contribution of this paper is to include a new viewpoint, the wind power OEM and this allows an insight into a critical question: what can an OEM do in the different stages of path creation to stimulate further diffusion of the technology to simultaneously meet societal and business objectives?

This paper is structured as follows: section 2 describes the theoretical foundation, followed by the method and data in section 3. Section 4 states the results and the discussion. The last section concludes.

2. Path creation for wind energy

2.1 Theoretical foundation of path creation

The differences in global exploitation of wind can be explained through technology diffusion theories. One way to structure theories about technology diffusion is to distinguish between exogenous (autonomous) and induced (stimulated) technological change (Böhringer, Mennel, & Rutherford, 2009), or more pragmatically, a combination of both (Newell, Jaffe, & Stavins, 2006). Global adoption and diffusion of technology have been frequently modelled using epidemic S-curves (Bass, 1969; Davies, 1979; Griliches, 1957). However, path creation is generally described through a multi-level approach

(Geels, 2002), based on evolutionary economics (Nelson & Winter, 1982; Schumpeter, 1934). The levels defined by Geels (2002) are niches, patchwork of regimes, and landscape developments. Each level displays a different interaction between diffused technologies and its environment. Geels (2002) approach describes transitions in socio-technical landscapes, whereas Technological Innovation Systems (TIS) (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008) focus on path creation of a particular technology. The different functions of TIS influence the performance of the path creation of that specific technology. Bergek et al (2008) cite the functions as knowledge development, resource mobilization, market formation, influence on the direction of search, legitimation, entrepreneurial experimentation, and development of external economies. Sustainable Innovation Systems (SIS), is the sustainable application of TIS (Zartha Sossa, López Montoya, & Acosta Prado, 2021). SIS follows the same functions as TIS but places sustainability in the centre.

Key constructs of path creation are stages and paths (figure 1). Surana and Anadon (2015) list the constituent stages as pre-commercialization, early commercialization, commercialization, and widespread diffusion. Polzin (2017) adds the earlier stages of basic R&D and applied R&D. The literature generally categorizes paths into the creation of new paths and the existence of established paths. Lock-in in established paths could limit the creation of new paths (van der Vleuten & Raven, 2006). New paths follow the different stages and either move down (failed innovation) or break through the niche to become widespread diffusion, forming established paths (Geels, 2002). Forces that facilitate breakthrough are technology, infrastructure, culture, symbolic meaning, industrial networks, strategic games, techno-scientific knowledge, sectoral policy, markets, and user practices (Geels, 2002) or structural components, functions, assessing functionality, formulation of process goals, inducement and blocking mechanisms, and key policy issues (Bergek et al., 2008).

2.2 Extension of the theory

To date, path creation within wind energy is mostly studied using historical descriptive and interview-based methods (for example, (Bento & Fontes, 2015; Inoue & Miyazaki, 2008; van der Vleuten & Raven, 2006), there is only limited mixed methods and quantitative research (for example, (Halleck-Vega & Mandel, 2018; Steen & Hansen, 2018; Steffen et al., 2018)). In nascent fields of research, qualitative research allows for pattern development. Qualitative data, however, needs to be interpreted for meaning (Edmondson & Mcmanus, 2007). The primarily qualitative research has developed knowledge on patterns of wind energy diffusion. However, there is still a need to determine the relative influence of factors affecting the diffusion to enable the design of effective and efficient OEM strategies. Previous research used an interpretivist or realist lens. Meaning and unquantifiable reality formed the basis for the studies. This paper aims to add to the theory by using measurement as the exclusive basis for reality by quantitatively studying the factors influencing when moving from one stage of path creation to another. A recent review identified that most research in business strategy and the environment use quantitative methods (Kumar, Sureka, Lim, Kumar Mangla, & Goyal, 2021), demonstrating the importance of such methods to formulate corporate strategies. Observations are objective, but the researcher needs to be critical in the selection of measurement tools (Blaikie, 2007), hence the critical rationalist lens is used.

The approach is deterministic and aims to increase understanding of what significantly induces a move from one stage of path creation to another stage. Path creation stage position (**PCSP**) for country **i** is proposed to be a function of explanatory variables ($\boldsymbol{x_i}$).

$$\boldsymbol{PCSP_i} = f(x_i), with\ \boldsymbol{PCSP} = [0,1] \quad (1)$$

Following the concept of Zwarteveen et al (2021), this paper will choose the explanatory variables that are related to the desire for change, not the variables related to the mechanism of change. This is to specifically understand the drivers and barriers in the early stages of path creation. The selection of variables will be explained in the following section.

Using the deterministic approach to explain path creation quantitatively, the question becomes if and how the explanatory variables can be influenced to affect further diffusion of wind energy? Generally, this is studied from a policymakers viewpoint (Ericsson, Nilsson, & Nilsson, 2011; Inoue & Miyazaki, 2008; van der Vleuten & Raven, 2006). The second extension to the theory of this paper is to include a new viewpoint, the wind power OEM. What can business managers in OEMs do in the different stages of path creation to stimulate further diffusion of the technology?

Thus, the focus of the paper is to quantitatively study wind diffusion path creation, taking the OEM perspective, focussing on variables related to the desire for change, explaining global differences with a special focus on the lag of DEEs.

3. Method and data

3.1 Method

Multiple studies define the boundaries of the stages of path creation. Using the concept of TIS, Surana and Anadon (2015) present stages of technology diffusion specific to wind energy: the formative stage and the growth stage. The formative stage is defined as pre-commercialization (first grid-connected project) and early commercialization (three consecutive years with an annual capacity increase of more than 50 MW, corresponding to roughly annual 100 million USD investment); the growth stage as commercialization (three consecutive years with an annual capacity increase of greater than or equal to 10%) and widespread diffusion (three consecutive years with an annual capacity increase less than 10%, considered to be the ceiling of S-curve).

To focus on the early steps of path creation, this study concentrates on pre-commercialization, early commercialization, and commercialization as steps within path creation. The specified volume categories and the rationale are shown in table 1. The threshold for pre-commercialization is chosen to start at 1 MW to exclude any non-utility scale wind energy. The R&D phases as shown in figure 1 are not accounted for since the focus of this study is on the country-specific diffusion of technology, not on the often centrally organized development of technology.

Warm glow, the psychological reward from pro-social behaviour, is an important driver of pro-environment behaviour (Hartmann & Apaolaza-Ibáñez, 2012; Hartmann, Eisend, Apaolaza, & D'Souza, 2017). Because of the complexity introduced with the warm-glow effect, surveys might not provide the real reasons for wind energy exploitation. Multiple methods exist to explore hidden needs (Goffin & Lemke, 2004). Among others, observation is one. Although Goffin and Lemke (2004) recommend anthropological exploration as the observation method, behaviour can also be observed through historical actions. Measuring the environment at the time of investment in wind energy would explain which conditions lead to the decision to exploit wind energy. Therefore, the chosen method to analyse the different factors that influence the path creation from one stage to the next is panel-based regression. Regression can quantify the impacts of factors as well as explaining model goodness of fit. Since panel-based regression has been used frequently to explain 'wind energy growth' (for example, (Best & Burke, 2018; Mulder, 2008; Polzin, Migendt, Täube, & von Flotow, 2015; Shrimali & Kniefel, 2011; Sisodia & Soares, 2015)), the advantages of this method can also be applied to 'path creation'.

In this study, path creation is analysed by studying thresholds rather than the increase of wind energy within the different volume categories (table 1). Hence, these are nominal data, which can be analysed through binary logistic regression and multinomial logistic regression (Tabachnick & Fidell, 2013). Binary logistic considers a dependent variable with two possible, mutually exclusive, outcomes (such as winning or losing), multinomial logistic regression (or also called polychotomous logistic regression) considers a dependent variable with multiple nominal outcomes (such as favourite car brand). The regression determines the probability of the dependent variables given the values of the independent variables (for instance, for the case of winning or losing: age, gender, hours of training, diet). In this particular case, the movement from one stage to the next will be modelled separately for every transition to understand potential differences. Therefore, three binary logistic regression models are needed, each according to equation 2 (Verbeek, 2004). **P** is the likelihood of **PCSP** having the value 1 for country **i**, based on the explanatory variables $\mathbf{x_j}$ (with **j** the number of the variable), expressed as a function **G** of the explanatory variables and the regression coefficient (or log odd) $\boldsymbol{\beta_j}$**.**

$$P\{PCSP_i = 1 | x_{i,j}\} = G(x_{i,j}, \beta_j) \tag{2}$$

For binary logistic regression, function **G** is non-linear. Therefore, the regression coefficient **β** is different from the predicted probability. However, the sign and size of the coefficient are related to the sign and size of the change in probability. For all other factors to be constant, the change in probability $\mathbf{p_j}$ for **PCSP = 1** for a change in variable $\mathbf{x_{i,j}}$ follows equation 3 (UCLA, 2021).

$$p_j = e^{\beta_j} \quad (3)$$

The marginal effect can be calculated consequently. One unit change of $\mathbf{x_{i,j}}$ results in exp($\boldsymbol{\beta_j}$) units of change in the odds that **PCSP** = 1.

Data is collected from archival data sets (section 3.3). STATA is used for the analysis (StataCorp, 2019). Descriptive statistics are firstly presented, and the variables are analysed for their correlation and multicollinearity. The binary logistic regression is executed through the XTLOGIT command, followed by post-regression analysis for model fit and model robustness. Consistent with other studies in the field (Fetz & Filippini, 2010; Ruokamo, Kopsakangas-Savolainen, Meriläinen, & Svento, 2019), McFadden's pseudo-R squared (McFadden, 1974) ($\mathbf{R^2_{MF}}$) is used to calculate the model fit, based on the ratio of the full model (**M(Full)**) and the null model (**M(Null)**):

$$\boldsymbol{R^2_{MF}} = 1 - \frac{\boldsymbol{M(Full)}}{\boldsymbol{M(Null)}} \quad (4)$$

3.2 Models

Three binary models were developed, following the four stages of wind diffusion (table 1). All three models will use the same explanatory variables as presented in the next section. The first model (M1) considers the change from no wind to pre-commercialization. Passing the threshold from pre-commercialization to early commercialization is studied with model two (M2). The last step of path creation, moving from early commercialization to commercialization, is measured by the last model (M3).

3.3 Variables

The study aims to measure the desire-related factors that influence wind energy path creation. Wind energy growth is generally measured as the annual increase in installed capacity. However, for path creation, four different stages of installed capacity have been defined in section 3.1. The capacity levels of installed wind energy globally are tracked since 2000 by the International Renewable Energy Agency (2020a). The amount of installed capacity per country is translated into nominal values of the stage of path creation they are in. To control the wind resource differences, only high wind countries are included (Zwarteveen et al., 2021). Sudan is excluded since South Sudan gained independence within the period studied. The dependent variable consists of a panel of 67 countries (Appendix A), studied for the period between 2000 and 2019.

In the meta-analysis of Zwarteveen et al (2021), 170 sub-category factors were identified to influence wind energy diffusion. It was assumed that the categories of economic, environmental, and technical potential factors were related to the desire for wind. To review this in detail, all 170 sub-category factors were screened, sorted, and regrouped. As the outcome, 8 groups of variables were defined that influence the desire for wind. The groups, chosen variables, and data sources are shown in table 2.

The business case potential variable (V4) is a combination of two variables. The first being the electricity price (residential household prices for Chad, Eritrea, Mauritania, Mongolia, Niger, Somalia, Turkmenistan, Venezuela from (United Nations, 2020a) and for the remaining countries from (Global Petrol Prices, 2020)). The 2020 values were discounted for the period using the global average electricity price index for 103 countries (Euromonitor International, 2020). The levelized cost of wind energy (LCoE) (International Renewable Energy Agency, 2019, 2020b) is deducted to calculate the business case potential.

The energy import dependency (V8) is provided directly by The World Bank (2019a), whereas the electricity import dependency (V9) was calculated by deducting the electricity export from the import divided by the gross demand from United Nations (2020f). The spillover variable (V11) considers the fraction of countries in the geographical cluster that has adopted wind energy. Details on the clusters are provided in Appendix A.

Data for the explanatory variables were collected for the 67 high wind countries between 2000 and 2019. Tabachnick and Fidell (2013) recommend screening the accuracy of the data by analysing out-of-range values, by inspecting the plausible means, and by reviewing the standard deviations and univariate outliers. They also state that, regarding missing data, firstly the amount and distribution of missing data needs to be analysed before taking appropriate steps to solve it. All variables (V1-V19) have been screened accordingly. Outliers were omitted for the electricity import dependency (V7), gaps were interpolated for GHG emission (V9). Greenland is missing in the IMF definition. Since is part of the kingdom of Denmark, it was assumed to be an AE. After screening, the balance of the data improved. The dataset remained slightly unbalanced, STATA is however programmed to execute robust regressions under these conditions (StataCorp, 2019). Since logistic regression is used, there is no need for the predictive variables to be of equal variance within each set, normal distribution, or linear dependency with the predictive variable (Tabachnick & Fidell, 2013).

4. Result & discussion

4.1 Descriptive statistics

For both the dependent and the explanatory variables, the descriptive statistics are shown in table 3.I. The three different models were built around the three different dependent binary variables. The number of observations differs per variable, depending on the completeness of the dataset used and the chosen selection. V4, V7, and V8 all have a negative mean. Regarding the business case potential, this illustrates that wind energy exploitation is unlikely to result in cost savings, relative to existing means of electricity generation. For energy security, a negative import is referring to an export. The means of all variables specific to DEEs and AEs are listed in Appendix B.

67 countries are included in this study, of which 17 AEs and 50 DEEs. In the year 2000, 74% of the considered DEEs had no wind installed, compared to only 12% of the AEs (figure 2). In 2019, this was reduced to respectively 34% and 6%. This shows both the increase in diffusion, as well as the lag of DEEs.

Considering the share of commercialized exploitation (figure 3), in 2001 AEs in the commercial wind stage passed 24%, whereas this level was only achieved for DEEs in 2015. This shows a 14-year lag. The rate of change (figure 3) between 2000 and 2010 for AEs and DEEs was respectively 5.3% and 1.2%. For the period 2010 until 2019, this is was 0.7% versus 1.6%. It indicates that the lag increased from 2000 until 2010, but that a catch-up is observed during the second part of the studied period.

4.2 Analysis of variables

The pairwise correlation table (table 4) highlights that most variables have a low correlation. However, exceptions exist, such as variable V12 (globalization) with V6 (education index) or V17 (renewable - hydro) with V15 (fossil - coal). To test for multicollinearity, the Variance Inflation Factors (VIF) were calculated (STATA command "Collin" (Ender, 2010)). As shown in table 5, all VIF values are below 10, indicating there is no major multicollinearity concern (Bowerman & O'Connell, 1990). The only exception is V6 (education index) for M3, which just exceeds the threshold. During the interpretation of the regression results, this must be taken into account. To understand if one of the variables is simply a representation of the time, a separate multicollinearity analysis was executed for each of the models, including the year as a variable. The VIFs for the year variable were between 3.00 and 4.21, demonstrating sufficient independence between the variables in the analysis and the time.

4.3 Results

The outcome of the three binary logistic regression models is stated in table 6. As the specifications show, there is evidence of a proper model fit in comparison to the null model (Prob > Chi^2 = 0.000). Also, the choice for a binary panel model is justified (Prob>=$chibar^2$ = 0.000). Furthermore, the Hausman test results (Hausman, 1978) justify the choice for random effects. The McFadden pseudo-R squared (McFadden, 1974) for M1, M2 and M3 are 0.478, 0.449, and 0.684 respectively. This shows the chosen explanatory variables predict a significant share of the variation in the dependent variable. Furthermore, the model fit for the last stage is better than for the first two stages.

Regarding the business case potential, the log odds for all three models are positive and highly significant. Also, the magnitude of the log odds is increasing across M1 to M2 to M3. A different effect is seen for the economic contribution. The unemployment rate appeared only to have a significant contribution for M3, a positive log odd. Education is significant for M1 and seems to have a positive effect. The multicollinearity problem in M3 does not create any conflicts, since the log odd is not significant. The energy security group of variables shows a more complex picture. Electricity import dependency has a positive log odd for all three models, only M1 and M3 are significant. However, the value for M3 is much larger than for M1. Energy import dependency is also significant for M1 and M3, however, the log odd is positive for M1 but negative for M3. Regarding the environment, no significant impact of GHG is observed for M1 and M2. For M3, the variable has a negative log odd. Smog on the other hand has a positive sign for M2 and M3. Spillover effects seem to play a significant role, especially in M3 for both globalization and neighbour influence. Globalization only also has a significant effect in M1, yet much smaller compared to M3. Vested interests show that hydro energy has a positive log odd for all three models. Also, the most significant influences of vested interests seem to take place in M3: gas, coal, and hydro positive, oil negative. The country classification did not significantly impact the binary variable.

Table 7 shows the marginal effect, calculated by using equation 3. One dollar improvement in the business case potential will increase the odds to move from no wind to pre-commercialization with a factor of 1.11, from pre-commercialization to early commercialization with a factor of 1.33, and from early commercialization to commercialization with a factor of 1.59. This indicates that the business case has a significant impact and the magnitude increases in later stages of path creation.

4.4 Discussion

4.4.1 Quantitative and qualitative research comparison

As stated previously, most research in this area is qualitative in nature. Table 8 shows a comparison between this study and the existing path creation research.

Regarding the business case, this study complements other qualitative studies. A negative business case is a barrier to path creation and in addition, a positive business case forms a driver. Economic contribution, more specifically, job creation is also seen as a driver in the literature, which is also confirmed by this study. Both quantitative and qualitative studies confirm energy security as a driver. However, this study shows energy import to be a barrier in later stages of path creation. The negative correlation between energy import and entering commercial wind exploitation means the higher the energy import level, the less likely a country will enter the commercial exploitation stage; or the lower the energy import level, the more likely it to enter the commercial exploitation stage. The question is if this is cause or effect? Does a higher import level lead to less wind diffusion, or does a higher wind diffusion lead to lower energy import levels? The climate change risk mitigation as a driver has not been confirmed by this study. A higher GHG emission does not form a confirmed driver for the early stages of path creation, it only forms a barrier to the last stage of path creation. Here the same question applies: cause or effect? More wind energy has the consequence of lower GHG emissions. Spillover effects identified in mixed methods studies were also confirmed by this research. However, vested interests show a more complex picture. In qualitative and mixed methods research, the dominance of fossil fuels is presented as a barrier. However, this research shows gas and coal-based electricity are drivers in path creation. Both quantitative and qualitative studies show the importance of hydro. A hydro lock-in however was not observed.

The observed lag in wind power adoption between DEEs and AEs was 14 years. DEEs lagging AEs was also concluded by Halleck-Vega and Mandel (2018), however, the 14 years is slightly longer than the decade delay caused by being a follower (Bento & Fontes, 2016).

Building on studies in this area, the results suggest that a positive business case potential is a key driver of wind path creation in DEEs, as are vested interests. The results do not confirm climate change risk mitigation as a driver, it introduces vested fossil interests as drivers instead of barriers and it does not confirm a hydro lock-in. What do these differences mean? Firstly, business case related drivers are key to path creation of wind exploitation. Secondly, energy diversification is observed instead of lock-in. Thirdly, GHG reduction is often considered a climate change risk mitigation strategy (Edenhofer et al., 2011). However, this study showed that the GHG level was not a driver for the early stages of path creation for wind exploitation.

António Guterres, the UN Secretary-General warned that “adaptation must not be the neglected half of the climate equation” (UN News, 2021). Climate adaptation is the response to a changing climate rather than measures to prevent climate change. Climate adaptation is an important driving force behind business model innovation (DiBella, 2020). A different approach to the deployment of renewable energy is, not to avoid climate change, but to be more resilient to climate change (Mauree et al., 2019). The energy sector will be affected in different ways by a changing climate, each technology in a different way (Ciscar & Dowling, 2014). The results show the positive impact of hydropower increase on the path creation of wind diffusion. This indicates climate change adaptation as a driving factor for wind energy path creation. Dependence on only hydropower makes the energy supply vulnerable to climate change with less rain (Espinoza & Vredenburg, 2010). The benefits of wind are that it provides decentralized electricity, is water-independent (for more about water-energy nexus (Teotónio, Rodríguez, Roebeling, & Fortes, 2020)), is flood resistant (even offshore wind energy exists), and has a short construction time (Jaber, 2014). Also, in case of damage, only a small unit needs repair, compared to larger units in for example gas turbine-based electricity generation. This results in less impact on electricity production. The only downside is the intermittency. The combination with hydropower is technically interesting since the excess of energy can be stored and if the wind blows, it preserves the water levels in case of longer droughts. GHG reduction as a risk mitigation strategy to avoid global climate change requires collective action for a global problem (Ostrom, 2010). However, climate adaptation measures require local action for local problems (Mauree et al., 2019). The findings in this study indicate that local actions for local problems are prioritized over global issues (Brunel & Johnson, 2019). Moreover, human-caused GHG emissions are not the only factors influencing climate change (Cohen & Stanhill, 2021; Dorman, 2021; Haywood, 2021; Lourens, 2021; Stenchikov, 2021). Even if countries become carbon neutral, there remains a risk of climate change. Therefore, the focus on climate adaptation strategies is highly relevant.

What consequences does this have? It introduces a different focus in new countries for path creation diffusion. There are indications that the motivation to exploit wind energy seems to be less driven by climate change mitigation, more by the business case value and climate adaptation. The implications for the market entry strategy of the wind power OEM are described in the next section.

4.4.2 Wind power OEM strategy implications

Wind turbines are the practical components for wind diffusion path creation. Since OEMs control of the design, installation, and operation of wind turbines, they play an instrumental role in path creation. The research results and how they relate to OEMs are visualized in figure 4. At the top, it contains the distribution of the considered countries for 2019 followed by the regression results. At the bottom, it shows the mean values for the variables for 2000-2019, sorted into AEs and DEEs (details in Appendix B). In the middle, the OEM implications, the plausible approaches for business managers in wind power OEMs to promote path creation from one stage to another. Specific for each country, these approaches can be taken into consideration by the wind power OEM to develop successful market entry and development strategies.

The first stage transition is from no wind to the first wind farm. Introducing flexibility in the energy generation system is necessary for the uptake of large-scale intermittent wind energy (Barasa, Bogdanov, Oyewo, & Breyer, 2018; Chen, McElroy, Wu, Shu, & Xue, 2019). The early stage of path creation only introduces a very small amount of intermittency which has, therefore, limited impact on grid stability. This is the testing phase. Seventeen DEEs did not exploit wind energy at all in 2019 and only one AE. Business case potential, as one of the drivers, shows a negative value for many DEEs. Also, many DEEs seem to be electricity and energy exporters, rather than importers. The lower education level and lower spillover effects introduce further barriers for DEEs. This introduces implications for OEMs that aim to enter these markets without any wind installed. Firstly, the OEMs must study the country’s specific business case potential to ensure that the LCoE is below the electricity price. This means OEMs should reduce the LCoE and in parallel work with the industry and government to ensure the unsubsidized electricity prices will be implemented. Secondly, work with hydropower OEMs and operators on combined growth strategies. Synergies could be created through the technical integration of their operational systems. Thirdly, invest in education to increase the understanding of the consequences of the electricity sources choice. Creating educational programs or competitions accessible for students in countries without wind energy would disseminate knowledge to new areas. Arnold (2018) highlights the important role multinational companies have in providing education to achieving the SDGs. Therefore, OEMs should work with governments on climate adaptation and energy security strategies. For example, this could be done by forming an OEM advisory board together with existing fossil and hydro players to advise the governments. For energy importing countries, wind exploitation increases energy security. For energy exporting countries, wind exploitation reduces local consumption of energy, hence maximizing energy export.

The second stage transition is from pre-commercial to early commercial exploitation. In 2019, nine DEEs and one AE were in the pre-commercialization stage. Regarding the breakthrough to early commercialization, business case potential, hydro energy diffusion, and air quality form significant drivers. Despite a higher smog level in DEEs, the lower hydropower level and negative business case potential still limit wind energy diffusion in DEEs. Compared to the first step in path creation, the strategic focus for OEMs now includes air quality. Coal and oil based electricity generation results in relatively high $PM_{2.5}$ emissions (United States Environmental Protection Agency, 2010), which have significant health implications. For wind power OEMs, it is recommended to engage in clean air initiatives to stimulate further wind energy diffusion. Many AEs have strict air quality regulations governing emissions of particulate matter (Wu et al., 2017), OEMs could lobby with environmental stakeholders to strengthen regulations in many DEEs.

The last studied stage transition of path creation is from early commercialization to commercialization. Additional drivers are unemployment and a variety of vested interests in traditional power. The barriers of vested interests in oil, GHG, and energy import are introduced. Additional to approaches in stages one and two, the OEMs targeting further market growth might want to particularly focus on collaboration with fossil and hydropower OEMs.

Energy transition has the risk of defining good (low carbon technology) and bad (high carbon technology) energy resources. However, the promotion of wind exploitation fits in a diversification environment, to de-risk the total energy portfolio, without defining good or bad. The selection of the optimal technology is eventually the next step of the evolutionary process (Zartha Sossa et al., 2021). Because of the increase in scale in the commercialization stage, economic values become important: the need for job creation. Many countries have introduced localization requirements for wind energy (for example, Russia (Kudelin & Kutcherov, 2021) or South Africa (Leigland & Eberhard, 2018)). Currently, manufacturing, sales, and research for many OEMs are still concentrated in Europe (Lacal-Arántegui, 2019). Instead of waiting and responding to local content requirements of new markets, another more inclusive approach could be to actively drive localization to stimulate large-scale exploitation.

The recommendation for practitioners, such as strategic managers within the wind power OEMs, are: stimulate local job and value creation even though it might not be a local legal requirement, collaborate with hydro and fossil OEMs on joined energy plans and joined operations, and collaborate with governments on education and environmental programs related to clean air and climate mitigation.

4.4.3 Limitations and scope for further research

The results of this study should be interpreted with some caution. Path creation is a highly complex socio-economic-technical phenomenon which to date, for wind energy, has been largely studied qualitatively. Many argue that a simplistic quantitative regression will be unable to enhance understanding of this complexity (for example, (Sorrell, 2018)). However, it would not be the first study to digest socio-economic-technical matters quantitively: for instance, in a review by Chappin and Van der Lei (2014), 23 of 48 considered studies on socio-technical adaptation of interconnected infrastructures to climate change were quantitative. It is also important to view problems through quantitative as well as a qualitative lens to get a more comprehensive view of phenomena.

The scope of this study introduced limitations. It only focussed on the desire for wind energy, not for the mechanism of change (as defined by Zwarteveen et al (2021)). Also, even though 67 countries were studied over 20 years, the size of the dataset for certain countries was limited. Including more countries would have been possible. However, this would include countries with fewer wind resources, and introduce the need to take the amount of wind energy capacity into consideration. The calculation of the business case took 2020 values into account and discounted them based on the average electricity price index. A country-specific real historical electricity price would have been better, but the measure selected allowed for a more complete data set. The very high significance of this variable (1%) showed its appropriateness for usage. GHG and energy import appeared to be a barrier for the last stage of path creation, the limitation of regression is that it cannot differentiate between cause or effect.

Further research could extend the model to simulate the exploitation paths for a selection of countries. Furthermore, the effects of state-of-the-art technology such as utility-scale battery storage or hydrogen on path creation lend themselves to further analysis. Currently, wind energy is to be used locally, but by converting it into either hydrogen or ammonia, it can be transported and exported. In recent years, a catch-up was observed: the rate of DEEs adopting wind energy exceeded that of AEs. Future research is needed to understand the potential saturation rates of AEs and further diffusion expansion for DEEs.

Further studies could make a risk assessment of climate adaptation (higher average temperatures, temperature extremes, shortage of water, melting ice, increase in sea level, climate migration) and understand how and where wind energy diffusion is supporting the resilience in this change. The future diffusion of energy storage technologies (batteries, hydropower, or hydrogen) on the diffusion of wind energy to improve climate resilience is a field that might deserve further attention as well.

The global economic growth requiring a consistent increase in energy exploitation introduces negative side effects (for example, health issues for non-conventional oil and gas in the US (Apergis, Mustafa, & Dastidar, 2021)). The question is to which level exploitation of wind energy is desirable (Tabassum-Abbasi, Premalatha, Abbasi, & Abbasi, 2014).

This study used a deterministic approach. Evolutionary economists argue “that the paths and stages that Innovation Systems follow towards sustainability is an evolutionary process and not of an intentional nature” (Zartha Sossa et al., 2021). Hence, there might be limits to the impact of the strategic responses of an OEM manager, however, the role of strategy to stimulate innovation and experimentation is likely to influence the diversification and selection.

This analysis is based on the historical path creation of wind energy diffusion. The findings presented in figure 4 could potentially even be used for business managers in OEMs of nascent clean technologies - such as hydrogen or nuclear fusion – for which historical data is still missing.

5. Conclusion

Wind power OEMs form an important part of the wind industry. There are numerous markets with unused wind potential. With the right strategy, OEMs can enter new markets and turn this potential into new business opportunities.

This study modelled path creation for wind energy diffusion. It appeared that DEEs lag AEs by approximately 14 years; in 2015 the same share of DEEs achieved commercial exploitation as AEs in 2001. However, recent data suggest that DEEs are catching up.

The diffusion of wind energy can be split into factors related to desire and factors related to the mechanism of change. This study showed the model only taking the desire into account has a good model fit, moreover, the model fit improved in the later stages of path creation.

The business case potential appeared to be a constant, significant, and strong driver for path creation. The difference in diffusion levels between AEs and DEEs can partly be explained by the business case potential. Negative business cases especially in DEEs create significant barriers. One USD improvement in the business case potential resulted in a factor 1.11 increase in odds to move from no wind to pre-commercial wind. The business case potential impact increased in strength for later stages of path creation.

Contrary to the evidence from the existing qualitative wind energy path creation studies, GHG emission levels have no influence on early diffusion of wind energy, indeed reduction in smog ($PM_{2.5}$) levels appears to be a more important issue in DEEs. Also, vested interests in coal, gas, and hydro energy act as drivers, rather than barriers of early diffusion of wind energy, perhaps related to a need to diversify energy supply.

The key implication for OEM business strategy is to create inclusive market entry strategies. Besides improving the business case for wind energy, local job creation is one of the crucial strategies for business managers of wind power OEMs to stimulate the diffusion of wind. Instead of waiting and responding to local content requirements of new markets, another approach could be to actively drive localization to stimulate large-scale exploitation. This would stimulate the uptake of wind and the inclusive market entry approach would also have a large impact on achieving the Sustainable Development Goals (Arnold, 2018). Localization can be achieved through diversifying supply chains, decentralization of research and development, and flexible production (Arnold, 2018).

Sector-specific private-public collaboration is essential to work towards more detailed approaches (Redman, 2018). Strategic private collaboration with hydro and fossil OEMs to joined energy expansion and operation is another novel approach for business managers of wind power OEMs. Strategic public collaboration can focus on the environmental contribution of climate adaptation and clean air contribution.

The policy implications of this study are that it is essential for policy makers to stimulate private-public partnerships, increase local content requirements while assessing the impact this has on the electricity price. Long-term policies allow for industrial development, hence the stability of policies is important (Barradale, 2010). Additional implications are to link the energy policy with climate adaptation, clean air, and economic development policies.

This research brings broader implications for other industries involved in sustainability: a revised triple bottom line for inclusive market entry. Regarding the economic dimension, for an inclusive market entry of sustainable products, the value proposition needs to be both cost-competitive for the country compared to the alternatives and at the same time profitable for the company that enters the market. The social dimension could be defined as the corporate responsibility to contribute to education and local job creation. Lastly, the environmental dimension should include climate adaptation in addition to the existing emission focus. True development happens if the benefits of internationalization are not merely flowing to the headquarters in AEs, but are staying in the country where the products are deployed.

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Tables

TABLE 1

Stages in wind diffusion path creation

Stage	**Total installed capacity in China and India [MW]** (Surana & Anadon, 2015)	**Volume bandwidths installed capacity chosen for this study [MW]**	**Rationale**
No wind		0-1 MW	No wind farm
Pre-commercialization	40 MW / 40 MW	>1-50 MW	1 wind farm
Early commercialization	370 MW / 970 MW	>50-500MW	2-10 wind farms
Commercialization	5230 MW / 44330 MW	>500MW	>10 wind farms

TABLE 2

Independent variables, groups, measurement units and data sources

Dependent variables		Unit	Rationale	Source
V1	Total installed wind capacity M1	Stage: no wind to pre-commercialization	Understanding path creation from no wind to one wind farm	(International Renewable Energy Agency, 2020a)
V2	Total installed wind capacity M2	Stage: pre-commercialization to early commercialization	Understanding path creation from one wind farm to 10 wind farms	(International Renewable Energy Agency, 2020a)
V3	Total installed wind capacity M3	Stage: early commercialization to commercialization	Understanding path creation from 10 wind farms to more	(International Renewable Energy Agency, 2020a)
Independent variables		**Unit**	**Rationale**	**Source**
Business case				
V4	Business case potential	USD / MWh	Price advantage of wind energy compared to electricity price. Electricity price – LCoE of wind energy	(Euromonitor International, 2020; Global Petrol Prices, 2020; United Nations, 2020a) (International Renewable Energy Agency, 2019, 2020b)
Economic contribution				
V5	Unemployment rate	Fraction of labour force without work	Urgency for a country to create jobs, as measured in unemployment rate	(The World Bank, 2019c)
Education				
V6	Education index	Index	Education level to influence energy source choice	(United Nations, 2020b)
Energy security				
V7	Electricity import dependency	Electricity net import as fraction of electricity gross demand	Security to provide the required electricity	(United Nations, 2020f)
V8	Energy import dependency	Energy nett import as fraction of total energy consumption	Security to provide the required energy	(The World Bank, 2019a)
Environment				
V9	GHG emission	CO_2 emissions (metric tons per capita)	High CO_2 levels might influence choice for low CO_2 energy technology	(The World Bank, 2020)
V10	Smog	$PM_{2.5}$ air pollution, mean annual exposure in mg / m^3	High $PM_{2.5}$ levels might influence choice for low $PM_{2.5}$ energy technology	(The World Bank, 2019b)
Spill over				
V11	Neighbour influence	Fraction of countries in geographical cluster that has adopted wind energy	The effect of having neighbours with wind energy. Knowledge and products might spill over across borders.	(International Renewable Energy Agency, 2020a)
V12	Globalization	KOF globalization index	Global partners with wind energy. Knowledge and products might spill over through globalized network	(Gygli, Haelg, Potrafke, & Sturm, 2019)
Vested interests				
V13	Fossil - Oil	Oil based electricity production in kWh billion	Existing fossil interests might have impact on wind exploitation	(United Nations, 2020e)
V14	Fossil - Gas	Gas based electricity production in kWh billion	Existing fossil interests might have impact on wind exploitation	(United Nations, 2020e)
V15	Fossil – Coal	Coal based electricity production in kWh billion	Existing fossil interests might have impact on wind exploitation	(United Nations, 2020e)
V16	Renewable - Solar	Solar based electricity production in kWh billion	Existing renewable interests might have impact on wind exploitation	(United Nations, 2020d)
V17	Renewable - Hydro	Hydro based electricity production in kWh billion	Existing renewable interests might have impact on wind exploitation	(United Nations, 2020c)
Country classification				
V18	Country classification IMF	Category (1=developing and emerging economies, 0=advanced economies)	Controlling variable for country classification	(International Monetary Fund, 2018)

TABLE 3

The descriptive statistics

Dependent variables		Unit	Obs	Mean	Std. Dev.	Min	Max
V1	Total installed wind capacity M1	Stage: no wind to pre-commercialization	793	0.27	0.45	0.00	1.00
V2	Total installed wind capacity M2	Stage: pre-commercialization to early commercialization	413	0.47	0.50	0.00	1.00
V3	Total installed wind capacity M3	Stage: early commercialization to commercialization	547	0.64	0.48	0.00	1.00
Independent variables		**Unit**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
Business case							
V4	Business case potential	USD / MWh	1320	-27.05	87.12	-140.82	848.45
Economic contribution							
V5	Unemployment rate	Fraction of labour force without work	1320	0.08	0.05	0.00	0.33
Education							
V6	Education index	Index	1217	0.63	0.20	0.12	0.95
Energy security							
V7	Electricity import dependency	Electricity import as fraction of electricity gross demand	1232	-0.06	0.66	-8.01	0.85
V8	Energy import dependency	Energy import as fraction of total energy consumption	917	-0.59	1.65	-8.85	0.94
Environment							
V9	GHG emission	CO_2 emissions (metric tons per capita)	1137	5.26	4.94	0.02	20.40
V10	Smog	$PM_{2.5}$ air pollution, mean annual exposure in mg / m^3	1206	30.59	20.18	5.96	97.60
Spill over							
V11	Neighbour influence	Fraction of countries in geographical cluster that has adopted wind energy	1340	0.57	0.31	0.00	1.00
V12	Globalization	KOF globalization index	1188	61.37	16.33	24.51	91.31
Vested interests							
V13	Fossil - Oil	Oil based electricity production in kWh billion	1229	8.18	18.67	0.00	158.94
V14	Fossil - Gas	Gas based electricity production in kWh billion	1227	52.97	146.40	0.00	1513.41
V15	Fossil – Coal	Coal based electricity production in kWh billion	1227	107.96	426.05	0.00	4308.16
V16	Renewable - Solar	Solar based electricity production in kWh billion	1210	1.05	5.88	0.00	96.72
V17	Renewable - Hydro	Hydro based electricity production in kWh billion	1212	43.52	113.06	0.00	1193.37
Country classification							
V18	Country classification IMF	Category (1=developing and emerging economies, 0=advanced economies)	1340	0.75	0.44	0.00	1.00

OBS = number of observations, Std.Dev. = standard deviation, Min = minimum, Max = Maximum

TABLE 4
Pairwise correlation

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18
V1	1.00																	
V2	.	1.00																
V3	.	.	1.00															
V4	0.17	-0.14	0.45	1.00														
V5	0.14	-0.18	0.03	-0.02	1.00													
V6	0.42	0.16	0.26	0.28	0.10	1.00												
V7	0.08	-0.10	0.02	0.06	0.07	-0.01	1.00											
V8	0.22	0.03	0.13	0.33	0.01	0.08	0.02	1.00										
V9	0.14	0.18	0.17	-0.05	0.01	0.72	0.07	-0.15	1.00									
V10	-0.22	-0.05	-0.06	-0.17	-0.06	-0.64	0.15	-0.13	-0.32	1.00								
V11	0.14	0.21	0.36	0.29	-0.20	0.62	-0.04	0.15	0.37	-0.42	1.00							
V12	0.48	0.32	0.38	0.11	0.03	0.87	-0.01	0.21	0.59	-0.55	0.68	1.00						
V13	0.10	0.09	0.06	-0.07	-0.08	0.10	0.04	0.08	0.24	0.12	0.03	0.09	1.00					
V14	0.32	-0.12	0.20	0.02	-0.07	0.27	0.03	0.10	0.42	-0.13	0.04	0.24	0.41	1.00				
V15	0.38	0.03	0.23	0.00	-0.07	0.11	0.02	0.12	0.23	0.12	0.14	0.14	0.20	0.46	1.00			
V16	0.16	0.17	0.21	0.20	-0.04	0.18	0.01	0.12	0.16	-0.07	0.20	0.19	0.09	0.40	0.44	1.00		
V17	0.35	0.04	0.20	-0.02	-0.09	0.17	-0.02	0.04	0.23	-0.04	0.15	0.19	0.19	0.35	0.79	0.39	1.00	
V18	-0.05	-0.29	-0.32	-0.23	0.13	-0.67	-0.03	-0.13	-0.55	0.55	-0.64	-0.75	-0.07	-0.22	-0.08	-0.21	-0.12	1.00

TABLE 5
VIF for the different models

	VIF - M1	**VIF - M2**	**VIF - M3**
V1	1.69		
V2		1.38	
V3			1.98
V4	1.38	1.72	3.14
V5	1.78	2.16	1.35
V6	6.26	7.22	10.14
V7	1.17	1.60	1.17
V8	1.31	1.26	1.43
V9	3.47	3.58	3.79
V10	2.76	3.14	4.21
V11	2.05	3.65	3.55
V12	3.57	4.08	8.02
V13	1.56	1.65	1.74
V14	2.53	2.58	2.80
V15	2.16	1.46	4.74
V16	1.11	1.48	1.74
V17	1.80	1.64	3.34
V18	1.74	4.16	5.30
Mean VIF	2.27	2.67	3.65

TABLE 6
Regression results

Model		M1	M2	M3
Variables		**Log odds**	**Log odds**	**Log odds**
	Constant	-62.947***	-11.783	-119.541**
	Business case			
V4	Business case potential	0.104***	0.288***	0.464***
	Economic contribution			
V5	Unemployment rate	9.505	-2.498	129.410***
	Education			
V6	Education index	35.578**	3.689	-45.690
	Energy security			
V7	Electricity import dependency	4.478**	6.844	33.992*
V8	Energy import dependency	2.382*	0.678	-2.670*
	Environment			
V9	GHG emission	0.072	0.157	-1.493*
V10	Smog	0.143	0.302**	0.863***
	Spill over			
V11	Neighbour influence	8.112	2.235	46.756***
V12	Globalization	0.421**	0.267	1.396***
	Vested interests			
V13	Fossil – Oil	0.074	-0.004	-0.269*
V14	Fossil – Gas	0.037	0.017	0.214***
V15	Fossil – Coal	0.003	0.015	0.026***
V16	Renewable – Solar	257.083	51.045	0.675
V17	Renewable - Hydro	0.211**	0.060***	0.124***
	Country classification			
V18	Country classification IMF	9.751	-8.515	-11.778
Specifications		**Value**	**Value**	**Value**
	Number of Observations	518	305	379
	Number of Groups	46	39	35
	LR $chi^2(15)$	142.04	147.78	263.69
	Log likelihood	-77.684	-90.769	-61.022
	Prob > chi^2	0.000	0.000	0.000
	/lnsig2u	4.813	5.574	5.627
	sigma_u	11.093	16.233	16.665
	Rho	0.974	0.988	0.988
	LR test of rho=0: $chibar^2(01)$	147.83	141.54	73.17
	Prob >= $chibar^2$	0.000	0.000	0.000
	Hausman	0.875	CNA	CNA
	McFadden's pseudo-R squared	0.478	0.449	0.684

* 0.1, ** 0.05, ***0.01 significant levels, CNA = Convergence not achieved

TABLE 7
Marginal effect for the Business Case Potential (V4)

Model	Regression coefficient	Marginal effect
M1	0.104	1.110
M2	0.288	1.334
M3	0.464	1.590

Table 8
Qualitative and quantitative research results comparison

Theme	Qualitative and mixed methods research (‡ = mixed methods) Driver	Barrier	Quantitative research (¶ = this study) Driver	Barrier
Business case	High and volatile electricity price (Ericsson et al., 2011)	Disequilibrium between incentives and contributions (Inoue & Miyazaki, 2008)	Positive business case potential	High LCoE (Wijayatunga et al., 2006) Negative business case potential
Economic contribution	Export potential, job creation (Jacobsson & Lauber, 2006)		Unemployment rate	
Education	Available competences for wind energy (Bento & Fontes, 2015)		Education index	
Energy security	Security of supply (Jacobsson & Lauber, 2006) Energy security concerns (Cherp et al., 2017)		Electricity import Energy import	Energy import
Environment	Forest die-back, climate change prevention (Jacobsson & Lauber, 2006)		Smog	GHG
Spill over	First wind project coming from international private developer (Steffen et al., 2018)‡		Neighbour influence Globalization index	
Vested interests	De-institutionalization of fossil fuel sector, dependence on only Hydropower (Espinoza & Vredenburg, 2010)	Strong fossil fuel sectors (Espinoza & Vredenburg, 2010) Negative path interdependence with dynamics of established paths (hydro lock-in) (Steen & Hansen, 2018)‡	Gas based electricity production Coal based electricity production Hydro based electricity production	Oil based electricity production
Explanation DEE lag	Missing actor-based spill over, environment not attractive for international private actors (Steffen et al., 2018)‡ Solving energy crisis is based on socio-economic issues, environment important yet secondary (Espinoza & Vredenburg, 2010)		Negative business case potential High level of energy security Low level of neighbour spill over Low level of globalization Low level of hydropower Weak grid leading to lower plant factor, leading to higher costs per kWh (Wijayatunga et al., 2006)	

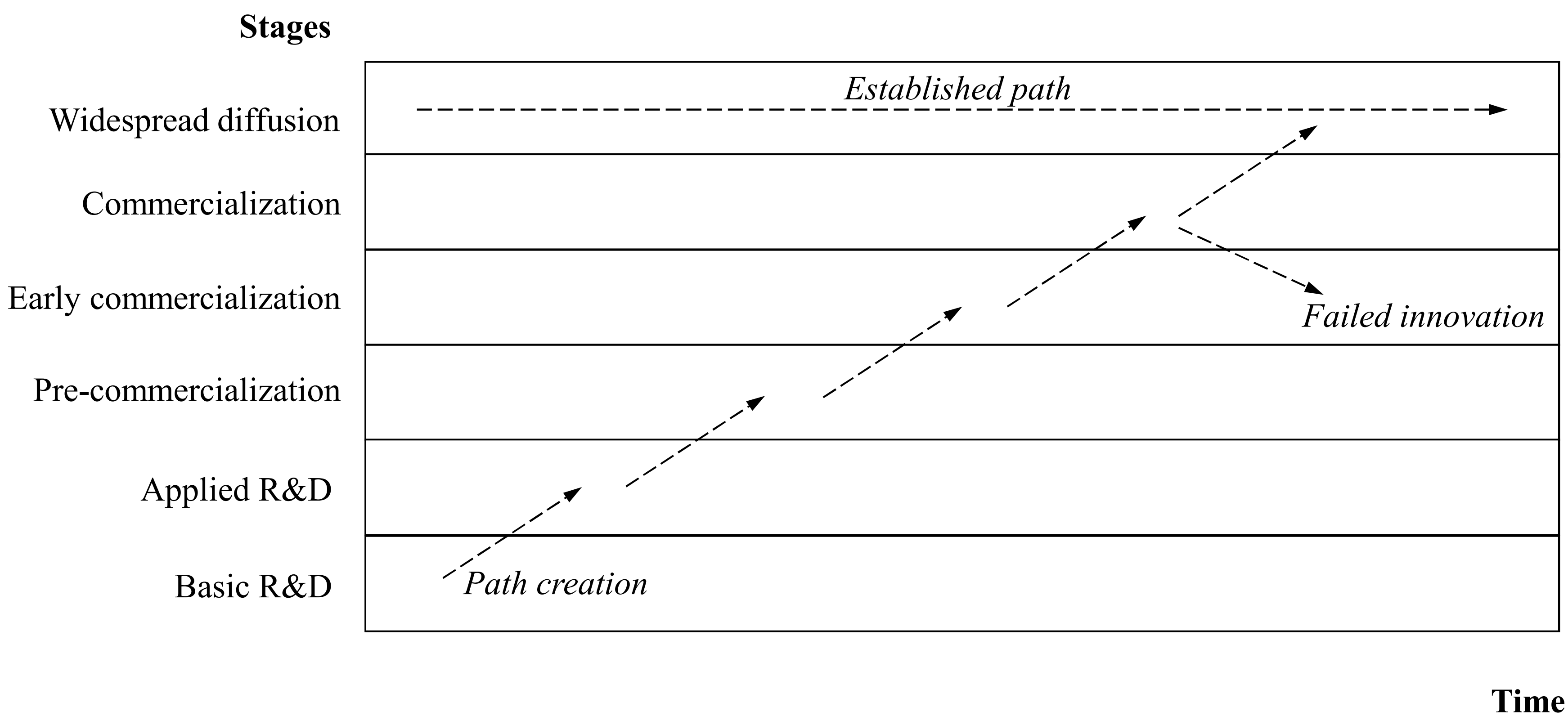
Figure legends

FIGURE 1. Paths and stages in path creation. Based on (Geels, 2002; Polzin, 2017; Surana & Anadon, 2015)

FIGURE 2. Path creation status anno 2000 and 2019, expressed as a share of the total number of AEs and DEEs.

FIGURE 3. Commercial stage development over the years, expressed as share of the total number of AEs and DEEs.

FIGURE 4. OEM strategic approaches to stimulate wind energy path creation, based on significant drivers and barriers and variable values for DEEs and AEs (details in Appendix B). Neighb. inf. = neighbour influence, el = electricity



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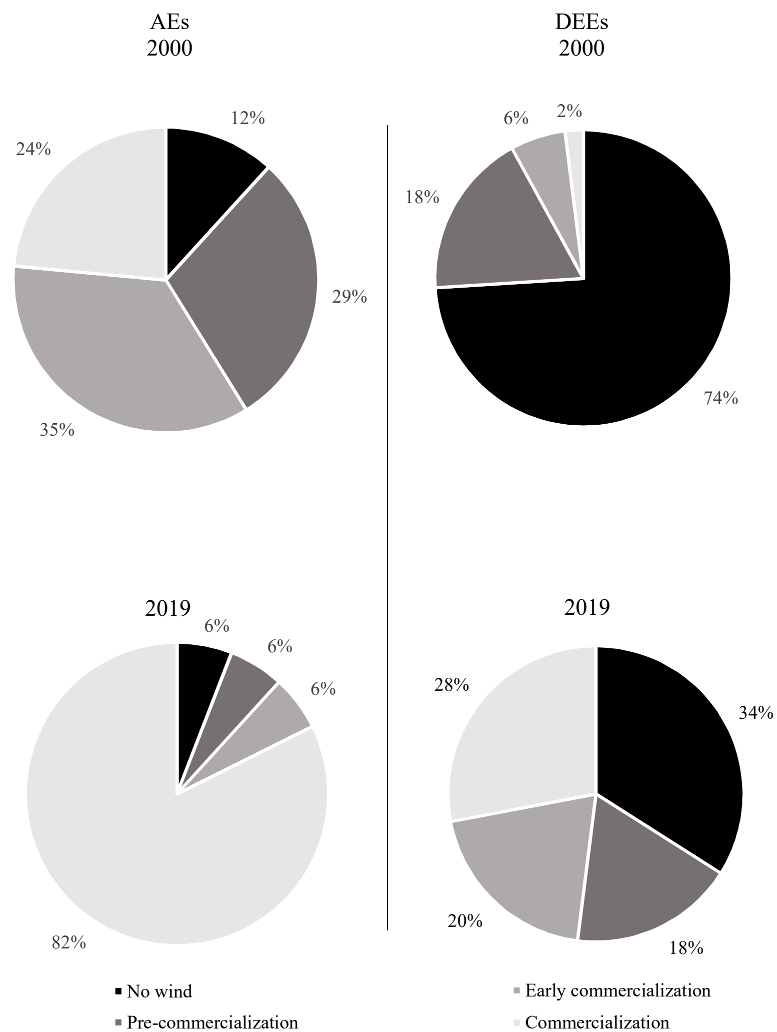

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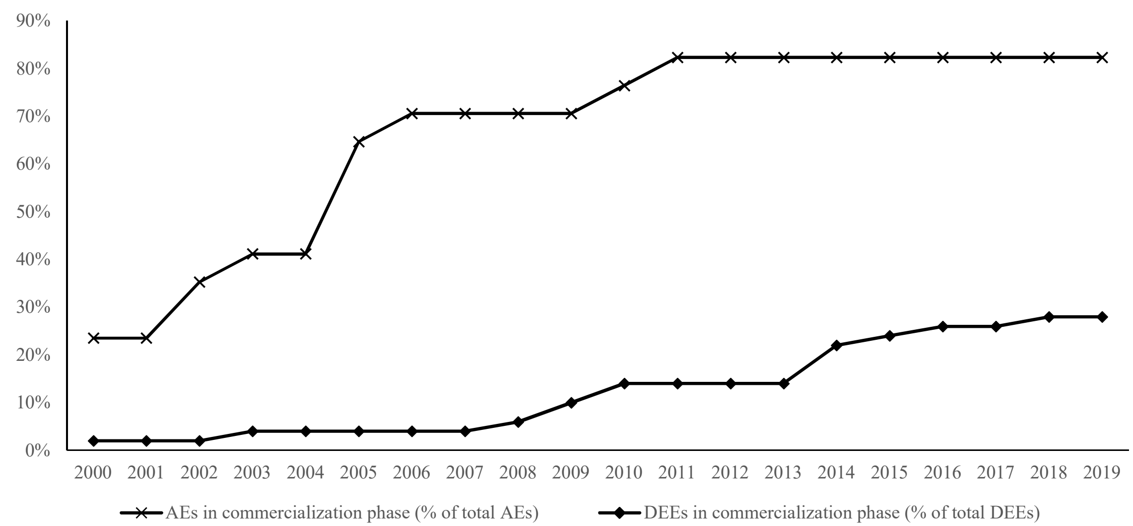

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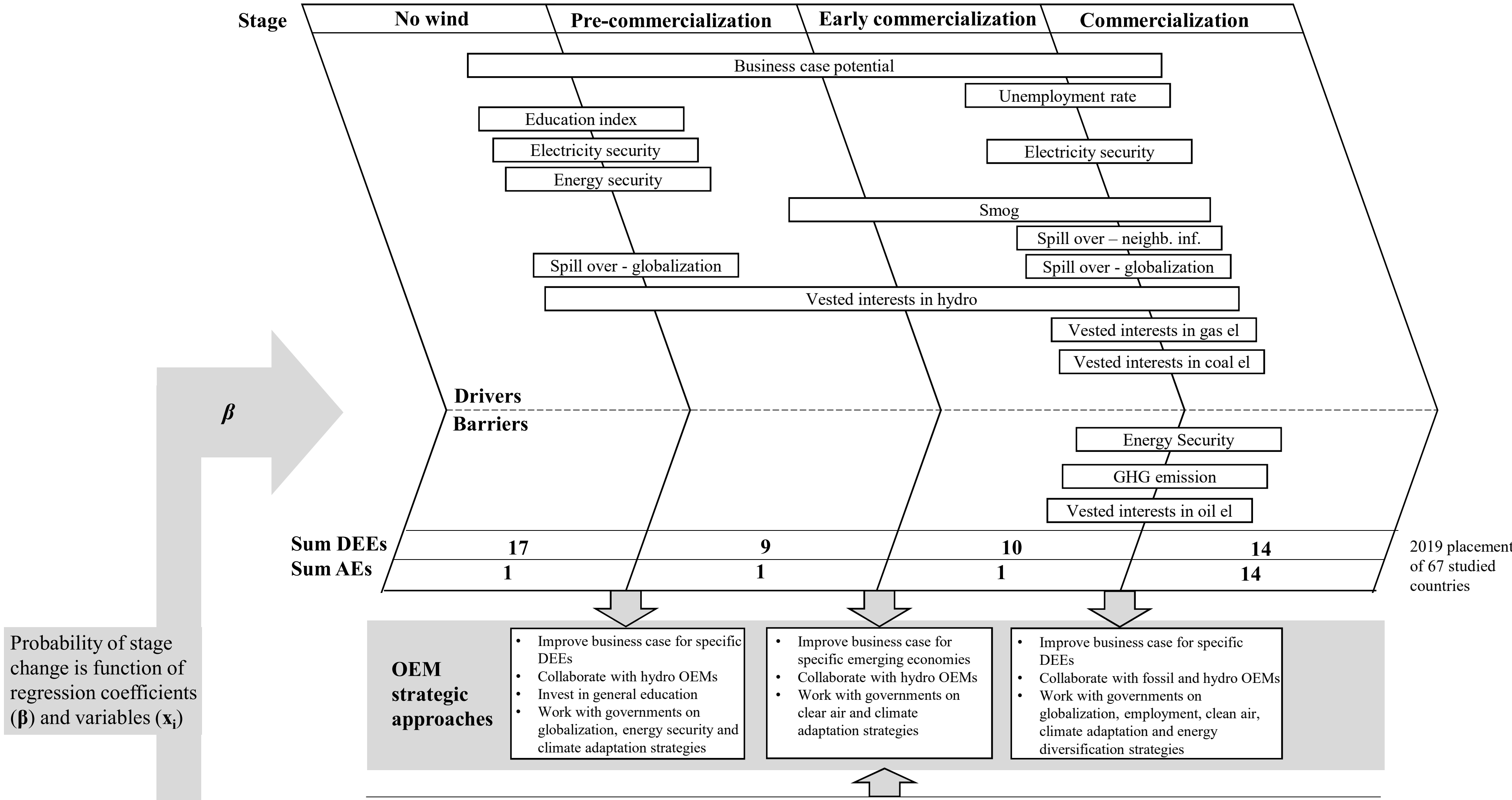

		2000-2019 Mean	□ DEE	■ AE		
Variable	**Unit**	**- -**	**-**	**0**	**+**	**++**
Business case potential	USD / MWh		□		■	
Unemployment rate	Fraction of labour force				■	□
Education Index	Index				□	■
Electricity security	Electricity import as fraction of electricity gross demand	□	■			
Energy security	Energy import as fraction of total energy consumption	□	■			
GHG emission	Metric tons CO_2 per capita				□	■
Smog	Mean annual $PM_{2.5}$ exposure in mg / m^3				■	□
Neighbor influence	Fraction of countries in cluster with wind energy				□	■
Globalization	KOF globalization index				□	■
Vested interests fossil - oil	Oil based electricity production in Billion kWh				□	■
Vested interests fossil - gas	Gas based electricity production in Billion kWh				□	■
Vested interests fossil – coal	Coal based electricity production in Billion kWh				□	■
Vested interests renewable – solar	Solar based electricity production in Billion kWh				□	■
Vested interests in renewable - hydro	Hydro based electricity production in Billion kWh				□	■

Appendices

Appendix A List of included countries

Table A1
Countries and clusters

Country	Cluster
Afghanistan	Central Asia
Kazakhstan	Central Asia
Mongolia	Central Asia
Russia	Central Asia
Turkmenistan	Central Asia
Uzbekistan	Central Asia
China	East Asia
India	East Asia
Indonesia	East Asia
Japan	East Asia
Pakistan	East Asia
Belarus	Europe
Czech Republic	Europe
Denmark	Europe
France	Europe
Germany	Europe
Iceland	Europe
Ireland	Europe
Netherlands	Europe
Norway	Europe
Poland	Europe
Spain	Europe
Sweden	Europe
Ukraine	Europe
United Kingdom	Europe
Argentina	Latin America
Bolivia	Latin America
Brazil	Latin America
Chile	Latin America
Colombia	Latin America
Paraguay	Latin America
Uruguay	Latin America
Venezuela	Latin America
Iran	Middle East
Iraq	Middle East
Oman	Middle East
Saudi Arabia	Middle East
Syria	Middle East
Turkey	Middle East
Algeria	North Africa
Chad	North Africa
Egypt	North Africa

Eritrea	North Africa
Libya	North Africa
Mali	North Africa
Mauritania	North Africa
Morocco	North Africa
Niger	North Africa
Tunisia	North Africa
Canada	North America
Greenland	North America
Mexico	North America
United States	North America
New Zealand	Oceania
Australia	Oceania
Ethiopia	Sub Saharan Africa
Somalia	Sub Saharan Africa
Angola	Sub Saharan Africa
Congo DR	Sub Saharan Africa
Kenya	Sub Saharan Africa
Madagascar	Sub Saharan Africa
Mozambique	Sub Saharan Africa
Namibia	Sub Saharan Africa
Nigeria	Sub Saharan Africa
South Africa	Sub Saharan Africa
Tanzania	Sub Saharan Africa
Zambia	Sub Saharan Africa

Appendix B means of variables per country classification

Table B1
2000-2019 means of variables, split in DEE and AE

Independent variables		Unit	Mean AE	Mean DEE
Business case				
V4	Business case potential	USD / MWh	8.482	-38.417
Economic contribution				
V5	Unemployment rate	Fraction of labour force without work	0.065	0.081
Education				
V6	Education index	Index	0.862	0.548
Energy security				
V7	Electricity import dependency	Electricity import as fraction of electricity gross demand	-0.020	-0.072
V8	Energy import dependency	Energy import as fraction of total energy consumption	-0.240	-0.723
Environment				
V9	GHG emission	CO_2 emissions (metric tons per capita)	9.968	3.669
V10	Smog	$PM_{2.5}$ air pollution, mean annual exposure in mg / m^3	11.516	37.069
Spill over				
V11	Neighbour influence	fraction of countries in geographical cluster that has adopted wind energy	0.909	0.456
V12	Globalization	KOF globalization index	83.037	54.438
Vested interests				
V13	Fossil - Oil	Oil based electricity production in kWh billion	10.364	7.405
V14	Fossil - Gas	Gas based electricity production in kWh billion	107.761	33.554
V15	Fossil – Coal	Coal based electricity production in kWh billion	167.549	86.841
V16	Renewable - Solar	Solar based electricity production in kWh billion	3.119	0.344
V17	Renewable - Hydro	Hydro based electricity production in kWh billion	66.616	35.724
Country classification				
V18	Country classification IMF	Category (1=developing and emerging economies, 0=advanced economies)	0.000	1.000