

CRANFIELD UNIVERSITY

Jan Willem Zwarteveen

WIND ENERGY DIFFUSION IN DEVELOPING COUNTRIES

CRANFIELD SCHOOL OF MANAGEMENT
DBA Thesis

Doctor of Business Administration
Academic Year: 2018 - 2022

Supervisor: Dr. Andrew Angus
Associate Supervisor: Dr. Imran Zawwar
April 2022

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This thesis is submitted in fulfilment of the requirements for the
degree of DBA

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ABSTRACT

*“Though we may never be able to comprehend human life, we know certainly
that it is a movement, of whatever nature it be”*

--- Nikola Tesla (in: The Problem Of Increasing Human Energy, 1900)

ABSTRACT

Wind energy is valuable, but many developing and emerging economies (DEEs) do not utilize their substantial wind potential. The objective of this research is to understand wind energy diffusion with the aim to promote wind energy in underdeveloped areas for sustainable benefits of both country and wind industry.

The literature review and meta-analysis identified 259 factors that influenced wind energy diffusion. A novel conceptual framework that describes wind energy diffusion was developed, dissecting factors that influence wind diffusion into factors related to the desire for wind energy, factors related to the mechanism of change and disturbing factors. Regarding DEEs, the meta-analysis showed indications of the importance of economic factors and, opposing expectations, environmental factors appear not to drive wind energy growth.

Based on path creation theories but using binary logistic regression as a novel quantitative approach, the empirical study explored the factors influencing early wind energy diffusion. Key indicated drivers appeared to be climate adaptation, vested interests (fossil fuels and hydropower), and the business case potential. Regarding DEEs, a negative business case potential formed a key barrier. Novel market entry strategies for the wind power Original Equipment Manufacturer (OEM) are to collaborate with vested power producers rather than compete and promote wind for climate adaptation instead of climate change mitigation.

Most high wind potential countries have installed less than 500 MW of wind power capacity (commercialization threshold). The remaining countries have on average 20596 MW of wind capacity installed per country. The lagging wind adopting countries were assessed on their probability to adopt commercial wind in the near future, by using a novel quantitative path creation forecasting method. Passive entry, passive waiting, active entry and active waiting were defined as suggested market entry and development strategies for the wind OEM.

Keywords: Wind Power, Diffusion, Developing and Emerging Economies, Sustainable Development Goals, Market Entry, Original Equipment Manufacturer

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1 INTRODUCTION

“Contrary to popular belief, the power obtainable from wind is very considerable”

--- Nikola Tesla (in: The Problem of Increasing Human Energy, 1900)

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1 Context

Global investment in renewable power generation in 2017 was USD 298 billion (Figure 1). It significantly exceeded fossil power generation investments, which was only USD 132 billion. However, in many developing countries¹ renewable energy investment was not dominating. In the Middle East, Africa, non-OECD² Europe/Eurasia and non-OECD Asia (without China and India), coal, gas and oil power generation investments (USD 49 billion) surpassed renewable power generation investments (USD 24 billion). A more recent publication shows that especially developing countries are investing significantly less in renewable energy compared to what is required by the Sustainable Development Scenario (International Energy Agency, 2020).

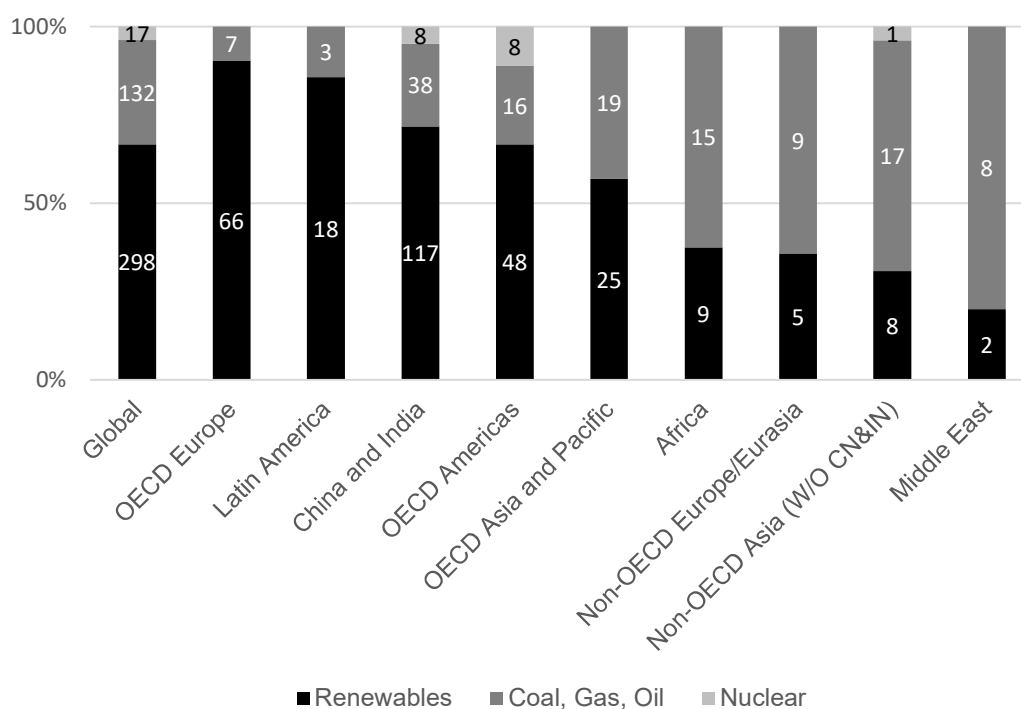


Figure 1 Global power generation investment per fuel type and region in 2017 [USD billion and % of total investment] (International Energy Agency, 2018).

¹ Developing countries defined as countries within the IMF classification "Emerging market and Developing Economies" (International Monetary Fund, 2018)

² Organisation for Economic Co-operation and Development, consisting of 36 mainly Advanced Economies (Organisation for Economic Co-operation and Development, 2018)

Within the field of renewable energy, solar PV and wind together form the largest share of total investments (International Energy Agency, 2020). Operationally and technically, solar PV and wind differ significantly, therefore the diffusion patterns will most likely differ. To focus, the scope of this study is limited to wind energy.

Wind energy diffusion involves multiple stakeholders. The largest share of the investment volume is captured by the Original Equipment Manufacturers (OEMs): around 70% of the initial investment covers the wind turbines, the rest addresses the financial costs and the balance of plant (Stehly and Beiter, 2019). Siemens Gamesa Renewable Energy (SGRE) and Vestas are the biggest Original Equipment Manufacturers (OEM) of almost equal size in the wind market with a combined market share of around 30% (Bloomberg New Energy Finance, 2018). The author has over 10 years of experience in SGRE in different senior management roles in developing countries across Africa, Asia and the Middle East. He has seen how promising the wind resources in many developing countries are, but how difficult it is to open new markets for new wind projects. Understanding the hurdles of wind energy in developing countries would help to grow the wind industry and support sustainable development.

2 Wind energy diffusion in developing countries

2.1 Wind energy potential

Even though there are sufficient wind resources (Figure 2), there is a very low amount of wind power installed in Middle East, Central America, Caribbean, Africa, Oceania and Eurasia (Table 1). However, there are developing countries, such as China and India, with a large installed wind power base.

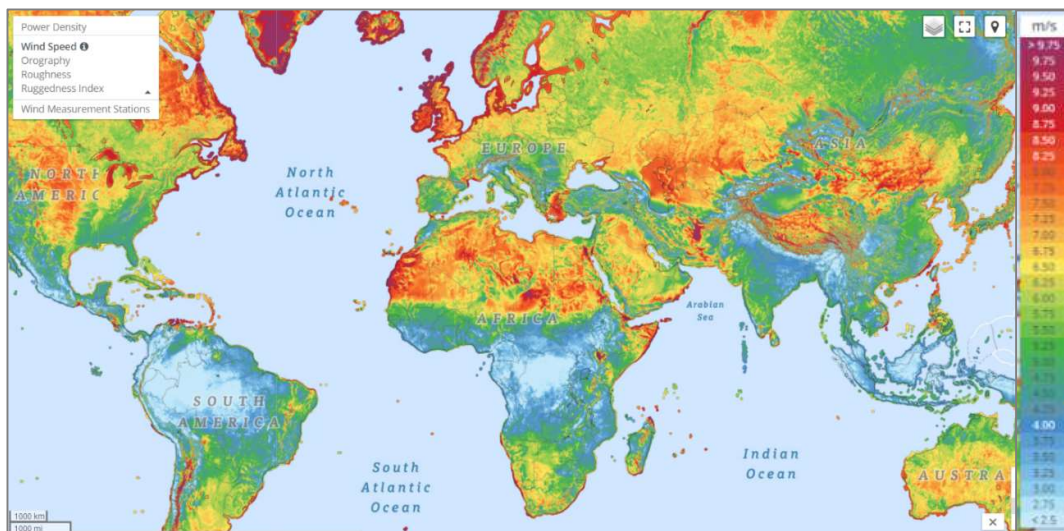


Figure 2 Global wind speed at 100m (picture take from (DTU Wind Energy and The World Bank, 2017)).

Table 1 Global accumulated installed wind capacity in 2017 (International Renewable Energy Agency, 2018).

	Installed Wind Capacity 2017 (GW)	% of global capacity
World	514	
Middle East	0.434	0.084%
C America + Carib	1.60	0.31%
Africa	4.61	0.90%
Oceania	5.30	1.0%
Eurasia	6.61	1.3%
S-America	15.8	3.1%
N-America	104	20%
Europe	171	33%
Asia from which China and India	204 197	39% 38%

2.2 Business impact

In certain developing countries, fossil-based power generation is attracting more investments than wind (Figure 1). Turning this balance in favour of wind, would create new business opportunities for the wind industry. Being an early mover could create competitive advantages in new growth markets. However, to date, non-attractive risk-return business cases limit further private investment to progress towards the Sustainable Development Goals (SDGs) (Barua, 2020). As the major wind power OEMs already suffer from pressure on their margins (Binnie, Steitz and Hübner, 2021; Thomas and Sanderson, 2021), it is key to identify which markets are promising to reduce the risk of a lack of return on the initial market entry investment costs.

2.3 Sustainable development impact

In 2015, the UN has created the 17 SDGs to increase the prosperity of people and the planet by 2030. SDG number 7 calls for a substantial increase in renewable energy (Table 2). Utilizing the wind potential in developing countries would contribute to achieving this goal. Also, due to the interlinked effects between the SDGs (Mantlana and Maoela, 2020), increase in wind energy is likely to contribute to larger parts of the agenda. Wind energy is more labour intensive compared to the oil and gas industry (Bacon and Kojima, 2011). Significant local job creation is therefor one of the socioeconomic benefits of wind energy in Europe (Ortega-Izquierdo and Río, 2020). Wind energy can also play an important role in emerging markets, where local job creation is essential for sustainable development (Arnold, 2018).

Table 2 The targets and indicators of SDG number 7 (United Nations, 2018).

Target	Indicators
By 2030, ensure universal access to affordable, reliable and modern energy services	Proportion of population with access to electricity, Proportion of population with primary reliance on clean fuels and technology
By 2030, increase substantially the share of renewable energy in the global energy mix	Renewable energy share in the total final energy consumption
By 2030, double the global rate of improvement in energy efficiency	Energy intensity measured in terms of primary energy and GDP
By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology	Mobilized amount of United States dollars per year starting in 2020 accountable towards the 100 billion USD commitment
By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support	Investments in energy efficiency as a percentage of GDP and the amount of foreign direct investment in financial transfer for infrastructure and technology to sustainable development services

3 Objective of the research

The objective of this research is to understand wind energy diffusion with the aim to promote wind energy in underdeveloped areas for sustainable benefits of both the country and the wind power OEM.

4 Structure of the thesis

The structure of the thesis follows the paper format (Cranfield University, 2016), with distinct chapters, covering the different parts of the research. Each chapter has its own table of content, independent structure, appendices and list of references. Chapter 3, 6 and 7 were accepted for publication in academic peer reviewed international journals. These chapters have a stand-alone introduction that positions the paper in the relevant academic discussion.

Table 3 The structure of the thesis.

Research objective			
To understand wind energy diffusion with the aim to promote wind energy in underdeveloped areas for sustainable benefits of both the country and the wind power Original Equipment Manufacturer			
Chapter	Title	Objective	Journal reference
1	Introduction	To describe the motivation for the research and the business and academic context	
2	Positioning study	To map the relevant bodies of literature related to wind energy diffusion	
3	Literature study	To understand and structure the academic state of the art and highlight areas for further research related to wind energy diffusion	Journal of Cleaner Production
4	Research design	To define the research design with the research questions	
5	Empirical study	To quantify factors influencing path creation in wind energy and to describe the resulting implications for the wind power OEM	Business Strategy and Development
6	Simulation study	To identify which high wind capacity countries are the last adopters of wind energy and what the probability is per country to start commercial wind exploitation	Cleaner Production Letters
7	Impact assessment	To show evidence of academic, business and societal practical impact	
8	Discussion and conclusion	To discuss, mention the limitations, describe how the literature has developed since the publication of the literature review, and conclude	

Chapter 2 describes the positioning of the research. The objective of the research to understand wind energy diffusion intersects multiple areas of literature. The positioning study maps these bodies of literature to provide a foundation of the research and to define where the research is embedded. Chapter 3 includes the literature review and meta-analysis. The purpose of the literature review is to identify, according to literature, which factors influence global wind diffusion. It contains the last submitted version of the published review in the Journal of Cleaner Production (Zwarteveen *et al.*, 2021). The journal's focus of transitions to sustainable societies fits well to the contribution of wind diffusion to SDG7. Following the identified areas worthy of further research, chapter 4 contains the research design with the research questions. The empirical research is listed in chapter 5. The purpose of the empirical research is to quantify factors influencing path creation in wind energy and the resulting implications for the wind power OEM. The empirical study has been published in Business Strategy and Development (Zwarteveen, Zawwar and Angus, 2021). The journal was chosen for its emphasis on business implications (fitting to the wind power OEM focus) and development contributions (fitting to developing and emerging markets focus). Building on the models developed in chapter 5, the following chapter

highlights the simulation study. The purpose of the simulation study is to identify which high wind potential countries are the last adopters of wind energy and what the probability is per country to start commercial wind exploitation. The simulation study has been accepted for publication in *Cleaner Production Letters* (Zwarteveen and Angus, 2022). The open-access journal was chosen for its focus on high societal impact. Targeting to increase the amount of wind energy used in emerging and developing countries has the potential of high societal impact, hence the journal fit. Because of the journal's requirement to publish multi-disciplinary research, not only were the implications for the wind power OEM listed, but also the policy implications were included. The co-authors of all submitted papers had a purely supervisory role. Unique to the Doctor of Business Administration degree, both academic and business impact is to be pursued. Hence, chapter 7 shows evidence of this dual impact. Chapter 8 discusses, mentions the limitations, including how the literature has developed since the publication of the literature review, and concludes. Because of the paper format, the chapters can be read independently. Repetition is deliberate because of this structure. In case the reader is processing the thesis in the normal sequence, many chapters can be read without the introduction. A summary of the thesis structure is shown in Table 3.

References

Arnold, M. G. (2018) 'Sustainability value creation in frugal contexts to foster Sustainable Development Goals', *Business Strategy & Development*, 1(4), pp. 265–275. doi: 10.1002/bsd2.36.

Bacon, R. and Kojima, M. (2011) *Issues in estimating the employment generated by energy sector activities*. Available at: <https://documents1.worldbank.org/curated/en/627831468159915345/pdf/827320WP0emplo00Box379875B00PUBLIC0.pdf>.

Barua, S. (2020) 'Financing sustainable development goals: A review of challenges and mitigation strategies', *Business Strategy & Development*, 3(3), pp. 277–293. doi: 10.1002/bsd2.94.

Binnie, I., Steitz, C. and Hübner, A. (2021) *Looming loss piles pressure on turbine maker Siemens Gamesa, Reuters*. Available at: <https://www.reuters.com/business/energy/siemens-gamesa-trying-pass-rising-steel-costs-turbine-customers-ceo-2021-07-15/> (Accessed: 13 August 2021).

Bloomberg New Energy Finance (2018) *Vestas Keeps Lead in Onshore Wind, Siemens Gamesa Narrows Gap*. Available at: <https://about.bnef.com/blog/vestas-keeps-lead-in-onshore-wind-siemens-gamesa-narrows-gap/> (Accessed: 20 December 2018).

Cranfield University (2016) *Senate Handbook: Managing Research Students*. Cranfield.

DTU Wind Energy and The World Bank (2017) *Global Wind Atlas*. Available at: <https://globalwindatlas.info/> (Accessed: 26 October 2018).

International Energy Agency (2018) *World Energy Investment 2018*. Paris: International Energy Agency (IEA). Available at: <https://www.iea.org/reports/world-energy-investment-2018>.

International Energy Agency (2020) *World Energy Investment 2020*. Paris: International Energy Agency (IEA). Available at:

<https://www.iea.org/reports/world-energy-investment-2020>.

International Monetary Fund (2018) *World Economic Outlook - Database - WEO Groups and Aggregates Information*. Available at: <https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/groups.htm> (Accessed: 5 November 2018).

International Renewable Energy Agency (2018) *Renewable capacity statistics 2018*. Abu Dhabi: International Renewable Energy Agency (IRENA). doi: 10.1016/S2255-4971(15)30126-9.

Mantlana, K. B. and Maoela, M. A. (2020) 'Mapping the interlinkages between sustainable development goal 9 and other sustainable development goals: A preliminary exploration', *Business Strategy & Development*, 3(3), pp. 344–355. doi: 10.1002/bsd2.100.

Organisation for Economic Co-operation and Development (2018) *OECD members and partners*. Available at: <http://www.oecd.org/about/membersandpartners/#d.en.194378> (Accessed: 29 November 2018).

Ortega-Izquierdo, M. and Río, P. del (2020) 'An analysis of the socioeconomic and environmental benefits of wind energy deployment in Europe', *Renewable Energy*, 160, pp. 1067–1080. doi: 10.1016/j.renene.2020.06.133.

Stehly, T. and Beiter, P. (2019) *2018 cost of wind energy review*. Golden, CO. Available at: <https://www.nrel.gov/docs/fy20osti/74598.pdf>.

Thomas, N. and Sanderson, H. (2021) *Vestas cuts outlook as commodity prices squeeze margins*, *Financial Times*. Available at: <https://www.ft.com/content/20e7a28f-3d20-4021-94de-d30022283ef6> (Accessed: 13 August 2021).

United Nations (2018) *Sustainable Development Goal 7*. Available at: <https://sustainabledevelopment.un.org/sdg7> (Accessed: 26 October 2018).

Zwarteveen, J. W. and Angus, A. (2022) 'Forecasting the probability of

commercial wind power development in lagging countries', *Cleaner Production Letters*, p. 100006. doi: 10.1016/j.clpl.2022.100006.

Zwarteveen, J. W., Figueira, C., Zawwar, I. and Angus, A. (2021) 'Barriers and drivers of the global imbalance of wind energy diffusion: A meta-analysis from a wind power Original Equipment Manufacturer perspective', *Journal of Cleaner Production*, 290, p. 125636. doi: 10.1016/j.jclepro.2020.125636.

Zwarteveen, J. W., Zawwar, I. and Angus, A. (2021) 'Market entry for wind energy: Strategic approaches for the original equipment manufacturer', *Business Strategy & Development*. doi: 10.1002/bsd2.188.

2 POSITIONING STUDY

“You’ve got to be careful adopting any new technology because you never know what the unintended consequences of that technology are going to be”

--- Yvon Chouinard (in: 180° South: Conquerors of the Useless, 2013)

Abstract

Global investment in renewable power generation in 2017 significantly exceeded fossil power generation investments. However, in many developing countries, coal, gas and oil power generation investments surpassed renewable power generation investments. To focus, the scope of this study is limited to wind energy. Utilizing the wind potential in developing countries would contribute to achieving Sustainable Development Goal 7 (substantial increase in renewable energy) and would create new business opportunities for the wind industry.

Literature identifies 68 high potential wind countries, many of which also have substantial fossil fuel reserves. There are significant differences in installed wind power capacity in the 68 high potential countries. Many developing and emerging economies have installed a very low wind power capacity. Most advanced economies have large scale wind power installed.

Renewable electricity has shown to be price competitive on a Levelized Cost of Energy (LCoE) level, however the Capital Expenditure (CAPEX) is in many cases higher compared to fossil electricity. Hydropower and natural gas based power generation are highly flexible in that the power output can be varied according to changing demand. Solar PV and wind energy are not. Flexible electricity generation, energy storage and the interconnection of grids facilitate a stable balance between supply and demand with a higher percentage of renewables.

Electricity technology diffusion can be described based on general technology diffusion theories. Literature describes how multiple environmental, economic, technical, politic and resource availability factors influence the electricity technology diffusion. Both quantitative factors (such as LCoE per technology) and event-based factors (such as incidents) are described. Multiple studies have been published from an energy planner, electricity producer or policy perspective.

The aim of the systematic literature review (chapter 3) is to identify, according to literature, which factors specifically impact the global wind energy adoption.

Keywords: Wind Power Diffusion, Wind Potential, Energy Potential, Power Generation Technologies, Technology Diffusion

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Glossary and abbreviations

Capacity factor	Average power generated as % of full power
Wind class 1	Average wind speed of 10 m/s
Wind class 2	Average wind speed of 8.5 m/s
Wind class 3	Average wind speed of 7.5 m/s
Wind classes	Categorization of wind conditions according to IEC61400
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CHP	Combined Heat and Power
CSP	Concentrated Solar Power
EJ	Exa Joule
GBP	Pound Stirling
GhG	Greenhouse Gas
GW	Giga Watt
HVDC	High Voltage Direct Current
IPP	Independent Power Produces
KW	Kilo Watt
KWh	Kilo Watt hour
LCoE	Levelized Costs of Energy
LCR	Local Content Requirement
MWh	Mega Watt hour
NM	Nautical Miles
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
PPA	Power Purchase Agreement
PV	Photovoltaic
PWh	Peta Watt hour

REC	Renewable Energy Certificate
RPS	Renewable Portfolio Standard
SDG	Sustainable Development Goal
SGRE	Siemens Gamesa Renewable Energy
SLR	Systematic Literature Review
TW	Tera Watt
TWh	Tera Watt hour
USD	United States Dollar

1 Introduction

Global investment in renewable power generation in 2017 significantly exceeded fossil power generation investments (298 vs 132 billion USD). However, in many developing countries¹, coal, gas and oil power generation investments surpassed renewable power generation investments.

Within the field of renewable energy, solar PV and wind together form the largest share of total investments (International Energy Agency, 2020). To focus, the scope of this study is limited to wind energy.

Utilizing the wind potential in developing countries would contribute to achieving SDG number 7 (substantial increase in renewable energy) and would create new business opportunities for the wind industry.

¹ Developing countries defined as countries within the IMF classification "Emerging and Developing Economies" (International Monetary Fund, 2018)

2 Literature domains

To increase the understanding of the problem or opportunity of unused wind potential in developing countries, the topic needs to be deconstructed.

Firstly, wind might not be the only energy source that is available in developing countries. The distribution of different available fossil and renewable energy reserves needs to be understood.

Secondly, besides wind power, there are many substitute technologies available to produce electricity. To understand what the alternatives are for wind power, an overview of the different technologies and their specifications is needed.

Thirdly, the emergence of wind energy is a form of technology diffusion. The mechanism of technology diffusion or adoption needs to be understood, both from a theoretical point of view as well as from a practical determinant point of view specific to wind energy. Also, the different viewpoints available in today's research will inform if applicable studies to the wind power OEM exist.

The sections 2.1, 2.2 and 2.3 will detail the three domains as described above. Having a better understanding of these bodies of knowledge will help identify the specific area for the systematic literature research. Based on the outcome of the systematic literature research, the specific focus of the empirical work can be defined.

2.1 Energy resource potential in developing countries

Wind energy is one of several energy resources available in developing countries. The aim of this section is to provide an overview of the global distribution of mainstream energy resources and to specifically address the global wind energy potential.

2.1.1 Global energy resource distribution

In this sub-section, the availability of the mainstream energy sources in developing and advanced economies is investigated. It includes the availability of oil, gas and coal reserves as well as the potential for hydro, wind, solar and bio

energy. Geothermal and marine energy are not considered owing to the very small contribution to the contemporary energy balance (Figure 2).

In 2019, the majority of electricity was produced by fossil-fuel (Coal, natural gas and oil sum up to 63.1%), followed by hydro power (15.7%) and nuclear power (10.4%). Renewables without hydro power (such as wind and solar) only counted for 10.8% (International Energy Agency, 2021).

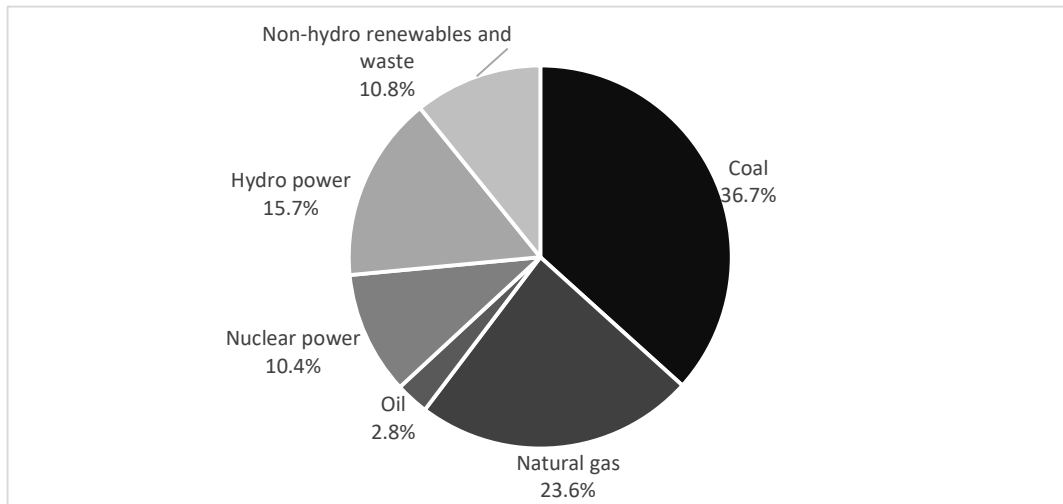


Figure 1 Global electricity production mix per fuel type in year 2019 The percentages refer to the share in relation to the total electricity production mix (International Energy Agency, 2021).

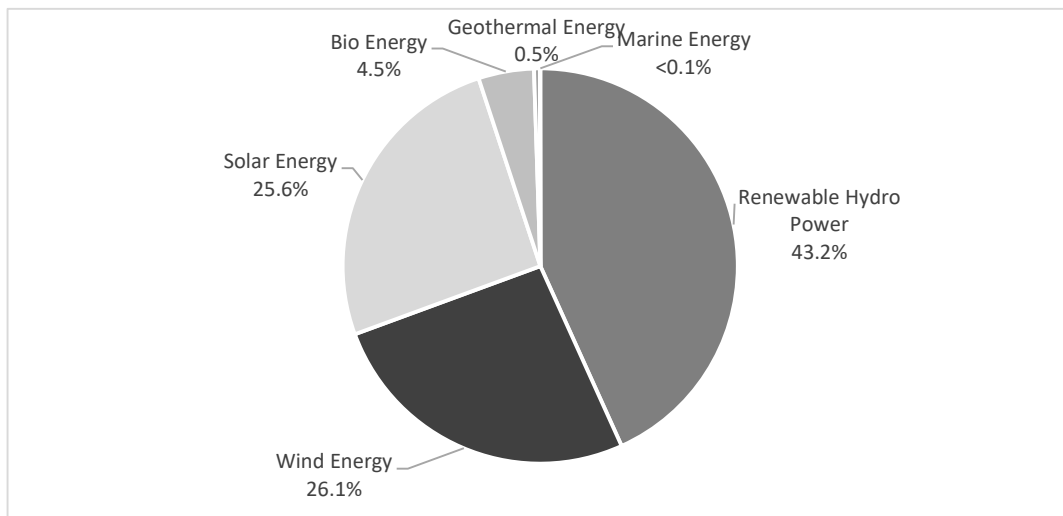


Figure 2 Global installed renewable energy end of 2020, split per technology type. The percentages refer to the share of the total installed renewable energy (International Renewable Energy Agency, 2021).

The total global installed renewable energy capacity end of 2020 was 2802 GW (International Renewable Energy Agency, 2021). The split into the different technologies can be found in the Figure 2. Hydro power, solar energy and wind energy form the largest share, summing up to 94.9% of total installed renewable energy.

The resources needed to produce both fossil and renewable energy are globally available but are not equally geographically distributed. Table 1 shows the available energy resources per area.

Nuclear reserves

Both uranium and thorium are naturally occurring fissile fuels. Uranium is the most used fuel for nuclear reactors. The availability of uranium is expressed in its weight, sorted by the costs needed to recover it. Declining demand for uranium focus the recovery on areas with the lowest costs (UNDP, 2000). Uranium at recovery costs lower than 80USD a kilogram can be predominantly found in Pacific OECD (27% of global total), former Soviet Union (24% of global total), Sub Saharan Africa (20% of global total) and North America (18% of global total) ((NEA and IAEA, 1997) in (UNDP, 2000)).

Reserves vs potential

The main difference between fossil fuel and renewable energy is that the availability of the fuel is limited versus (practically) unlimited respectively. Fossil fuel availability can be measured in different ways. Figure 3 shows the difference between reserves, resources and additional occurrences. Table 1 only includes the identified reserves to avoid speculation. Decreasing costs of production and increasing market prices of fossil fuels both increase the size of the reserves and vice versa.

Table 1 Global fossil and renewable resource distribution.

Area	Fossil Proven Reserves [EJ] ²			Renewable Technical Potential [EJ yr ⁻¹]			
	Oil	Gas	Coal	Hydro	Solar ³	Wind ⁴	Biomass ⁵
North America	193	244	6065	5.4	181.1	168	
Western Europe	105	177	1178	6.6	25.1	58	
Centr & East Europe	8	17	744	0.8	4.5	127	17
Former Soviet Un	381	2112	4981	4.4	199.3		
Pacific OECD	17	47	1729	0.8	72.6		36
L America & Carr	833	298	533	10.3	112.6	65	113
Pacific Asia	63	196	10	2.9	41.0	59	5
South Asia	21	54	1611	3.4	38.8		0
C planned Asia	142	82	2344	7.8	115.5		8
Middle East	4053	2065	6	0.6	412.4		0
North Africa						127	9
Sub-Sah Africa	188	161	1465	7.2	371.9		74
Sum	6004	5454	20666	50.2	1575	640	226
Sources	(BP, 1999) in (UNDP, 2000)	(BP, 1999) in (UNDP, 2000)	(WEC - World Energy Council, 1998) in (UNDP, 2000)	(World Atlas and Industry Guide, 1998) in (UNDP, 2000)	(International Energy Agency, 1998; Nakicenovic, Grubler and McDonald, 1998) in (UNDP, 2000)	(Grubb and Meyer, 1993) in (UNDP, 2000)	derived from (D'apote, 1998; Fischer and Heilig, 1998; Nakicenovic, Grubler and McDonald, 1998) in (UNDP, 2000)

² Oil-producing countries report proven reserves, authors would define this as identified reserves (UNDP, 2000)

³ Min and max potential in source. Min is taken as technical potential, as also done by (UNDP, 2000)

⁴ Assessed wind energy potential is taken as tech pot, as also done by (UNDP, 2000), Central Am is assumed to be part of Latin am, Pacific OECD only includes Australia

⁵ SSA is East, Central, Southern West Africa, M.E is Western Asia, Centrally Planned Asia is East Asia and China, South Asia is South-Central Asia, Pacific Asia is South-East Asia

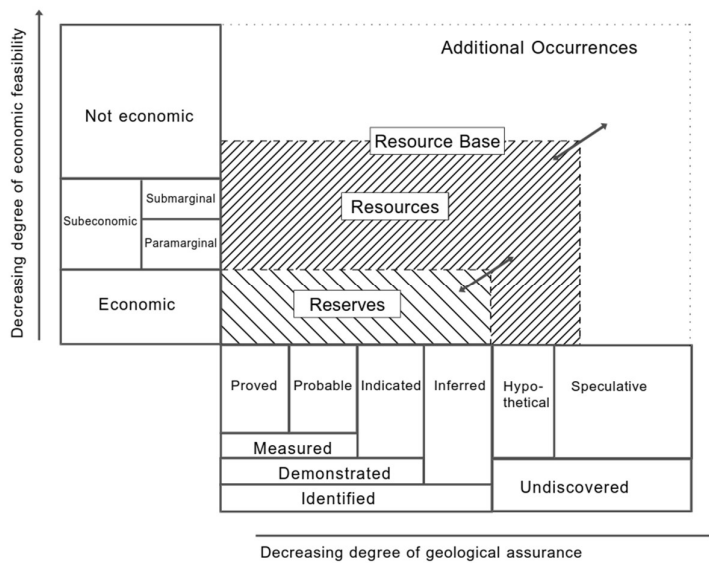


Figure 3 Classification of energy reserves and resources (picture source: (Rogner, 1997) modified from (McKelvey, 1972)).

Also, the renewable energy potential can be classified in different ways, with varying degrees of economic and technical feasibility (Figure 4). According to UNDP (2000) the renewable economic potential is equal to fossil reserves. However, since the cost of renewables are decreasing so quickly over time, this paper considers the technical potential in Table 1 to avoid excluding non-economic renewable energy that might become economic in the near future.

Potential and reserve changes over time

Table 1 is based on a comprehensive study including all mainstream energy sources (UNDP, 2000). The advantage is that it shows both the potential and the reserves in a comparable measurement unit, all measured around the same time. The disadvantage is that the study is relatively dated. Since then, parts of the fossil fuel reserves have been consumed. At the same time, new discoveries have been made. The new discoveries since the UNDP report (2000) and end of 2017 outpaced the consumption. For all fossil fuel types the proven fossil reserves increased: oil with 67%, gas with 32% and coal with 5% (BP, 2018). The uranium reserves decreased with 8% between 1996 and 2015, current reserves are expected to be sufficient for the next 135 years (NEA and IAEA, 1997, 2016).

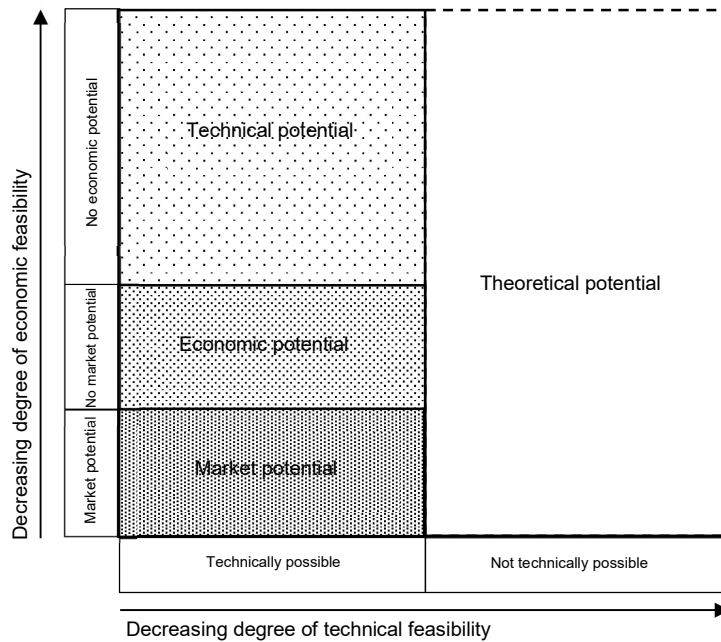


Figure 4 Classification of renewable energy potential (Author's own work).

Also, since the UNDP report (2000), new technologies enabled more of the theoretical renewable energy to be reclassified as technical potential renewable energy. At the same time, population increases have meant there is a decreased availability of land for energy harvesting, decreasing the technical potential. For example, in 2009 by placing a dense array of 2.5 MW and 3.6 MW turbines, the available wind potential was estimated to be 2470 EJ year⁻¹ (Lu, McElroy and Kiviluoma, 2009), almost 4 times the UNDP study. Different hub heights assumptions (100m instead of the 50m by UNDP), different geographical limitations (>0.2 capacity factor versus only wind class 3 and higher) and the development of offshore wind energy up to 50 NM off the coast resulted in a significant increase of technical wind potential. A more recent study looking at the impact of extractability of wind energy from the atmospheric boundary layer showed a technical wind potential of 18 – 68 TW or 569 – 2146 EJ year⁻¹ (Miller, Gans and Kleidon, 2011). However, Jung, Schindler and Laible (2018) argue that more factors have to be taken into account to calculate a more accurate technical

potential. Assuming a maximum turbine density of 2% of the area, they calculate a maximum wind potential of 25648 TWh year⁻¹ or 92 EJ year⁻¹.

Geographic distribution of fossil reserves and the renewable potential

The sum of fossil reserves in the UNDP report (2000) equals 32124 EJ, whereas the sum of renewable technical potential equals 2491 EJ year⁻¹. Assuming no new fossil reserves are discovered (and excluding volatility in costs and prices) and that all renewable technical potential is used, in 12.9 years renewable energy would produce the same amount of energy as the fossil fuel reserves.

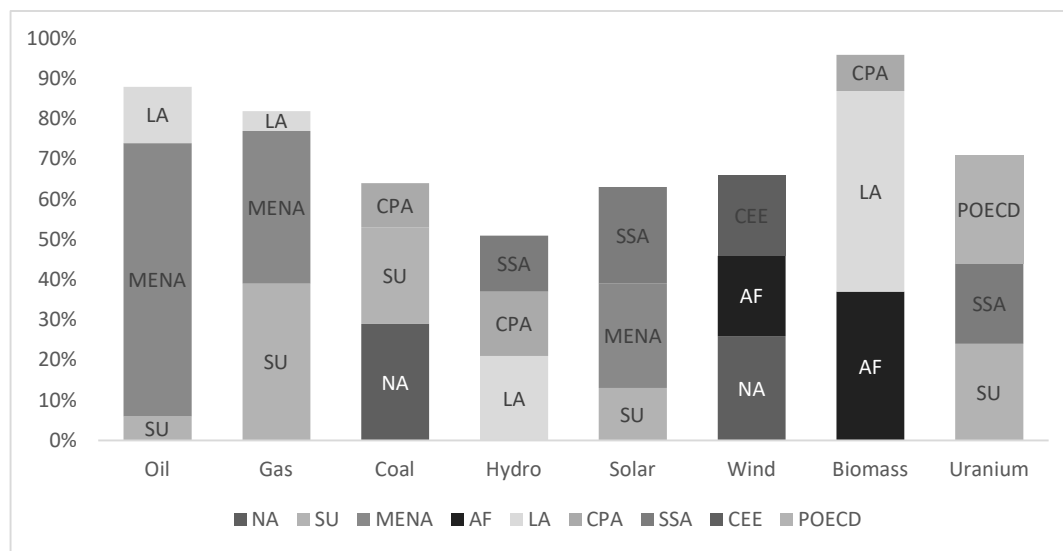


Figure 5 Percent of reserves (fossil) and % of technical potential (renewable) for top 3 areas as shown in Table 1 (UNDP, 2000). [NA=North America, MENA=Middle East & North Africa, LA=Latin America, SSA=Sub Saharan Africa, SU=Former Soviet Union, AF=Africa, CPA=Centrally Planned Asia, CEE=Central Eastern Europe incl. Russia, POECD=Pacific OECD].

In the transition from fossil to renewable energy, the areas with dominant resources will change. For oil and gas, over 80% of reserves are concentrated in 3 areas, whereas wind and solar energy are geographically more equally distributed (Figure 5). North America, former Soviet Union, Middle East and North Africa are the dominant regions for fossil energy, whereas renewable energy is more distributed with less strong, but still dominant roles for Africa, Latin America, North America and the Middle East. However, within the areas large country differences exist. For the sake of brevity, to limit the number of countries to consider, the next section aims to select the countries with high wind potential.

2.1.2 Countries with high wind potential

Both Lu, McElroy and Kiviluoma (2009) and Jung, Schindler and Laible (2018) provide studies on a country level perspective of technical wind potential (respectively Figure 6 and Figure 7). Lu, McElroy and Kiviluoma (2009) assume a dense array of 2.5 MW and 3.6 MW turbines and estimate the global wind potential to be 2470 EJ year⁻¹. Within their onshore scenario presented in Figure 6, 59 countries show a potential of ≥ 1 PWh year⁻¹ potential (1 PWh year⁻¹ equals 380 GW installed wind power by capacity factor of 0.3).

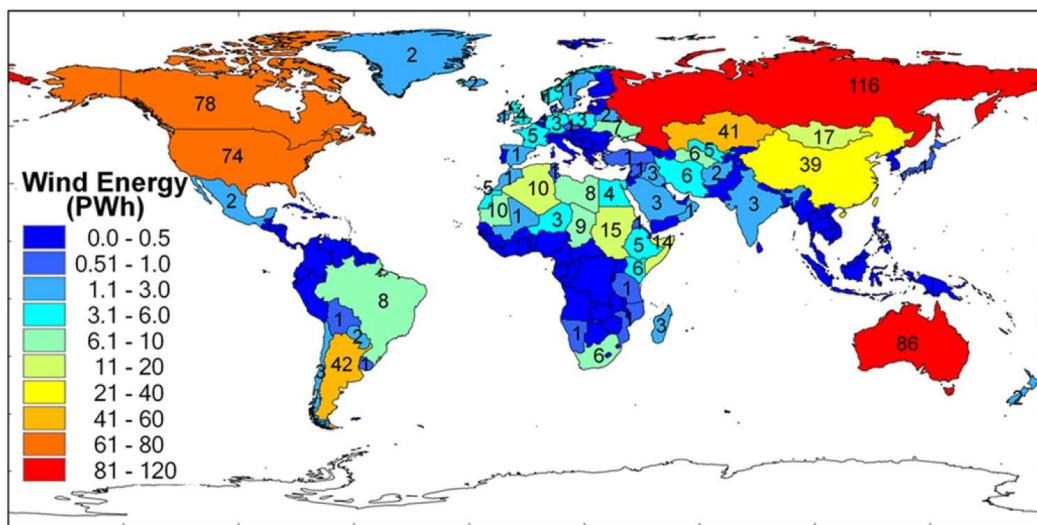


Figure 6 Annual technical wind energy potential per country (picture taken from (Lu, McElroy and Kiviluoma, 2009)).

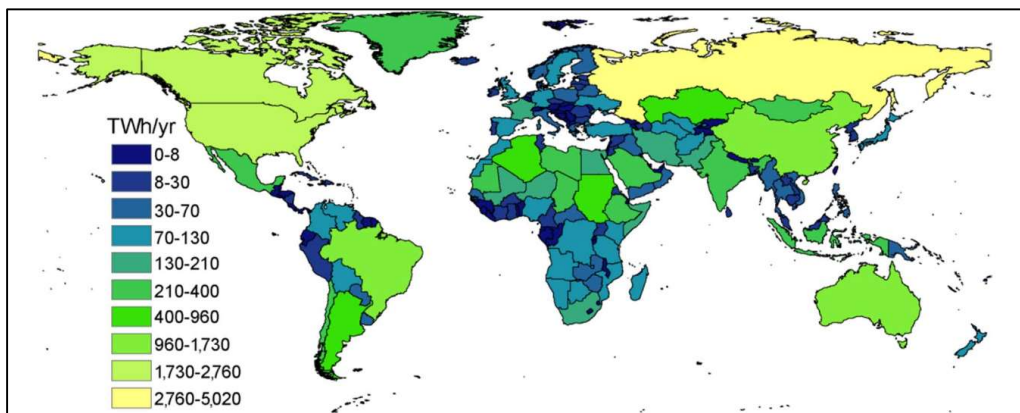


Figure 7 Annual technical wind energy potential per country (picture taken from (Jung, Schindler and Laible, 2018)).

Because of more strict land based turbine technical density limitations, Jung, Schindler and Laible (2018) estimate the maximum technical wind potential to be significantly lower. In their 2% turbine density scenario they end up with 92 EJ year⁻¹. Of this total, 53 countries show a potential of ≥ 70 TWh year⁻¹ (70 TWh year⁻¹ equals 27 GW installed wind power by capacity factor of 0.3). With 23 GW installed wind power by end of 2017, Spain is one of Europe's leading markets regarding installed wind power (International Renewable Energy Agency, 2018). In both studies, Spain falls just within the limits set for high wind countries in this study (≥ 1 PWh year⁻¹ and ≥ 70 TWh year⁻¹).

Table 2 shows the high wind potential countries combining the two studies mentioned (59 countries ≥ 1 PWh year⁻¹ and 53 countries ≥ 70 TWh year⁻¹ result in 68 unique countries), grouped by the current installed wind power capacity. Several developing and emerging economies have very low installed wind power capacity. Conversely, most advanced economies have large scale wind power installed.

Table 2 High wind potential countries, derived from Lu, McElroy and Kiviluoma (2009) and Jung, Schindler and Laible (2018) grouped by installed wind power capacity by end of 2017 (International Renewable Energy Agency, 2018). Underlined: "Developing and Emerging Economies" (International Monetary Fund, 2018).

0 GW	0-0.1GW	0.1-1GW	1-10GW	>10GW
<u>Afghanistan</u>	<u>Chad</u>	<u>Mongolia</u>	<u>Morocco</u>	<u>Brazil</u>
<u>Angola</u>	<u>Eritrea</u>	<u>Kazakhstan</u>	Norway	Canada
<u>Congo</u>	<u>Indonesia</u>	<u>Iran</u>	<u>Chile</u>	France
<u>Iraq</u>	<u>Syria</u>	<u>Tunisia</u>	<u>Uruguay</u>	United Kingdom
<u>Libya</u>	Iceland	<u>Argentina</u>	<u>South Africa</u>	Spain
<u>Madagascar</u>	<u>Nigeria</u>	Czech Republic	Japan	<u>India</u>
<u>Mali</u>	<u>Saudi Arabia</u>	<u>Ethiopia</u>	Ireland	Germany
<u>Mozambique</u>	<u>Somalia</u>	<u>Ukraine</u>	<u>Mexico</u>	United States
<u>Niger</u>	<u>Namibia</u>	New Zealand	Netherlands	<u>China</u>
<u>Oman</u>	<u>Algeria</u>	<u>Egypt</u>	Australia	
<u>Paraguay</u>	<u>Russia</u>	<u>Pakistan</u>	Denmark	
<u>Sudan</u>	<u>Colombia</u>		<u>Poland</u>	
<u>Tanzania</u>	<u>Kenya</u>		<u>Turkey</u>	
<u>Turkmenistan</u>	<u>Bolivia</u>		Sweden	
<u>Uzbekistan</u>	<u>Mauritania</u>			
<u>Zambia</u>	<u>Venezuela</u>			
Greenland ⁶	<u>Belarus</u>			

⁶ No data available on Greenland in (International Renewable Energy Agency, 2018)

2.1.3 Summary

Large fossil fuel reserves exist both decreasing through consumption as well as increasing through new discoveries. Also, large amounts of renewable energy potentials are globally available. The literature identifies 68 high potential wind countries, many of which also have relatively large fossil fuel reserves. There are significant differences in installed wind power capacity in the 68 high potential countries. Many developing and emerging economies have very low installed wind power capacity. The advanced economies have large scale wind power installed, with the exception of Iceland, Czech Republic and New Zealand.

2.2 Electricity mix specifications

Wind power is one of several electricity production technologies used globally. The aim of this section is to provide an overview of the different electricity production technologies and their integration.

2.2.1 Global installed mix

In 2020, the majority of electricity was produced by fossil-fuel (63.1%), followed by hydro power (15.7%) and nuclear power (10.4%). Renewables (without hydro power) and other energy sources only counted for 10.8% (International Energy Agency, 2021). The detailed split is shown in Figure 1.

2.2.2 Power generation technologies

There are multiple fuel types and technologies available to produce electricity. This section describes how electricity is produced from 9 different fuels: coal, oil, natural gas, hydro, nuclear, wind, sun, biomass and geothermal. The capital and levelized costs of these technologies and their corresponding CO₂ emissions are presented in Figure 8, 9 and 10. A comparison of the mechanism of conversion into electricity of the different fuels is shown in Table 3.

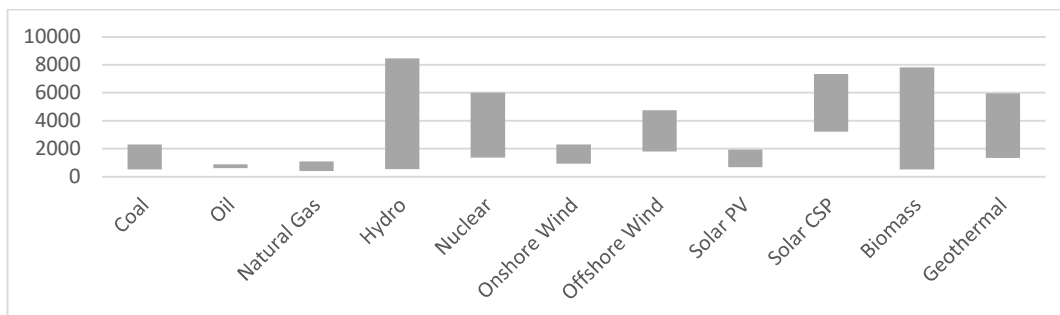


Figure 8 CAPEX range in €/kW for electricity production per fuel type (Ram *et al.*, 2018)⁷ (Organisation for Economic Co-operation and Development and International Energy Agency, 2015)⁸ (Kost *et al.*, 2013)⁹.

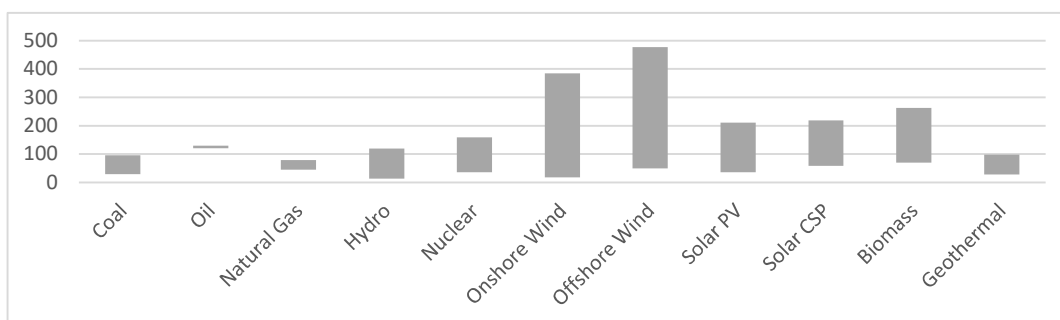


Figure 9 LCoE range in €/kWh for electricity production per fuel type (Ram *et al.*, 2018)¹⁰ (Organisation for Economic Co-operation and Development and International Energy Agency, 2015)¹¹ (Kost *et al.*, 2013)¹².

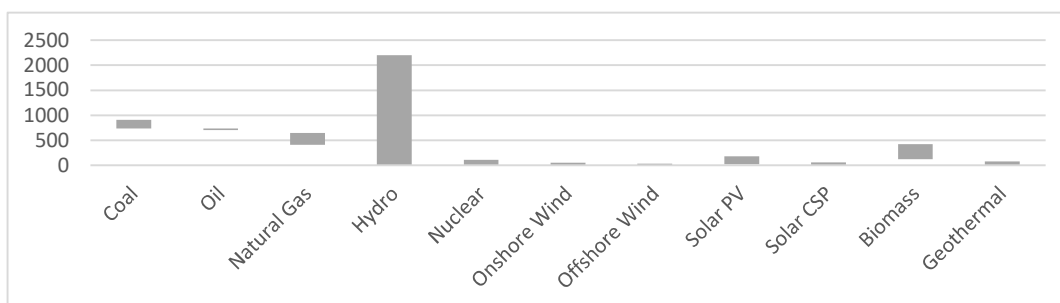


Figure 10 Lifecycle greenhouse gas emission in grams CO₂ equivalent / kWh for electricity production per fuel type (Schlömer *et al.*, 2014)¹³ (Hondo, 2005)¹⁴.

⁷ Overnight costs for Wind, Solar PV, Coal, Gas (CCGT), Nuclear. Based on 24 sources from 2007-2014. Details in reference.

⁸ Overnight costs for CSP, Hydro, Geothermal, Biomass. EGC 2015 database with 181 plants. Source states USD/kWh. Assumed exchange rate 1.11 US = 1 Euro.

⁹ Investments for Utility Scale Diesel

¹⁰ LCoE for Wind, Solar PV, Coal, Gas (CCGT), Nuclear. Based on 24 sources from 2007-2014. Details in reference.

¹¹ LCoE for CSP, Hydro, Geothermal, Biomass. EGC 2015 database with 181 plants. Source states USD/kWh. Assumed exchange rate 1.11 US = 1 Euro.

¹² LCoE for Utility Scale Diesel

¹³ GhG for Coal, Gas, Biomass, Geothermal, Hydropower, Nuclear, CSP, Solar, Wind

¹⁴ GhG for Oil based on Japan example. Min = direct emission, Max = direct + indirect emission

Table 3 Fuel types and electricity conversion comparison.

Fuel	Electricity conversion	Advantages and disadvantages	Recent research
Coal	The caloric value of coal is converted into electric energy by a combination of a combustion device with an electricity generator. There are three main technology types: pulverised coal boilers, fluidized bed boilers and coal gasifiers (Breeze, 2014). Waste heat is turned into additional electricity in combined cycle power plants.	The advantages of coal-based electricity production are low investment costs (Figure 8) and the low levelized costs of electricity (Figure 9). The disadvantages of coal-based electricity production are the high CO ₂ emissions (Figure 10) and fluctuating coal prices (Shafiee and Topal, 2010) resulting in fluctuating OPEX.	Current innovations are focussed on capturing the CO ₂ from the emissions (Haszeldine, 2009).
Oil	The caloric value of oil is converted into electric energy by a combination of a combustion device with an electricity generator. There are three main technology types: aero-derivative gas turbines, heavy duty gas turbines and piston engines (Breeze, 2014). Waste heat is turned into additional electricity in combined cycle power plants.	The advantages of oil based electricity (in many cases diesel based electricity) are the relatively low investment costs (Figure 8). Remote islands power generation are often based on diesel (Senjyu <i>et al.</i> , 2005), demonstrating that diesel base power is capable to balancing demand and supply even without interconnected electricity grids. The disadvantages of oil based electricity production are the high CO ₂ emission (Figure 10) and the relatively high LCoE (Figure 9). Moreover, the operational costs are subject to fluctuating oil prices (Shafiee and Topal, 2010).	Innovations centre on the use of hybrid systems, such as diesel-solar or diesel-wind (Senjyu <i>et al.</i> , 2005).
Natural gas	The caloric value of natural gas is converted into electric energy by a combination of a combustion device with an electricity generator. The same three main technology types for oil are also used for natural gas powered electricity generation: aero-derivative gas turbines, heavy duty gas turbines and piston engines. Heavy duty gas turbines are often used in combined cycle power plants (Breeze, 2014).	The advantages of gas based electricity are the low investment costs (Figure 8), its high flexibility in that the power output can be varied according to changing demand (Chen <i>et al.</i> , 2019) and the relatively low CO ₂ emissions compared to the other fossil options (Figure 10). The disadvantages of gas-based electricity production are high CO ₂ emissions compared to renewable options and unstable operational costs caused by fluctuating gas prices (Shafiee and Topal, 2010).	Co-producing the steam with CSP for a combined cycle turbine (Antonanzas <i>et al.</i> , 2014), capturing the CO ₂ emissions (Fichera, Samanta and Volpe, 2022) and blending natural gas with hydrogen (Capurso <i>et al.</i> , 2022) are the latest developments in this stream of technology.
Hydro	The potential energy, or kinetic energy of water is converted into electric energy by a combination of a water turbine and an electricity generator. Two main types of hydro power exist: run of the river hydro power and dam and reservoir hydropower (Breeze, 2014).	The advantages of hydro power are the low LCoE (Figure 9) and the high flexibility of use (Barasa <i>et al.</i> , 2018). In some cases electricity storage is provided by pumping water into a reservoir at higher altitudes (Breeze, 2014). The disadvantages of hydro power are the environmental harm and social disruption (Rosenberg, Bodaly and Usher, 1995). This is, however, less the case for small scale hydro power (Paish, 2002).	Knowledge transfer to stimulate the further deployment of small scale hydro is one of the areas for improvement (Paish, 2002).
Nuclear	Heat generated by atomic reactions is converted into electric energy by means of a steam turbine generator. Two types of nuclear power exist: fission and fusion (Breeze, 2014).	The advantages of nuclear power are the low LCoE (Figure 9) and the relatively low CO ₂ emissions (Figure 10). The disadvantages of nuclear power are public concerns about safety, proliferation risk and waste processing (Högselius, 2009). For Hinkley, the nuclear power plant currently under construction in the UK, the CAPEX for 3200 MW is expected to be 19.6 Billion Pounds (6125 GBP / kW) (Vukmanovic, 2018). This is significantly more expensive than contemporary offshore wind energy (1800-2800 € / kW, Figure 8).	Research efforts are focussed on improving safety, minimizing waste, making nuclear power proliferation resistant (Abram and Ion, 2008) and on the feasibility of nuclear fusion (Goto <i>et al.</i> , 2021).

Table 3 (continued) Fuel types and electricity conversion comparison

Fuel	Electricity conversion	Advantages and disadvantages	Recent research
Wind	The kinetic energy of wind is converted into a rotating movement by the blades connected to the rotor of a wind turbine. Either via a gearbox or directly, the rotation of the rotor is converted into electric energy by an electricity generator. Two main types of wind power exist: onshore wind power and offshore wind power (Breeze, 2014).	The advantages of wind power are the low LCoE (Figure 9) and the low CO ₂ emissions (Figure 10). One key disadvantage of wind power is that high wind resources are not always closely located to high demand areas. Furthermore, wind energy requires flexible electricity sources to keep the grid stable (Barasa <i>et al.</i> , 2018)	State of the art developments are generally focused on cost reductions by increasing wind turbine output, reducing material usage and improving reliability (Ellabban, Abu-Rub and Blaabjerg, 2014) and on improvement of the recyclability of particularly the blades (Jensen and Skelton, 2018).
Solar	Heat and radiation from the sun is converted into electric energy by means of either PV or CSP technology. With PV technology, the PV cells made of semi-conductors turn solar energy directly into electric currents. With CSP technology, the heat is concentrated and turned into electricity (Ellabban, Abu-Rub and Blaabjerg, 2014).	The advantages of solar power are the low LCoE (Figure 9) and the low CO ₂ emissions (Figure 10). A specific CSP advantage is the possibility to temporarily store energy in heat (Liu <i>et al.</i> , 2016). The disadvantage of CSP solar power is the high investment costs (Figure 8). The downside of PV solar power is the decreasing efficiency in high temperatures (Dubey, Sarvaiya and Seshadri, 2013) and that it needs to be combined with flexible electricity technologies to ensure electricity supply meets the variation in demand (Barasa <i>et al.</i> , 2018).	The latest developments are focused around increased efficiency, resulting in cost reductions (Kabir <i>et al.</i> , 2018).
Biomass	The caloric value of biomass is converted into electric energy by a combination of a combustion device with an electricity generator. The electricity is produced by burning biomass in a combustion plant, by co-firing biomass or by gasification of biomass (Breeze, 2014).	The advantages of biomass power are the low CO ₂ emissions (Figure 10), high flexibility (Barasa <i>et al.</i> , 2018) and job opportunities for farmers in oil importing and developing countries (Demirbas, 2008). Disadvantages of biomass power are the low energy density and the intensive usage of water, land, crops and fossil fuel (Ellabban, Abu-Rub and Blaabjerg, 2014). Also, burning biomass might result in air pollution (Ellabban, Abu-Rub and Blaabjerg, 2014).	Recent research is focussed on the increasing the quality of biogas to improve the commercial use in power generation, liquid fuel production and hydrogen production (Wang <i>et al.</i> , 2008). Also, the usage of different feedstocks is studied (Albuquerque <i>et al.</i> , 2009).
Geo-thermal	The heat in the centre of earth is converted into electric energy by a steam turbine generator. The electricity is produced by either a flash stem plant or by a binary cycle turbine system for lower temperatures (Breeze, 2014).	The advantages of geothermal power are the low CO ₂ emissions (Figure 10) and the low LCoE (Figure 9). Disadvantages of geothermal power are the relatively high CAPEX (Figure 8), air emissions and the risks of polluting waterways (Ellabban, Abu-Rub and Blaabjerg, 2014).	Reducing the investment risk is needed to make geothermal power attractive relative to other sources of power (Clauser and Ewert, 2018).

2.2.3 Integrated electricity systems

Global investment in renewable power generation significantly exceeds fossil power generation investments (International Energy Agency, 2020). Consequentially, energy systems will have to cope with an increased share of renewable energy. This has an impact on the supply-demand balance as well as the price of electricity, as further explained in the two sections.

Supply – demand balance

Solar power and wind power form the largest share of total renewable investment (International Energy Agency, 2020). The supply of energy from both technologies depend on non-equally distributed and variable natural forces, hence the production of electricity is inflexible in that it cannot be varied according to demand. This potentially creates a discrepancy between the energy demand and energy supply both geographically and temporally. To create a stable balance between electricity demand and supply, the following solutions are available:

- Compensate inflexible generation by integration flexible electricity generation in the same grid:
 - Renewable flexible electricity generation: hydro, biomass, biogas, to compensate for inflexible electricity generation from solar and wind (Barasa *et al.*, 2018).
 - Fossil flexible electricity generation: natural gas (Chen *et al.*, 2019).
- Connecting electricity systems:
 - Grid utilization, to connect supply and demand on a regional level (Barasa *et al.*, 2018).
 - HVDC transmission lines on region level to connect and balance multiple grids (Barasa *et al.*, 2018)
- Energy storage:
 - Energy storage to avoid curtailment and electricity shortages: battery storage, pumped hydro storage, compressed air energy storage, thermal energy storage and power-to-gas (Barasa *et al.*, 2018).

- Integration of water desalination (Barasa *et al.*, 2018) to directly utilize excess energy and store desalinated water instead of electricity.
- Integration of industrial gas (Barasa *et al.*, 2018) to directly utilize excess energy to produce gas for industrial purposes.
- Heat generation - electric conversion in thermal energy to take over the role of CHP (Chen *et al.*, 2019).

Electricity price development

Most markets for renewable energy utilize Power Purchase Agreements (PPAs), where the price and the uptake of electricity is determined for a fixed period by the government. The PPAs are essential for the success of renewable energy, because they offer a long-term revenue guarantee (Miller *et al.*, 2017). The lifetime of the powerplants exceed in some cases the duration of the power purchase agreement. For instance, the latest Dutch offshore wind parks have a PPA for 15 years (Tisheva, 2018), while the lifetime of the turbines is expected to be 25 years. This means the renewable electricity will most likely eventually be sold on the open market once the PPA expires. With the current increase of renewable energy, more countries will have a system with both flexible (mainly fossil) and inflexible (mainly renewable) power generation capacity. Inflexible generation capacity does not respond to electricity demand. Open market auction electricity pricing is based on actual supply and demand. The marginal costs of wind and solar are zero, hence once the sun or wind is available, it will drive down the electricity price. Consequently, an increase of solar power and wind power installed capacity will decrease the price for both renewable and fossil energy (McElroy, Chen and Deng, 2018).

Barasa *et al* (2018) provide a futuristic simulation for a 100% renewable Sub Saharan Africa by 2030. A bottom-up cost based approach results in an electricity price range of 47-58 € / MWh. This is comparable to the lower part of the LCoE ranges of today's electricity production (Figure 9).

2.2.4 Summary

In 2019, the majority of electricity was produced by fossil-fuel (63.1%), followed by hydro power (15.7%) and nuclear power (10.4%). Renewables (without hydro power) and other energy sources only counted for 10.8% (International Energy Agency, 2021).

Renewable electricity has shown to be price competitive on a LCoE level, however the CAPEX is in many cases higher compared to fossil electricity (Figure 8 and 9).

Hydropower and natural gas based power generation are highly flexible in that the power output can be varied according to changing demand. On the other hand, solar PV power and wind power are not flexible. Flexible electricity generation, energy storage (electric, other form of energy or as industrial output) and the interconnection of grids facilitate a stable balance between supply and demand with a higher percentage of renewables (Barasa *et al.*, 2018; Chen *et al.*, 2019).

Auction based open market electricity prices are not expected to increase with more renewables (Chen *et al.*, 2019). Also, a cost driven simulation shows that a 100% renewable power system is possible in the same range as today's LCoE cost (Barasa *et al.*, 2018).

2.3 Electricity technology diffusion

2.3.1 Technology diffusion theories

Electricity technology diffusion can be described based on general technology diffusion theories. The concept is explained in literature through different theoretical constructs. One way to address the global diffusion of technology is through epidemic S-curves. Griliches (1957) studied the diffusion of hybrid corn seeds within the US and fitted a logistic growth curve to the data. Bass (1969) used s-curves to explain increase in consumer product sales. Generalizing further, Davies (1979) based his innovation diffusion theory on the same pattern. More recent research by Phillips (2007) focussed specifically on the tipping points

within this diffusion model. The second way to describe global diffusion of technology is based on evolutionary technological transitions. Based on the creation of new combinations (Schumpeter, 1934) and technological regimes (Nelson and Winter, 1982), Geels (2002) conceptualized a multi-level technological evolution theory. Technology diffusion starts with path creation in niches, moves on to a patchwork of regimes, and after large scale adoption ultimately influences landscape developments. Thirdly, Technological Innovation Systems provides a multi-function, socio-technical view on global diffusion of technology. Building on empirical studies, Bergek et al (2008) defined the innovation system in seven functions: knowledge development and diffusion, entrepreneurial experimentation, the influence of the direction of search, market formation, development of positive external economies, legitimation, and resource mobilization.

2.3.2 Factors influencing electricity technology diffusion

Multiple studies describe different factors influencing the electricity technology diffusion. A summary of a selection of studies is shown in Table 4.

All of the studies in Table 4 describe environmental factors influencing the electricity mix, most of them also highlight economic, technical, political and resource availability factors. The majority of the factors can be expressed quantitatively (such as LCoE per technology), however Rogge and Johnstone (2017) introduce the concept of incidents leading to destabilization and discontinuation of technologies. In their particular study, the impact of the nuclear technology phase out policy - that followed the Fukushima incident - on the electricity mix competition was explored.

Table 4 Factors influencing energy technology diffusion.

Reference	Factors				
	Economic	Technical	Environmental	Political / institutional	Regional resource availability
(Malikarjun and Lewis, 2014)	Turnkey cost, O&M cost, Fuel cost, Financial cost	Performance, Availability	Carbon emission, Nitrogen emission, Sulphur emission		
(Önüt, Tuzkaya and Saadet, 2008)	<i>Benefits</i> Changeover among resources in necessity, Availability ratio, Frequency of maintenance, Effect to total productivity, Long-term usage consistency, Low extraordinary costs <i>Cost</i> Maintenance cost, Storage cost, Labour cost, Running cost, Transportation cost, Investment cost <i>Opportunities</i> More availability, Diversibility, Investment feasibility of private sector <i>Risks</i> Increase in prices, Risk costs, Demand explosion	<i>Benefits</i> Changeability of the current system in the future, Suitability to minor improvements, Suitability to the current technologies	<i>Risks</i> Acid rain, Emissions, Air/water/earth pollution, Global warming, Social results, Fire, Poisoning	<i>Opportunities</i> To bound the other countries <i>Risks</i> Dependence on foreign countries, Economic crises, Risk of exhausting in short terms, International crisis, National crisis	<i>Benefits</i> Probability of attaining the new resource in necessity, Availability in wide area, Long-term availability, Domestic availability <i>Opportunities</i> Opportunity of obtaining the resource locally in the future
(Zangeneh, Jadid and Rahimi-Kian, 2009)	<i>Cost</i> Investment cost, Operating cost <i>Market</i> Potential of ancillary service supply, Participate in electricity market	<i>Operational Issues</i> Power quality, Forced outage rate, Response speed, Efficiency, Start-up time, Capacity factor <i>Structural Issues</i> Footprint, Lifetime, Modularity, Installation lead time <i>Technical requirements</i> Maintenance, Domestic technical knowledge, Interconnection equipment	Noise emission, PM ₁₀ emission, SO ₂ emission, CO ₂ emission, NO _x emission, CO emission, Aesthetics		Regional primary energy availability
(Rogge and Johnstone, 2017)			Fukushima accident	Technology phase out policy	
(Keeley and Matsumoto, 2018b)	Exchange rate volatility, Access to local finance, Labour costs		Access to land	Political risk, Administrative procedure, Effective law enforcement, Feed in tariff, Auction, Tax-incentives, REC and RPS, Priority access to grid, Absence of LCR, Technical standards, Renewable target, Development plan, Social acceptance	Natural resources
(International Energy Agency, 2010)	Demographic development, Macroeconomic development, International energy prices		CO ₂ emission	CO ₂ emission targets	Availability of natural resources

The methods to determine the factors differ. Zangeneh, Jadid and Rahimi-kian (2009) and Mallikarjun and Lewis (2014) base it on literature, Rogge and Johnstone (2017) base it on historical events and Keeley and Matsumoto (2018b) base it on expert interviews.

A recent review on global diffusion of all renewable energy types was published by Can Şener et al (2018). The authors recommend the introduction of a technology focus for further research: “..clearly defined sets of renewable energy source types will increase the ability to understand both the drivers and barriers of renewable energy deployment..”.

2.3.3 Different viewpoints in research

Both advanced economies and developing economies have reformed their electricity sector in the last decades (Jamasb, 2006). Main reasons for privatization of the sector are clear and stable price determination and incentives to restore financial viability (Newbery, 2004).

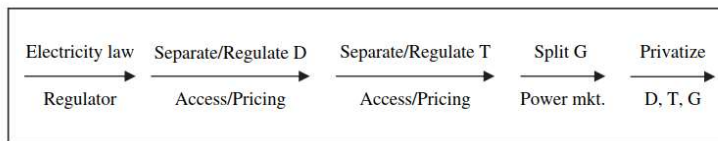


Figure 11 Steps in a generic electricity sector reform model. D=Distribution, T=Transmission, G=Generation (Figure from (Jamasb, 2006)).

One of the first steps in the privatization is to unbundle the distribution from the generation and transmission (Figure 11) (Jamasb, 2006). This creates the first 3 steps in the electricity supply chain. The two last steps are the sales of electricity and the (domestic or industrial) consumption of electricity. The different steps have their own suppliers and own competitions.

Not all steps of the supply chain are present in every electricity system. Small scale distributed generation systems don't have transmission, direct industrial integration of electricity generation does not have transmission, distribution and retail and in some state owned electricity systems there is no clear split between the different sub-systems.

As a consequence of different levels of privatization, markets vary in their degree of competitiveness. Generation and supply (sales) are potentially competitive activities, whereas transmission and distribution are natural monopoly segments (Jamاسب, 2006).

Even after decades of electricity reform, the markets are still in a transition. Jamاسب (Jamاسب, 2006) argues that especially in developing markets, because of fewer resources and weaker institutions the state should redefine its role rather than fully withdrawing from the sector. Table 5 shows the different privatization situations for the generation markets and corresponding ownership and business models for wind energy.

Table 5 Wind turbine power generation in different privatization stages. IPP = Independent Power Producer.

Privatization stage in generation	Non-privatized	Fully privatized	Partly privatized
Wind turbine owner	State-owned utility	<ul style="list-style-type: none"> Privatized utility IPP Investor 	<ul style="list-style-type: none"> State-owned utility IPP Investor
Wind turbine operator	State-owned utility	<ul style="list-style-type: none"> Privatized utility IPP 	<ul style="list-style-type: none"> State-owned utility IPP
Electricity market	<ul style="list-style-type: none"> State controlled electricity price Subsidies needed if price does not cover LCoE 	<p>Wholesale market:</p> <ul style="list-style-type: none"> Single buyer model Marginal cost-based pools Price based spot market (Jamاسب, 2006) <p>New entry via IPP with:</p> <ul style="list-style-type: none"> Full risk Power purchase agreement (auction based or feed in tariff (Becker and Fischer, 2013)) with existing generators, large users (Jamاسب, 2006) or state (Eberhard and Gratwick, 2011). <p>Renewable support mechanisms to combat global warming:</p> <ul style="list-style-type: none"> Grants Tax credits Carbon tax GHG certificates Renewable portfolio standards (Polzin <i>et al.</i>, 2019) 	<ul style="list-style-type: none"> State controlled electricity price Subsidies needed if price does not cover LCoE. <p>New entry via IPP with:</p> <ul style="list-style-type: none"> Full risk Power purchase agreement (auction based or feed in tariff (Becker and Fischer, 2013)) with existing generators, large users (Jamاسب, 2006) or state (Eberhard and Gratwick, 2011). <p>Renewable support mechanisms to combat global warming:</p> <ul style="list-style-type: none"> Grants Tax credits Carbon tax GHG certificates Renewable portfolio standards (Polzin <i>et al.</i>, 2019)

Privatization increased the number of stakeholders. Recent research acknowledged this and expanded the perspectives used. State of the art research on the diffusion of renewable energy technology includes policymakers (for

example She et al. (2019)), adopters (for example Mignon and Bergek (2016)) and investors (for example Keeley and Matsumoto (2018a)).

The purpose of the studies within renewable energy technology diffusion differ as well. Supporting the owner or operator of electricity generation equipment in their technology choice through a multiple-criteria decision model for a specific area is well described (Önüt, Tuzkaya and Saadet, 2008; Zangeneh, Jadid and Rahimi-Kian, 2009; Mallikarjun and Lewis, 2014) . Also, the impact of policies through interviews and regression analysis can be found in the selected literature (Rogge and Johnstone, 2017). A completely different field is a multiple criteria decision modelling for the flow of FDI (Keeley and Matsumoto, 2018b). Environmental impact of future energy scenarios form the last category (International Energy Agency, 2010). Complex models focus on the least-cost mix of energy technologies to meet the energy demand within certain constraints.

2.3.4 Summary

Electricity technology diffusion can be described based on general technology diffusion theories. The main theories are S-curve shaped diffusion, evolutionary technological transitions and technological innovation systems.

Literature describes how multiple environmental, economic, technical, politic and resource availability factors influence the electricity generation mix. The majority of the factors can be expressed quantitatively, Rogge and Johnstone (2017) however introduce the concept of incidents leading to destabilization and discontinuation of technologies. In their study, the impact of the nuclear technology phase out policy - that followed the Fukushima incident - on the electricity mix competition was explored.

The electricity supply chain consists of 5 steps: the electricity generation, the transmission, distribution, retail sales and (domestic and industrial) consumption. Generation and supply (sales) are potentially competitive activities, whereas transmission and distribution are natural monopoly segments (Jamassb, 2006). Multiple perspectives have been used in electricity mix studies, for example the energy planner, electricity producer or policy perspective.

3 Critical review of literature and further research

The literature identifies 68 high potential wind countries, many of which also have relatively large fossil fuel reserves. The 68 high potential wind countries include both advanced and developing economies. Many developing economies have installed very low wind power capacity. Most advanced economies have large scale wind power installed. What is missing is an overview of factors influencing global wind energy diffusion.

Along the electricity supply chain, multiple markets exist: the electricity generation, the transmission, distribution, retail sales and consumption markets. Generation and supply (sales) are potentially competitive activities, whereas transmission and distribution are natural monopoly segments (Jamasb, 2006). Multiple studies have been published from an energy planner, electricity producer or policy perspective how to influence the electricity mix. What is missing is an overview of which perspectives have been used to study wind energy diffusion and which perspectives might be absent.

Hence, the aim of the literature review is to identify, according to literature, which factors impact the global wind energy adoption. It will additionally provide an overview of the different research perspectives available to date. Based on the state of the art, the literature will identify areas worthy of further research relevant to the main theme of this DBA, exploring opportunities for further wind deployment in developing and emerging markets to benefit wind power OEM business growth and to contribute to the SDG agenda.

References

- Abram, T. and Ion, S. (2008) 'Generation-IV nuclear power: A review of the state of the science', *Energy Policy*, 36(12), pp. 4323–4330. doi: 10.1016/j.enpol.2008.09.059.
- Albuquerque, M. C. G., Machado, Y. L., Torres, A. E. B., Azevedo, D. C. S., Cavalcante, C. L., Firmiano, L. R. and Parente, E. J. S. (2009) 'Properties of biodiesel oils formulated using different biomass sources and their blends', *Renewable Energy*, 34(3), pp. 857–859. doi: 10.1016/j.renene.2008.07.006.
- Antonanzas, J., Jimenez, E., Blanco, J. and Antonanzas-Torres, F. (2014) 'Potential solar thermal integration in Spanish combined cycle gas turbines', *Renewable and Sustainable Energy Reviews*, 37, pp. 36–46. doi: 10.1016/j.rser.2014.05.006.
- Barasa, M., Bogdanov, D., Oyewo, A. S. and Breyer, C. (2018) 'A cost optimal resolution for Sub-Saharan Africa powered by 100% renewables in 2030', *Renewable and Sustainable Energy Reviews*, 92, pp. 440–457. doi: 10.1016/j.rser.2018.04.110.
- Bass, F. M. (1969) 'A New Product Growth for Model Consumer Durables', *Management Science*, 15(5), pp. 215–227. doi: 10.1287/mnsc.15.5.215.
- Becker, B. and Fischer, D. (2013) 'Promoting renewable electricity generation in emerging economies', *Energy Policy*. Elsevier, 56, pp. 446–455. doi: 10.1016/j.enpol.2013.01.004.
- Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008) 'Analyzing the functional dynamics of technological innovation systems: a scheme of analysis', *Research Policy*, 37(3), pp. 407–429. doi: <https://doi.org/10.1016/j.respol.2007.12.003>.
- BP (1999) *BP Statistical Review of World Energy*. London.
- BP (2018) *BP Statistical Review of World Energy*. 67th edn. London. Available at: <http://www.bp.com/energyoutlook>.

Breeze, P. (2014) *Power Generation Technologies*. Oxford: Elsevier. doi: 10.1016/C2012-0-00136-6.

Can Şener, Ş. E., Sharp, J. L. and Anctil, A. (2018) 'Factors impacting diverging paths of renewable energy: A review', *Renewable and Sustainable Energy Reviews*, 81(March 2017), pp. 2335–2342. doi: 10.1016/j.rser.2017.06.042.

Capurso, T., Stefanizzi, M., Torresi, M. and Camporeale, S. M. (2022) 'Perspective of the role of hydrogen in the 21st century energy transition', *Energy Conversion and Management*, 251, p. 114898. doi: 10.1016/j.enconman.2021.114898.

Chen, X., McElroy, M. B., Wu, Q., Shu, Y. and Xue, Y. (2019) 'Transition towards higher penetration of renewables: an overview of interlinked technical, environmental and socio-economic challenges', *Journal of Modern Power Systems and Clean Energy*, 7(1), pp. 1–8. doi: 10.1007/s40565-018-0438-9.

Clauser, C. and Ewert, M. (2018) 'The renewables cost challenge: Levelized cost of geothermal electric energy compared to other sources of primary energy – Review and case study', *Renewable and Sustainable Energy Reviews*, 82, pp. 3683–3693. doi: 10.1016/j.rser.2017.10.095.

D'apote, S. L. (1998) 'IEA biomass energy analysis and projections', in *Proceedings of Biomass Energy Conference: Data, Analysis and Trends, Paris, 23-24 March, 1998*.

Davies, S. W. (1979) *The diffusion of process innovations*. Cambridge, UK: Cambridge University Press.

Demirbas, A. (2008) 'Biofuels sources, biofuel policy, biofuel economy and global biofuel projections', *Energy Conversion and Management*, 49(8), pp. 2106–2116. doi: 10.1016/j.enconman.2008.02.020.

Dubey, S., Sarvaiya, J. N. and Seshadri, B. (2013) 'Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World – A Review', *Energy Procedia*, 33, pp. 311–321. doi: 10.1016/j.egypro.2013.05.072.

Eberhard, A. and Gratwick, K. N. (2011) 'IPPs in Sub-Saharan Africa: Determinants of success', *Energy Policy*, 39(9), pp. 5541–5549. doi: 10.1016/j.enpol.2011.05.004.

Ellabban, O., Abu-Rub, H. and Blaabjerg, F. (2014) 'Renewable energy resources: Current status, future prospects and their enabling technology', *Renewable and Sustainable Energy Reviews*, 39, pp. 748–764. doi: 10.1016/j.rser.2014.07.113.

Fichera, A., Samanta, S. and Volpe, R. (2022) 'Exergetic Analysis of a Natural Gas Combined-Cycle Power Plant with a Molten Carbonate Fuel Cell for Carbon Capture', *Sustainability*, 14(1), p. 533. doi: 10.3390/su14010533.

Fischer, G. and Heilig, G. K. (1998) *Report IIASA-RR-98-1: Population Momentum and the Demand on Land and Water Resources*. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Geels, F. W. (2002) 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study', *Research Policy*, 31(8), pp. 1257–1274. doi: [https://doi.org/10.1016/S0048-7333\(02\)00062-8](https://doi.org/10.1016/S0048-7333(02)00062-8).

Goto, T., Tanaka, T., Tamura, H., Miyazawa, J., Iwamoto, A., Yanagi, N., Fujita, T., Kodama, R. and Mori, Y. (2021) 'Feasibility study of tokamak, helical and laser reactors as affordable fusion volumetric neutron sources', *Nuclear Fusion*, 61(12), p. 126047. doi: 10.1088/1741-4326/ac3367.

Griliches, Z. (1957) 'Hybrid corn: an exploration in the economics of technological change', *Econometrica*. doi: 10.2307/1905380.

Grubb, M. J. and Meyer, N. I. (1993) 'Wind energy: Resources, systems, and regional strategies', in *Renewable energy: Sources for fuels and electricity; Johansson, T.B.; Kelly, H.; Reddy, A.K.N.; Williams, R.H. [eds.]*; Washington, D.C.: Island Press.

Haszeldine, R. S. (2009) 'Carbon Capture and Storage: How Green Can Black Be?', *Science*. doi: 10.1126/science.1172246.

Högselius, P. (2009) 'Spent nuclear fuel policies in historical perspective: An international comparison', *Energy Policy*, 37(1), pp. 254–263. doi: 10.1016/j.enpol.2008.09.043.

Hondo, H. (2005) 'Life cycle GHG emission analysis of power generation systems: Japanese case', *Energy*, 30(11–12), pp. 2042–2056. doi: 10.1016/j.energy.2004.07.020.

International Energy Agency (1998) *World Energy Outlook*. Paris.

International Energy Agency (2010) *Energy technology perspectives: 2010. Scenarios & strategies to 2050*, International Energy Agency.

International Energy Agency (2020) *World Energy Investment 2020*. Paris: International Energy Agency (IEA). Available at: <https://www.iea.org/reports/world-energy-investment-2020>.

International Energy Agency (2021) *Key World Energy Statistics 2021*. Paris: International Energy Agency (IEA). Available at: <https://www.iea.org/reports/key-world-energy-statistics-2021>.

International Monetary Fund (2018) *World Economic Outlook - Database - WEO Groups and Aggregates Information*. Available at: <https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/groups.htm> (Accessed: 5 November 2018).

International Renewable Energy Agency (2018) *Renewable capacity statistics 2018*. Abu Dhabi: International Renewable Energy Agency (IRENA). doi: 10.1016/S2255-4971(15)30126-9.

International Renewable Energy Agency (2021) *Renewable Energy Statistics 2021*. Abu Dhabi: International Renewable Energy Agency (IRENA).

Jamasb, T. (2006) 'Between the state and market: Electricity sector reform in developing countries', *Utilities Policy*, 14(1), pp. 14–30. doi: 10.1016/j.jup.2004.11.001.

Jensen, J. P. and Skelton, K. (2018) 'Wind turbine blade recycling: Experiences,

challenges and possibilities in a circular economy', *Renewable and Sustainable Energy Reviews*, 97, pp. 165–176. doi: 10.1016/j.rser.2018.08.041.

Jung, C., Schindler, D. and Laible, J. (2018) 'National and global wind resource assessment under six wind turbine installation scenarios', *Energy Conversion and Management*. doi: 10.1016/j.enconman.2017.11.059.

Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A. and Kim, K.-H. (2018) 'Solar energy: Potential and future prospects', *Renewable and Sustainable Energy Reviews*, 82, pp. 894–900. doi: 10.1016/j.rser.2017.09.094.

Keeley, A. R. and Matsumoto, K. (2018a) 'Investors' perspective on determinants of foreign direct investment in wind and solar energy in developing economies – Review and expert opinions', *Journal of Cleaner Production*, 179, pp. 132–142. doi: 10.1016/j.jclepro.2017.12.154.

Keeley, A. R. and Matsumoto, K. (2018b) 'Relative significance of determinants of foreign direct investment in wind and solar energy in developing countries – AHP analysis', *Energy Policy*, 123, pp. 337–348. doi: 10.1016/j.enpol.2018.08.055.

Kost, C., Mayer, J. N., Thomsen, J., Hartmann, N., Senkpiel, C., Philipps, S., Nold, S., Lude, S., Saad, N. and Schlegl, T. (2013) *Levelized Cost of Electricity Renewable Energy Technologies*. Freiburg: Fraunhofer Institute for Solar Energy Systems ISE.

Liu, M., Steven Tay, N. H., Bell, S., Belusko, M., Jacob, R., Will, G., Saman, W. and Bruno, F. (2016) 'Review on concentrating solar power plants and new developments in high temperature thermal energy storage technologies', *Renewable and Sustainable Energy Reviews*, 53, pp. 1411–1432. doi: 10.1016/j.rser.2015.09.026.

Lu, X., McElroy, M. B. and Kiviluoma, J. (2009) 'Global potential for wind-generated electricity', *Proceedings of the National Academy of Sciences*. doi: 10.1073/pnas.0904101106.

Mallikarjun, S. and Lewis, H. F. (2014) 'Energy technology allocation for

distributed energy resources: A strategic technology-policy framework', *Energy*, 72, pp. 783–799. doi: 10.1016/j.energy.2014.05.113.

McElroy, M. B., Chen, X. and Deng, Y. (2018) 'The missing money problem: Incorporation of increased resources from wind in a representative US power market', *Renewable Energy*, 126, pp. 126–136. doi: 10.1016/j.renene.2018.02.129.

McKelvey, V. E. (1972) 'Mineral Resource Estimates and Public Policy: Better methods for estimating the magnitude of potential mineral resources are needed to provide the knowledge that should guide the design of many key public policies', *American Scientist*. Sigma Xi, The Scientific Research Society, 60(1), pp. 32–40. Available at: <http://www.jstor.org/stable/27842943>.

Mignon, I. and Bergek, A. (2016) 'System- and actor-level challenges for diffusion of renewable electricity technologies: an international comparison', *Journal of Cleaner Production*. Elsevier Ltd, 128, pp. 105–115. doi: 10.1016/j.jclepro.2015.09.048.

Miller, L., Carriveau, R., Harper, S. and Singh, S. (2017) 'Evaluating the link between LCOE and PPA elements and structure for wind energy', *Energy Strategy Reviews*, 16, pp. 33–42. doi: 10.1016/j.esr.2017.02.006.

Miller, L. M., Gans, F. and Kleidon, A. (2011) 'Estimating maximum global land surface wind power extractability and associated climatic consequences', *Earth System Dynamics*, 2(1), pp. 1–12. doi: 10.5194/esd-2-1-2011.

Nakicenovic, N., Grubler, A. and McDonald, A. (1998) *Global Energy Perspectives*. Cambridge, UK: Cambridge University Press.

NEA and IAEA (1997) *Uranium 1997: resources, production and demand*. Paris: Organisation for Economic Co-operation and Development.

NEA and IAEA (2016) *Uranium 2016: resources, production and demand*. Paris: OECD (Uranium). doi: 10.1787/uranium-2016-en.

Nelson, R. and Winter, S. (1982) *An evolutionary theory of economic change*.

London: Belknap Press of Harvard University.

Newbery, D. (2004) *Issues and Options for Restructuring Electricity Supply Industries*.

Önüt, S., Tuzkaya, U. R. and Saadet, N. (2008) 'Multiple criteria evaluation of current energy resources for Turkish manufacturing industry', *Energy Conversion and Management*, 49(6), pp. 1480–1492. doi: 10.1016/j.enconman.2007.12.026.

Organisation for Economic Co-operation and Development and International Energy Agency (2015) *Projected Costs of Generating Electricity*. France.

Paish, O. (2002) 'Small hydro power: technology and current status', *Renewable and Sustainable Energy Reviews*, 6(6), pp. 537–556. doi: 10.1016/S1364-0321(02)00006-0.

Phillips, F. (2007) 'On S-curves and tipping points', *Technological Forecasting and Social Change*, 74(6), pp. 715–730. doi: <https://doi.org/10.1016/j.techfore.2006.11.006>.

Polzin, F., Egli, F., Steffen, B. and Schmidt, T. S. (2019) 'How do policies mobilize private finance for renewable energy?—A systematic review with an investor perspective', *Applied Energy*, 236, pp. 1249–1268. doi: 10.1016/j.apenergy.2018.11.098.

Ram, M., Child, M., Aghahosseini, A., Bogdanov, D., Lohrmann, A. and Breyer, C. (2018) 'A comparative analysis of electricity generation costs from renewable, fossil fuel and nuclear sources in G20 countries for the period 2015-2030', *Journal of Cleaner Production*, 199, pp. 687–704. doi: 10.1016/j.jclepro.2018.07.159.

Rogge, K. S. and Johnstone, P. (2017) 'Exploring the role of phase-out policies for low-carbon energy transitions: The case of the German Energiewende', *Energy Research & Social Science*, 33, pp. 128–137. doi: 10.1016/j.erss.2017.10.004.

Rogner, H.-H. (1997) 'AN ASSESSMENT OF WORLD HYDROCARBON

RESOURCES', *Annual Review of Energy and the Environment*, 22(1), pp. 217–262. doi: 10.1146/annurev.energy.22.1.217.

Rosenberg, D., Bodaly, R. A. and Usher, P. J. (1995) 'Environmental and social impacts of large scale hydroelectric development: who is listening?', *Global Environmental Change*, 5(2), pp. 127–148. doi: 10.1016/0959-3780(95)00018-J.

Schlömer, S., Bruckner, T., Fulton, L., Hertwich, E., McKinnon, A., Perczyk, D., Roy, J., Schaeffer, R., Sims, R., Smith, P. and Wiser, R. (2014) 'Technology Specific Cost and Performance Parameters', in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group 3 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Schumpeter, J. A. (1934) *The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle*. Cambridge, MA: Harvard University Press.

Senjyu, T., Nakaji, T., Uezato, K. and Funabashi, T. (2005) 'A Hybrid Power System Using Alternative Energy Facilities in Isolated Island', *IEEE Transactions on Energy Conversion*, 20(2), pp. 406–414. doi: 10.1109/TEC.2004.837275.

Shafiee, S. and Topal, E. (2010) 'A long-term view of worldwide fossil fuel prices', *Applied Energy*, 87(3), pp. 988–1000. doi: 10.1016/j.apenergy.2009.09.012.

She, Z. Y., Cao, R., Xie, B. C., Ma, J. J. and Lan, S. (2019) 'An analysis of the wind power development factors by Generalized Bass Model: A case study of China's eight bases', *Journal of Cleaner Production*. Elsevier Ltd, 231, pp. 1503–1514. doi: 10.1016/j.jclepro.2019.05.255.

Tisheva, P. (2018) 'Fin close reached on 731.5-MW Dutch offshore wind park', *renewablesnow*, 28 June. Available at: <https://renewablesnow.com/news/fin-close-reached-on-7315-mw-dutch-offshore-wind-park-618117/>.

UNDP (2000) 'World Energy Assessment. Energy and the challenge of Sustainability', *UNDP*.

Vukmanovic, O. (2018) 'EDF sees UK Hinkley C nuclear plant online by end of 2025', *Reuters.com*. Available at: <https://www.reuters.com/article/us-britain-nuclear-hinkley/edf-sees-uk-hinkley-c-nuclear-plant-online-by-end-of-2025-idUSKBN1F61QK>.

Wang, L., Weller, C. L., Jones, D. D. and Hanna, M. A. (2008) 'Contemporary issues in thermal gasification of biomass and its application to electricity and fuel production', *Biomass and Bioenergy*, 32(7), pp. 573–581. doi: 10.1016/j.biombioe.2007.12.007.

WEC - World Energy Council (1998) *Survey of Energy Resources, Survey of Energy Resources*. London. doi: 10.1016/j.matcom.2009.06.033.

World Atlas and Industry Guide (1998) *International Journal on Hydropower and Dams*. Sutton, Surrey: Aqua-Media International.

Zangeneh, A., Jadid, S. and Rahimi-Kian, A. (2009) 'A hierarchical decision making model for the prioritization of distributed generation technologies: A case study for Iran', *Energy Policy*. Elsevier, 37(12), pp. 5752–5763. doi: 10.1016/j.enpol.2009.08.045.

3 LITERATURE STUDY

“Is it possible to control a system capable of evolving?”

--- Nigel Goldenfeld (in: The Last Unknowns, 2019)

The literature study was published in 2021 in the Journal of Cleaner Production. The co-authors had a purely supervisory role.

The last submitted version of the published paper shown in this section,
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Zwarteveen, J. W., Figueira, C., Zawwar, I. and Angus, A. (2021) ‘Barriers and drivers of the global imbalance of wind energy diffusion: A meta-analysis from a wind power Original Equipment Manufacturer perspective’, *Journal of Cleaner Production*, 290, p. 125636. doi: 10.1016/j.jclepro.2020.125636.

Abstract

Significant progress has been made globally in the transition towards a sustainable society. Since 2007, the annual investment in renewable energy exceeded the combined investment in fossil and nuclear energy. However, for many developing countries, the balance is still in favour of conventional energy.

The purpose of this paper is to understand the barriers and drivers of this global imbalance in wind energy diffusion in developing countries through a systematic literature review and meta-analysis. Furthermore, it highlights the different viewpoints the literature has to offer, with the aim of understanding wind power growth from an Original Equipment Manufacturer (OEM) point of view. This is important as the sales of wind turbines are the practical building blocks of the transition towards a sustainable society.

259 factors influencing wind energy diffusion were identified and clustered into 8 categories: economic, environmental, technical potential, technological, social, regulatory, political and also an amalgam of other factors. Policymakers formed the most frequently used viewpoint, no study addressed the OEM perspective specifically. A novel closed-loop feedback system was proposed as a conceptual framework to categorize factors influencing wind energy diffusion into two types: factors related to the desire for wind energy and factors related to the mechanism for this change. This paper shows indications that economic factors are of key importance in emerging and developing countries, whereas environmental factors are not driving wind energy growth, contrary to expectations. OEM managers might consider the rebranding of wind turbine technology from “green technology” to “job-creating technology” to increase sales and stimulate a transition to a more sustainable society in many emerging and developing markets.

Keywords: Wind Energy, Transition, Sustainability, Meta-Analysis, Developing and Emerging Economies, Wind Power OEM

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1. Introduction

In 2015, the UN created the 17 Sustainable Development Goals (SDGs) to increase the prosperity of people and the planet by 2030. As part of this targeted transition towards a sustainable society, SDG number 7 aims to “ensure access to affordable, reliable, sustainable and modern energy for all” (United Nations, 2018). Dovi et al (2009) highlight the importance of the “implementation of technologies and management approaches ... to make the transition to more sustainable societies”. Global investment in power generation, a management and technology indicator for the transition, was approximately 480 USD billion in 2018. Since 2007, the annual investment in renewable energy exceeded the combined investment in fossil and nuclear energy (International Energy Agency, 2019). However, in many developing and emerging economies (Russia, South East Asia, Middle East and North Africa), investments in conventional energy are still dominant. The annual investment in total power generation (renewable and non-renewable) is decreasing in high-income countries but has been increasing in emerging markets since 2011 (International Energy Agency, 2019). This illustrates that emerging markets are catching up in their electrification but falling behind in their transition towards a sustainable society. Understanding the reasons why there is relatively little investment in renewable energy in certain developing and emerging markets could help turn the balance in favour of renewable energy and support the achievement of SDG 7.

Within the field of renewable energy, solar PV and wind formed the largest share of total investments in 2018 (International Energy Agency, 2019). Solar PV and wind technologies are technically and operationally very different, hence the barriers and drivers for these technologies will most likely differ. To focus, this paper will consider wind energy only.

The relatively low investment in wind energy in many developing and emerging markets is not a consequence of a lack of wind. Lu et al (2009) estimate the total global onshore wind potential by taking all non-forest, non-ice and non-urban areas with a capacity factor of 20% and above. Offshore wind potential is estimated at water depths lower than 200 m and closer than 30 nm to shore. With

23 GW installed wind power by the end of 2017, Spain is one of Europe's leading markets regarding installed wind power (International Renewable Energy Agency, 2018). Taking the wind potential of Spain as the threshold, the study of Lu et al (2009) shows 59 high wind potential countries. Almost a decade later, and Jung et al (2018) use multiple scenarios to estimate the global wind capacity. By using 2% of the area for wind power, the world would produce sufficient wind energy to meet the demand. In this scenario, 53 countries would have a greater or equal wind potential compared to Spain. Combining both studies, result in 68 unique high wind potential countries. Table 1 displays these countries, sorted by the amount of accumulative wind energy installed. Despite having high wind potential, the total accumulative wind energy installed in many developing and emerging economies is very low. This demonstrates the scale of the potential opportunity in developing and emerging countries.

Table 1 59 high wind countries identified by Lu et al (2009) and 53 high wind countries identified by Jung et al (2018) resulted in a combined list of 68 countries, below grouped by installed wind power capacity by end of 2017 (International Renewable Energy Agency, 2018). Underlined: developing and emerging economies (definition by International Monetary Fund (2018)).

0 GW	0-0.1GW	0.1-1GW	1-10GW	>10GW
<u>Afghanistan</u>	<u>Chad</u>	<u>Mongolia</u>	<u>Morocco</u>	<u>Brazil</u>
<u>Angola</u>	<u>Eritrea</u>	<u>Kazakhstan</u>	Norway	Canada
<u>Congo</u>	<u>Indonesia</u>	<u>Iran</u>	<u>Chile</u>	France
<u>Iraq</u>	<u>Syria</u>	<u>Tunisia</u>	<u>Uruguay</u>	United Kingdom
<u>Libya</u>	Iceland	<u>Argentina</u>	<u>South Africa</u>	Spain
<u>Madagascar</u>	Nigeria	Czech Republic	Japan	<u>India</u>
<u>Mali</u>	<u>Saudi Arabia</u>	<u>Ethiopia</u>	Ireland	Germany
<u>Mozambique</u>	<u>Somalia</u>	<u>Ukraine</u>	<u>Mexico</u>	United States
<u>Niger</u>	<u>Namibia</u>	New Zealand	Netherlands	<u>China</u>
<u>Oman</u>	<u>Algeria</u>	<u>Egypt</u>	Australia	
<u>Paraguay</u>	<u>Russia</u>	<u>Pakistan</u>	Denmark	
<u>Sudan</u>	<u>Colombia</u>		Poland	
<u>Tanzania</u>	<u>Kenya</u>		<u>Turkey</u>	
<u>Turkmenistan</u>	<u>Bolivia</u>		Sweden	
<u>Uzbekistan</u>	<u>Mauritania</u>			
<u>Zambia</u>	<u>Venezuela</u>			
Greenland ¹	<u>Belarus</u>			

For several Original Equipment Manufacturers (OEMs) in the wind industry, stagnating markets and increased competition resulted in financial problems (for example: Suzlon coping with liquidity challenges (Craig, 2019), Senvion filing for insolvency (Hübner and Martin, 2019), Siemens Gamesa not delivering the target

¹ No data available on Greenland in International Renewable Energy Agency (2018)

margins (Gonzalez and Laudette, 2019) and Enercon witnessing a 60% drop in sales in the German market (Knight, 2019)). In certain developing countries, fossil-based power generation is attracting more investments than wind. Turning this balance in favour of wind would create new business opportunities for the wind industry. Ultimately, the sales of wind turbines are the practical building blocks of the transition towards a renewable energy system.

Wind energy investment differences can be described based on general technology diffusion. This concept is explained in literature through different theoretical constructs. One way to address the global diffusion of technology is through epidemic S-curves. Griliches (1957) studied the diffusion of hybrid corn seeds within the US and fitted a logistic growth curve to the data. Bass (1969) used s-curves to explain consumer product growth. Generalizing further, Davies (1979) based his innovation diffusion theory on the same pattern. More recent research by Phillips (2007) focussed specifically on the tipping points within this diffusion model. The second way to describe global diffusion of technology is based on evolutionary technological transitions. Based on the creation of new combinations (Schumpeter, 1934) and technological regimes (Nelson and Winter, 1982), Geels (2002) conceptualized a multi-level technological evolution theory. Technology diffusion starts with path creation in niches, moves on to a patchwork of regimes, and after large scale adoption ultimately influences landscape developments. Thirdly, Technical Innovation Systems provides a multi-function, socio-technical view on global diffusion of technology. Building on empirical studies, Bergek et al (2008) defined the innovation system in seven functions: knowledge development and diffusion, entrepreneurial experimentation, the influence of the direction of search, market formation, development of positive external economies, legitimization, and resource mobilization.

Multiple actors are involved in technology diffusion: “The diffusion process is governed by information transfer, changes in the technology and changes in the adopter environment: the tightening of regulations, changes in the price and cost structure, pressures from customers and the larger public” (Montalvo and Kemp,

2008). State of the art research on the diffusion of renewable energy technology includes policymakers (for example She et al. (2019)), adopters (for example Mignon and Bergek (2016)) and investors (for example Keeley and Matsumoto (2018)). This paper aims to build on the topic of multi-perspective diffusion research by introducing the OEM viewpoint.

Table 2 Related literature reviews in the field of renewable energy and global diffusion.

Study	Technology	Wind considered separately	Geographical focus	Developing economies separately considered	Review method	Meta-analysis	Perspective
(Polzin <i>et al.</i> , 2019)	Renewable energy	Yes	Global	Yes	Systematic	No	Investors / policymakers
(Keeley and Matsumoto, 2018)	Wind and solar	No	Developing economies	Yes	Unspecified	No	Investors
(Can Şener, Sharp and Anciau, 2018)	Renewable energy	No	Global	No	Systematic	Yes	Unspecified
(Strantzali and Aravossis, 2016)	Renewable energy	Yes	Global	No	Unspecified	Yes	Investors
(Abdmouleh, Alammari and Gastli, 2015)	Renewable energy	Yes	Global	No	Unspecified	No	Developers / policymakers
(Negro, Alkemade and Hekkert, 2012)	Renewable energy	Yes	Global	No	Systematic	No	Entrepreneurs, NGO's, Policymakers
This study	Wind	Yes	Global	Yes	Systematic	Yes	Multi perspective, introducing OEM viewpoint

Table 2 shows recent related literature reviews. Negro et al (2012) highlight systemic problems limiting the deployment of renewable energy: “Due to the lack of technological knowledge by policy makers, but also the lack of capabilities of entrepreneurs to pack together and formulate a uniform message about the kind of support they need from government, a lack or misalignment of regulations occurs that blocks the development and diffusion of RETs or strengthens ‘lock-in’ into the fossil fuel based system”. They argue that policy needs to be made technology and market specific, there is no one size fits all. This is also confirmed by Abdmouleh et al (2015). In their literature review, the advantages and disadvantages of multiple support mechanisms, such as feed-in-tariffs, renewable portfolio standards and competitive bidding are described, from a

developer and policy maker point of view. Using the perspective of the investor, Strantzali and Aravossis (2016) present an overview of the different decision making processes to select renewable energy sources. Making the decision in which renewable energy source to invest is based on technical, economic, environmental and social criteria. The study concludes that the multicriteria decision making method is the most frequently used tool for investment decision making. Keeley and Matsumoto (2018) also take the perspective of investors, in particular foreign direct investment in developing countries. The main findings in their literature study are that economic, regulatory and political support policies influence renewable energy investments. The foreign direct investment determinants, however, could vary for different industries. Polzin et al (2019) address investors and additionally policymakers to study how policies influence the mobilization of private finance to stimulate global diffusion of renewable energy. The study concludes that private investment is attracted by policy instruments focusing on risk reduction and the creation of certainty for investors. A note is, however, made that results depend on the specific technology. The review on global diffusion of all renewable energy types, not specifying any viewpoint, was recently published by Can Şener et al (2018). Using a one-sample proportional statistical test, the only sub-category found to drive the global diffusion of renewable energy was “national income”. For all other sub-categories, the influence was undetermined. The authors recommend the introduction of a technology focus: “..clearly defined sets of renewable energy source types will increase the ability to understand both the drivers and barriers of renewable energy deployment..”.

The diffusion of renewable energy has been reviewed from multiple perspectives. Many of the studies point at the differences between the renewable energy technologies and the differences between countries. Yet, a holistic overview specific to wind energy taking country differences into account is missing. Also, multiple viewpoints have been included in the reviews, resulting in different conclusions. A review in the field of renewable energy that creates an overview of the different perspectives in literature was not identified. This paper aims to contribute to the academic field by creating a structured literature review and

meta-analysis that focuses on explaining the global diffusion of wind energy specifically, with special attention on differences between advanced economies, developing and emerging economies, and specifying the different viewpoints the literature has to offer. This is a significant topic because understanding the barriers helps to identify specific approaches to promote wind energy in developing and emerging economies and, thereby contributing to both the SDG 7 and would more specifically increase knowledge of how to stimulate the sales of wind turbines in emerging markets. This paper aims to introduce the OEM perspective, which is novel and important. Having a framework for OEMs to understand which factors specifically influence the demand for wind energy in underdeveloped markets, will allow OEM managers to alter their offerings to make the wind turbines more attractive in certain markets. Increasing the sales of wind turbines in specific emerging markets would help these markets to catch up in their transition towards a sustainable society. To understand the differences in perspectives in literature, this study includes all perspectives and categorizes them to enable a further focus towards the OEM.

The general question this paper aims to answer is: according to literature, what are the factors impacting global diffusion (determinants & patterns) of wind energy?

The contribution this paper aims to make is to increase the understanding of factors influencing wind energy diffusion, specifically focussing on OEMs.

The structure of the review is the following. Section 2 describes the method used in this study. Section 3 contains both the descriptive overview and in-depth meta-analysis. The next section critically reviews and discusses. The article concludes with practical implications for the wind power OEM industry.

2. Method

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was published in 2009 to standardize literature review approaches (Liberati *et al.*, 2009). Although the PRISMA method is focussed on the medical field, “the general concepts and topics covered by PRISMA are all relevant to any systematic review, not just those whose objective is to summarize the benefits and harms of a health care intervention” (Liberati *et al.*, 2009). Tranfield and Denyer (2003) support the use of systematic reviews in business contexts. It provides a transparent and repeatable method of collecting evidence. A limitation of this method is that the search might exclude relevant papers not fitting within the bounded search strings. To overcome this, this study used relatively broad search strings that were screened according to fixed criteria. An overview of the research protocol following the PRISMA method is shown in Figure 1.

The research protocol displayed in Figure 1, consists of 3 selection steps: identification, screening and eligibility testing. The wind power specific search strings combined with diffusion related search strings resulted on the 4th of August 2019 in 2845 results from multiple electronic databases. The selection of search strings was broad to capture the different viewpoints of the wind power sector and the different theoretical fields related to technology diffusion, transition or adoption. A proximity maximum of 10 words was used for the search strings to limit the results to the relevant ones. For the electronic database Scopus, the proximity maximum would have resulted in over 3,000 results, hence the results were limited to the first term in the query preceding the second by a maximum of 10 words. The sequence was chosen to highlight the diffusion phenomena first, followed by the wind power related strings to specifically find papers addressing diffusion within the field of wind power. This resulted in 1,477 manuscripts in Scopus. The detailed search strings can be found in Appendix A.

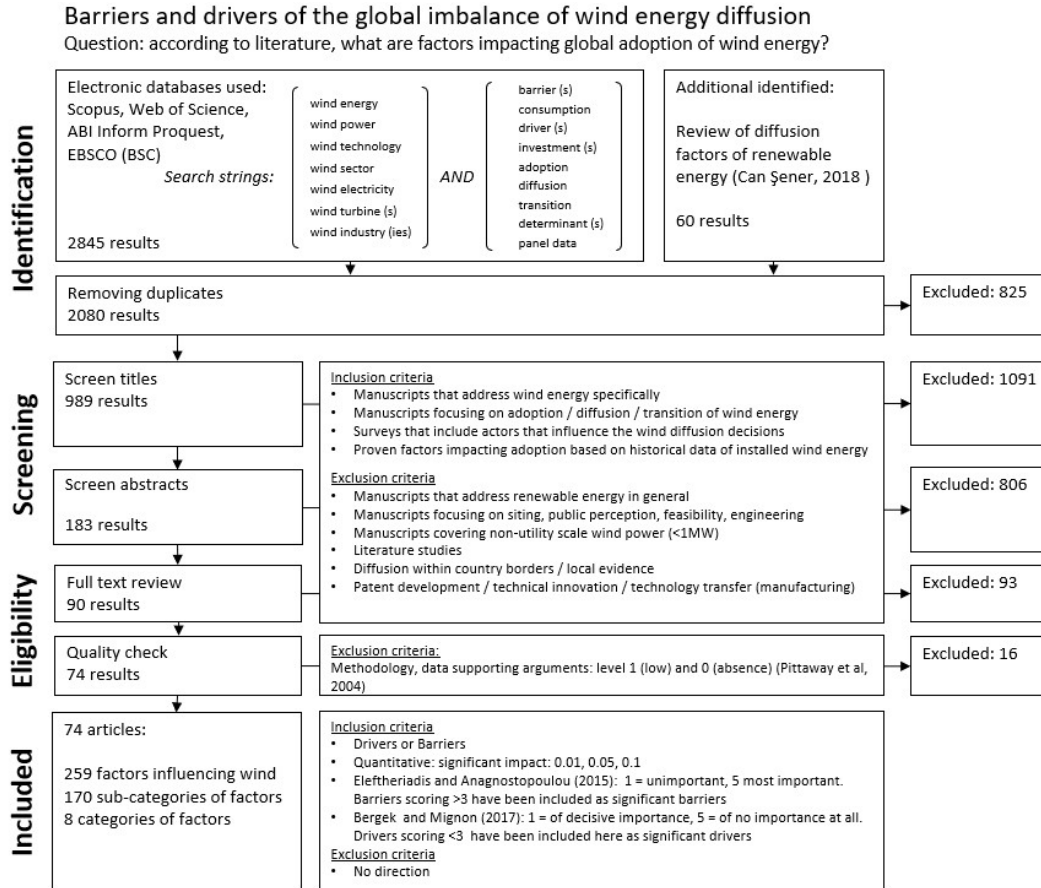


Figure 1 The research protocol (Pittaway *et al.*, 2004; Liberati *et al.*, 2009; Eleftheriadis and Anagnostopoulou, 2015; Bergeke and Mignon, 2017; Can Şener, Sharp and Ancil, 2018).

The findings of the recent systematic review in renewable energy diffusion (Can Şener, Sharp and Ancil, 2018) (which included many papers with wind energy specific data) were added separately. In sum, a total of 2905 papers were identified. After removal of duplicates, the titles and abstracts were screened, before the full articles were reviewed. In each of these 3 filtering phases, the same inclusion and exclusion criteria were used (Figure 1). Articles that provided evidence of wind specific diffusion on country level were included.

Pittaway et al. (2004) introduced a quality assessment for selecting papers as part of the systematic literature filtering process, consisting of five elements: theory robustness, the implication for practice, methodology, generalizability and contribution. All elements have defined levels of quality: 0 (absence), 1 (low), 2 (medium) and 3 (high). The element of methodology is of particular importance

to this study to determine if the identified factors explain the diffusion of wind were measured with an appropriate right level of rigor. A score of 2 or 3 for methodology was used as inclusion criteria for this study. The identification, screening and eligibility testing resulted in 74 articles suitable for further analysis.

In the final selection of papers, only barriers and drivers were analysed and with statistically insignificant factors being excluded, to ensure a robust meta-analysis. Studies with insignificant factors or factors where the direction of effect could not be distinguished were excluded. The details of the selection process are shown in Figure 1.

3. Analysis and results

This section addresses firstly the descriptive results of the literature review and secondly the meta-analysis of factors influencing global wind energy diffusion.

3.1 Descriptive results

The descriptive results of the meta-analysis include the geographical focus, the period studied, the development of the academic field over time, the different dependent variables studied and the viewpoints of the included journal papers.

3.1.1 Geography and length of studies

The final set of 74 articles are shown in Figure 2. The set of manuscripts is geographically diverse and covers the period between 1970 and 2017. Many studies have covered long periods of time. Emerging and developing countries have frequently been studied as part of a larger global group of countries, however, very few studies have treated them as a separate group.

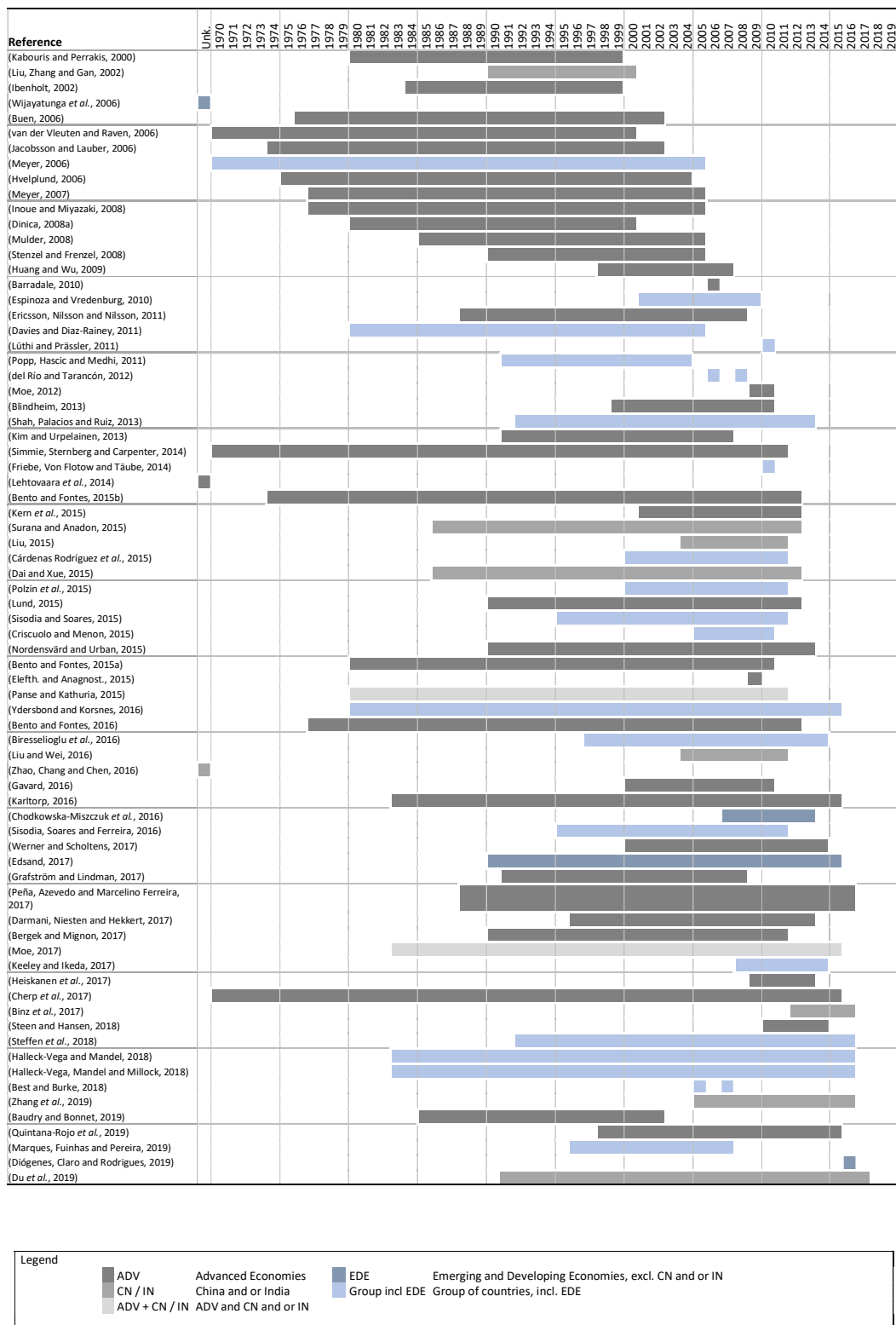


Figure 2 Overview of all 74 articles, including years studied and areas considered.

3.1.2 Development of academic field

Figure 3 illustrates the development of the academic field over time, split into country groups. China and India are considered separately because of the large installed wind power base compared to the rest of emerging and developing economies (respectively 164GW and 32GW by end of 2017 (International Renewable Energy Agency, 2018)).

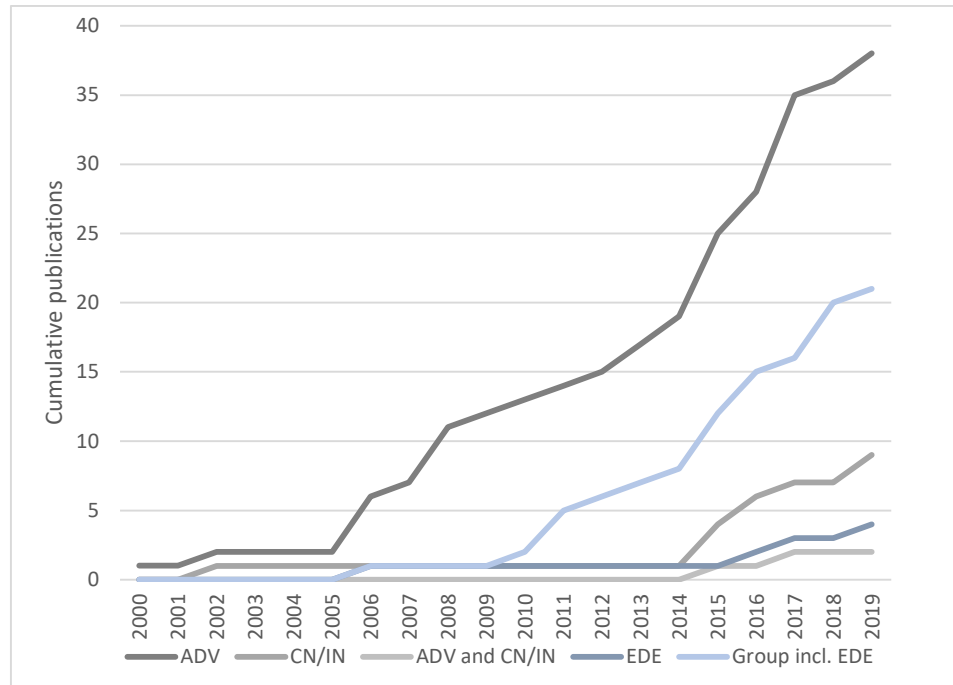


Figure 3 Development of research field: cumulative publications per year, split into country groups (ADV= advanced economies, CN / IN = China and/or India, EDE = Emerging and developing economies (excl. CN and IN)., Group incl. EDE = EDE and other countries. Definition of country groups according to IMF (2018)).

The topic of wind energy diffusion has gained popularity since 2005. Emerging markets were studied frequently since 2010, whereas China and India have only picked up academic interest since 2014. In total, advanced economies are the most frequently studied, followed by more global studies that include advanced, emerging and developing economies. Studies on a combination of advanced economies and China and India and studies only focussing on emerging and developing economies are the least studied.

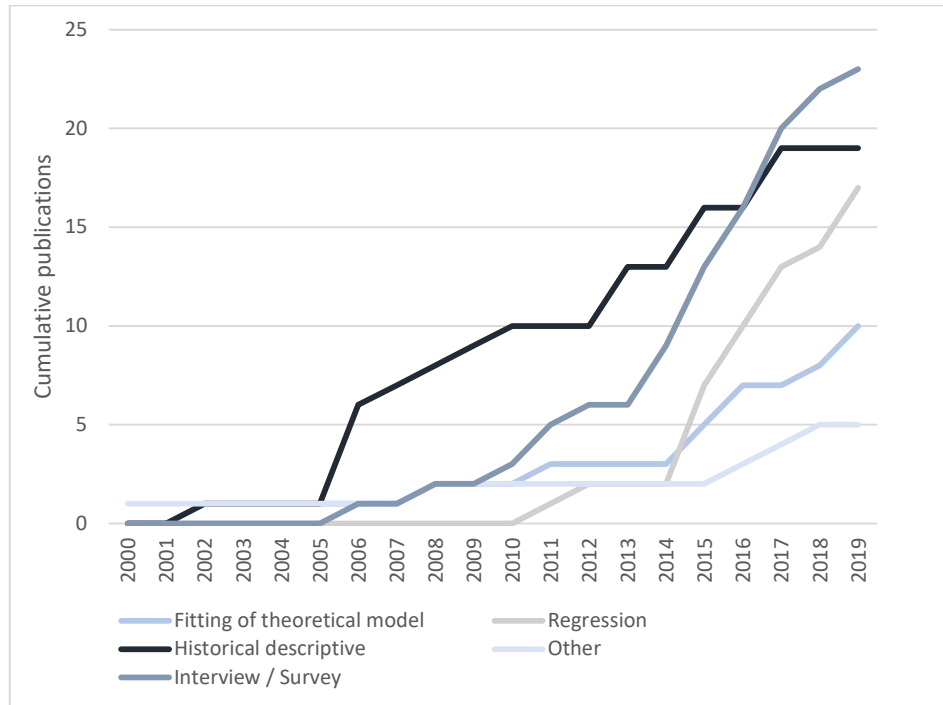


Figure 4 Development of research field: cumulative publications per year, split into research method used.

Different research methods were used to study the phenomena of wind energy diffusion. The historical descriptive method is often used to describe the trajectories of change (e.g.(Furman and Hayes, 2004)). This category includes reports, press, statistical data and academic literature, analysed through different lenses, for instance, through the framework of technological innovation systems. Fitting of theoretical models is applied by for example fitting data points to diffusion S-curves or learning curves. Often panel data is used combined with regression to understand the impact of numerous independent variables. The perception of actors relevant to the studied field is recorded through interviews and surveys. In some studies, this method is combined with historical descriptive approaches. The other methods used include technical descriptive methods, statistical network analysis and structural equation modelling.

Figure 4 shows the development of the academic field, split by research method. Regression, interview/survey and historical descriptive are the most frequently used methods. The amount of historical descriptive studies has grown since 2005, interviews/surveys since 2009 and regression since 2014. Historical

descriptive fits well to nascent fields of study, most likely because of a lack of other available data. Qualitative research increased popularity in 2005, whereas quantitative gained popularity since 2014. The more mature the field of study became, the more quantitative studies were published, as would be expected by Edmondson and McManus (2007).

3.1.3 Different dependent variables

The 74 selected articles can be split into 2 dependent variables:

- Wind energy growth (factors explaining capacity *growth* measured in the increase of MW installed) (for example Pop et al (2011))
- Path creation (factors explaining the *start* of wind energy in a country, measured in the transition from no wind into wind energy installed) (for example Steen and Hansen (2018))

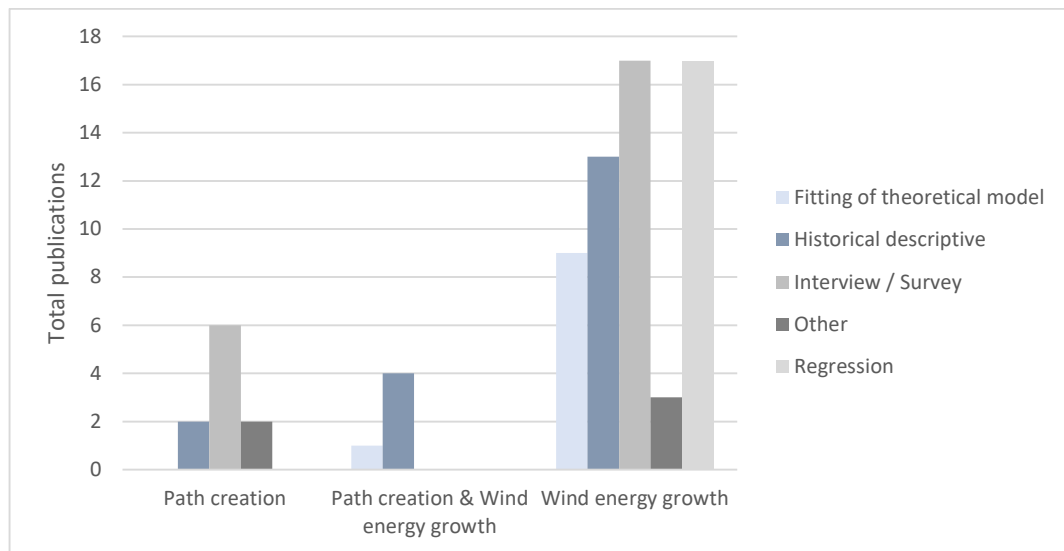


Figure 5 Overview of all 74 articles, sorted by dependent variable and research method category.

The split of the previously defined research methods per dependent variable is visualized in Figure 5. Overall, path creation is less frequently studied than wind energy growth. Perceptions (interview/survey) and direct data-driven measurements (model fitting and regression) are both frequently used to explain wind energy growth; however, path creation is mainly studied with historical descriptive and interview/survey approach. Regression was not used to explain path creation.

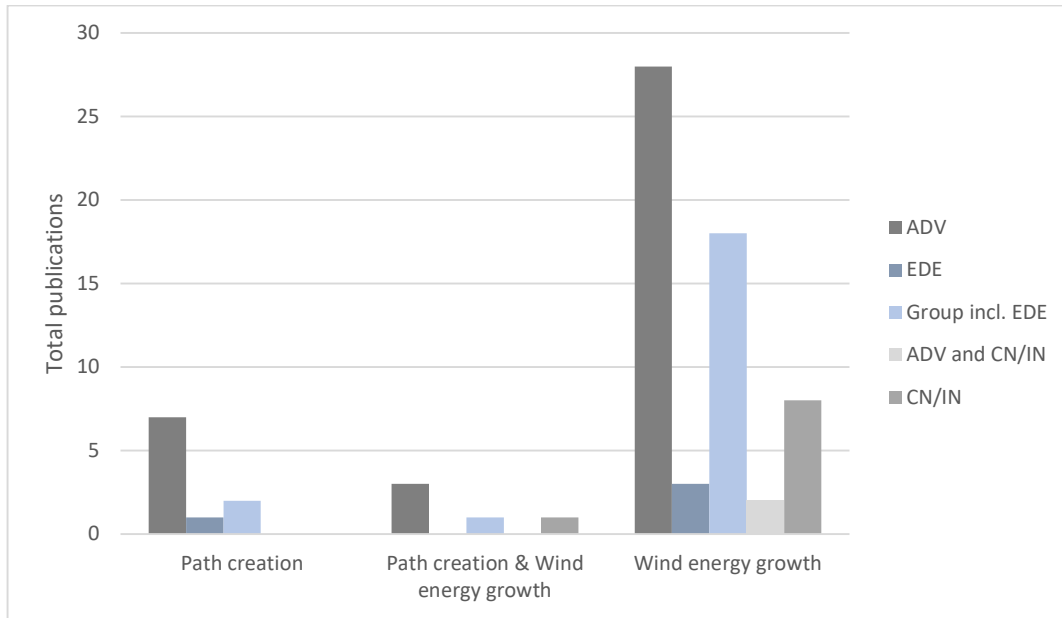


Figure 6 Overview of all 74 articles, sorted by dependent variable and country group.

Figure 6 shows that wind energy growth is studied globally. However, path creation is more frequently studied in advanced economies. The focus on emerging and developing economies and path creation is rare.

3.1.4 Viewpoint of study

The wind energy industry has multiple actors. In Figure 7, the number of studies is split per focus actor. By far the most dominant viewpoints are policymakers and multi-actor analysis. The other actors addressed in the literature are investors, financiers and developers. Importantly, the viewpoint of wind power OEMs was unrepresented in the selected sample. This means that the strategic (policymakers) and demand-side (investors, financiers, developers, utilities) of wind energy diffusion are covered in literature, however the supply side of wind turbines has received little to no attention.

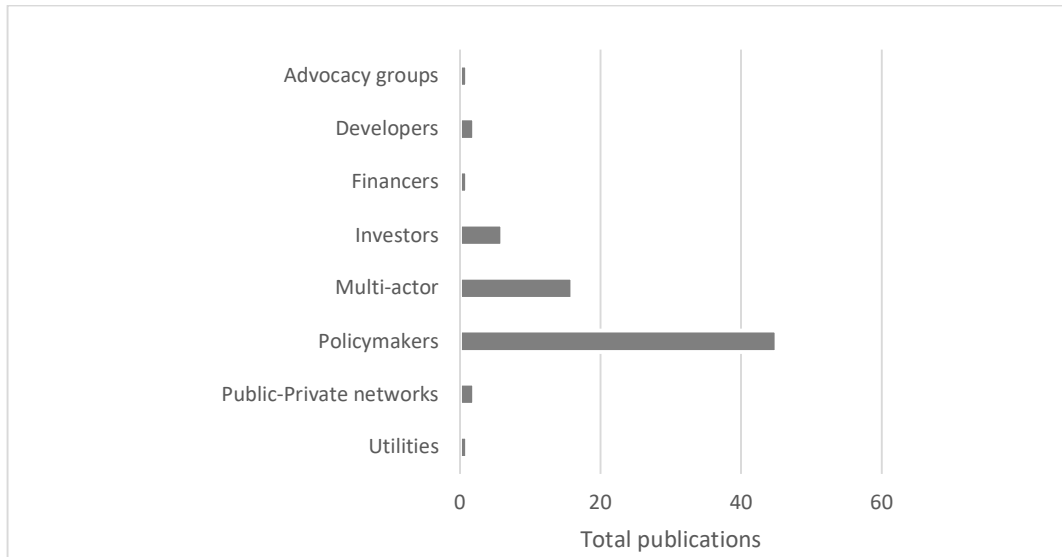


Figure 7 Overview of all 74 articles, sorted by viewpoint used in study.

3.2 Meta-analysis of factors influencing global diffusion

In the 74 papers, 259 factors were identified that explained wind energy diffusion. The 259 factors were split into 8 categories, based on Can Şener et al. (2018). Technological factors include R&D, wind turbine technology, infrastructure technology, operational factors, wind experience and competences. Technical potential factors address the wind energy potential as a combination of natural supply and electricity demand. Social factors are opinions, knowledge, education and information. Regulatory factors comprise governmental and inter-governmental measures such as feed-in-tariffs, combined policy packages, codes and standards. Political factors cover governmental practices such as corruption, rule of law and complexity of administrative processes. Environmental factors describe emissions and climate change. Economic factors contain details such as GDP, capital, labour, prices of natural resources and vested interests. The category “combination factors” has been added by the authors since some studies in the meta-analysis presented their results as a combination of different drivers or barriers. The 8 categories were further specified in 170 sub-categories, such as feed-in-tariffs/premium (belonging to the regulatory category) or GDP (belonging to the economic category). Appendix B contains the different factor categories and sub-categories, sorted per country group. The influencing

direction, barrier or driver, is included. Table B-1 shows the total wind sample, Table B-2 the sample filtered for the dependent variable wind energy growth.

Because of the large number of different sub-categories, there are limited sub-categories that were discussed by multiple studies. Therefore, limited meta-analysis can be done on a sub-category level, especially if the data set is to be split into country groups. However, on a category level, the sample sizes are larger, hence a more comprehensive analysis can be made.

The Factor Direction (FD) is an indication of the combined direction of the factors within each category. The FD is calculated according to the following formula:

$$FD_i = \frac{F_{d,i}}{F_{t,i}} - \frac{F_{b,i}}{F_{t,i}} \quad (1)$$

Where

FD_i = Factor direction (in %) per category *i*

F_{d,i} = Total count of driving factors per category *i*

F_{b,i} = Total count of barrier factors per category *i*

F_{t,i} = Total count of factors per category *i*

An FD between <0% and -100% means the majority of all factors are barriers, an FD between >0% and +100% means that the majority of all factors are drivers. In case of 50% drivers and 50% barriers, the FD equals zero and means there is no clear factor direction. A limitation of FD is the assumption that only the direction of the drivers and barriers is considered, not their magnitude. When combining qualitative studies, where magnitudes are difficult to measure, and quantitative studies, only taking the direction into account allows to use of meta-analysis. The alternative would be to include only either quantitative or qualitative studies, which would exclude a large section of the research field. Studying a similar problem in their meta-analysis on factors influencing renewable energy diffusion, Can Şener et al (2018), also only includes the direction of the factors, not the magnitude. Hence, for this study, the decision to only take the direction of the

factors is justified by the aim to include the rich knowledge provided by both quantitative and qualitative studies.

Table 3 lists the FD for the 8 categories based on the 74 journal papers. It also includes the FD for renewable energy in general, where the data of the review of Can Şener et al. (2018) was used. For wind, the data is split into two dependent variables. For the dependent variable wind energy growth, the split into country groups is shown.

The sample size refers to the number of data points consisting of barriers or drivers. The number of studies only considering emerging and developing studies was low (sample size 12), so the results have been consolidated with the studies that focussed on emerging and developing studies as part of a larger group of countries (resulting in a combined sample size of 109). FDs that were based on a sample of more than 5 studies have been highlighted in the Table (following Can Şener et al (2018) method: judging a factor with a sample size of below or equal to 5 studies factor as neither a driver nor barrier). Only economic factors have a sample of more than 5 for the complete horizontal comparison. In the next sections, the FDs are analysed in more detail.

Table 3 FD per category, split into technology, dependent variable and country group. * = sample size larger than 5. (ADV= advanced economies, Group EDE = all studies that included emerging and developing economies, also as part of a larger group. Group CN / IN = China and or India. Definition of country groups according to IMF (2018)).

	Renewable energy	Wind energy					
	Diffusion (Can Şener, Sharp and Anctil, 2018)	Diffusion	Path creation	Wind energy growth			
	Global	Global	Global	Global	ADV	Group EDE	CN / IN
Combination	NA	75% *	50%	100%	100%	100%	NA
Economic	27% *	30% *	- 20% *	39% *	5% *	69% *	43% *
Environmental	47% *	17% *	NA	17% *	100%	- 11% *	NA
Political	14% *	22% *	100%	18% *	14% *	20% *	NA
Regulatory	6% *	25% *	60%	23% *	25% *	14% *	29% *
Social	28% *	- 8% *	100%	- 17% *	-60%	60%	- 100%
Technical pot	- 16% *	33% *	- 100%	40% *	33%	27% *	67% *
Technological	- 7% *	- 27% *	100%	- 33% *	0% *	0%	- 78% *
Sample size	448	259	23	236	81	109	41

3.2.3 Wind energy versus renewable energy diffusion

As shown in Table 3, clear similarities and differences exist between wind energy and renewable energy diffusion. In both cases, economic, environmental, political and regulatory factors drive the diffusion. However, social and technological factors are barriers to wind energy even though they seem to drive renewable energy diffusion as a whole. Conversely, technical potential is a barrier to renewable energy growth, whereas it is a driver for wind energy diffusion. Because of the focus on studies that specify wind energy, several papers provided a deeper analysis of *combined* effects (through for example historical descriptive methods). One frequently mentioned driver was the *leadership provided by the main utility*, which means leadership in path creation or strategic focus on the development of wind energy.

The economic factor has a similar positive magnitude for wind and renewable energy. However, an interesting difference is that vested interests were mentioned both as a driver and as a barrier for wind energy diffusion, whereas it was not found as a factor for renewable energy diffusion. The evidence shows that GDP or national income are strong drivers of both wind and renewable energy. Environmental FDs for wind and renewable energy diffusion are both positive, however, the magnitude is higher for renewable energy than for wind. This is illustrated by CO₂ emission as a factor. For renewable energy, 10 studies identified CO₂ emission as a driver and 4 found it acted as a barrier. However, for wind, only 3 studies confirmed the driver and 2 showed the factor to be a barrier. On a political factor level, both wind and renewable energy have a similar positive FD. Also, the regulatory factor has a similar positive direction. Yet, the magnitude of the effect is bigger for wind. For example, the factor of feed-in-tariffs/premiums showed 3 drivers and 2 barriers for renewable energy, whereas, for wind, 19 studies were found where it was a driver and only 1 barrier. For wind, policy uncertainty was measured frequently as a barrier. The social factor has a positive direction for renewable energy but a negative direction for wind energy. Barrier factors for wind were for example opposition, misinformation and a preference for hydro and thermal. Renewable energy showed multiple studies where confidence in renewable energy were drivers. Technical potential has the

opposite effect. It has a positive direction for wind, but a negative direction for renewable energy. 4 drivers were found in the category of wind resource potential, whereas a more mixed picture between 8 drivers and 7 barriers were found in the category of renewable energy potential. This illustrates that wind energy is a high-value renewable energy resource. The technological factor is a stronger barrier for wind compared to renewable energy. Especially the lack of infrastructure was mentioned with high frequency as a barrier.

3.2.4 Path creation versus wind energy growth

Wind energy growth is mainly driven by economic and technical potential factors. GDP related factors are clear drivers, as is the diversification of the electricity portfolio. Wind resource and electricity consumption are key drivers in the technical potential category. Barriers are social and technological factors. Multiple studies indicated that a lack of infrastructure is a clear obstacle to wind energy growth. Overall, the most frequently mentioned driver is feed-in-tariffs/premiums. On the other hand, policy uncertainty is a barrier.

The sample size of studies related to path creation is significantly smaller in the meta-analysis compared to studies addressing wind energy growth (as seen in Table 3). Taking the minimum sample size to determine the directional aspect of the factor into account, only economic factors drive wind energy growth. However, these are barriers for path creation. Both path creation and wind energy growth have GDP as a driver, but barriers specific to path creation are established paths and a nonfunctional business case. Feed-in-tariffs/premiums are not mentioned as a driver for path creation.

Path creation is more complex compared to wind energy growth. It explains how a new technology establishes itself, how it passes certain volume or acceptance level thresholds. Pioneers are needed to align strategies and policies and to achieve a viable business case.

Wind energy growth is in transition. Stakeholders are gaining experience (Darmani, Niesten and Hekkert, 2017), drivers such as increasing electricity consumption (Quintana-Rojo *et al.*, 2019) are speeding up the transition whereas

barriers, such as lack of infrastructure (Diógenes, Claro and Rodrigues, 2019) are slowing it down.

3.2.5 Advanced versus emerging and developing economies

For advanced economies (see Table 3), the main drivers are regulatory, political and economic factors. However, the FD for all these categories is below 25%, meaning that a mix of drivers and barriers were found in these factor categories. Feed-in-tariffs/premiums are strong drivers, policy uncertainty and changes in tariffs are clear barriers. For economic factors, a main driver is investor experience. The barriers are very operational in nature, such as steel price, construction costs and investment costs. Only the social factors have a negative direction, yet the sample size is small.

The number of studies that considered emerging and developing countries specifically or as part of a larger group of countries represents the largest sample in this meta-analysis. Economic, political, and technical potential are the main drivers, environmental factors are the only barriers. The FD of economic factors is 69%, of which GDP is the strongest driver. Only a few barriers exist, an example is monetary stability. Politically, corruption and lead times are barriers, but the drivers in total outnumber barriers. The technical potential is driving wind energy diffusion through the energy import balance, and the increase of use of electricity and energy. Regulatory drivers are feed-in-tariffs/premiums and general policy support, barriers are industry codes and standards, voluntary approaches, market-based instruments. Environmental barriers are solar intensity and sunshine hours.

41 studies focussed on India and/or China. Even though the sample size is reasonable, the studies do not address environmental, political and a combination of factors. The main drivers are technical potential, regulatory and economic factors. In detail: wind resources, GDP and feed-in-tariffs/premiums are major drivers. The only main barriers are technological factors, related to quality issues or the electrical grid.

The results illustrate that different barriers and drivers exist for different country groups. One of the main differences is the role of GDP. For all country groups, it was a clear driver. However, for advanced economies, the meta-analysis did not find evidence to support this. Feed-in-tariffs/premiums are an essential driver to all country groups. Generally, economic factors are a smaller driver in advanced economies compared to the emerging and developing economies. Studies that included emerging and developing economies as part of a large group of countries showed that environmental factors such as sunshine hours (which could result in more installed solar energy) are barriers to wind diffusion, whereas these environmental barriers were not found for advanced economies. The results indicate that competition between energy sources and the import/export energy balance has an impact especially in emerging and developing economies. Also, political factors like rule of law, corruption and armed conflict are factors unseen in advanced economies.

3.2.6 Influence of research method

The FD per category split per research method is filtered for wind energy growth in Table 4. Regression, model fitting and historical descriptive generally directly consider the diffusion, whereas interviews and surveys introduce a subjective intermediate. Clear differences exist between the factor directions of the various research methods. Economic, regulatory and technological barriers identified in interviews and surveys were not confirmed by regression, model fitting and historical descriptive methods. The introduction of a subjective intermediate resulted in different outcomes compared to direct measurement, confirming Bertrand and Mullainathan (2001).

Table 4 FD per category, split into the different research methods (* = sample size larger than 5).

	Wind energy growth			
	Model fitting	Regression	Interview / Survey	Historical descriptive
Combination	NA	NA	100 %	100 %
Economic	67 % *	52 % *	- 9 % *	0 %
Environmental	NA	- 25 % *	100 %	100 %
Political	100 %	0 %	11 % *	50 %
Regulatory	78 % *	10 % *	- 18 % *	68 % *
Social	100 %	100 %	- 50 % *	- 100 %
Technical pot	33 %	33 % *	100 %	100 %
Technological	100 %	33 %	- 100 % *	100 %
<i>Sample size</i>	21	103	66	37

4. Discussion

To understand and structure the phenomena of wind energy diffusion, this section proposes a novel closed-loop feedback system. This framework is then applied to understand the state of the art global wind energy diffusion. Lastly, challenges for further research are addressed.

4.1 A framework to distinguish factors related to desire for change and factors related to the mechanism of change

A closer look at the main factors (Table 3) shows their overall influence, as judged by the literature. The economic sub-category ‘GDP per capita’ was identified as a strong driver (5 drivers, 0 barriers, appendix B, Table B-2). However, GDP as such does not buy wind turbines. It illustrates *the state* of the economic environment, which in turn influences many elements, such as the electricity demand (Keeley and Ikeda, 2017) or the stability of the macro-economic environment (Steffen *et al.*, 2018). Another driver was the regulatory sub-category of feed-in-tariffs/premiums (19 drivers, 1 barrier, appendix B, Table B-2). Logically, feed-in-tariffs/premiums make wind energy attractive to investors compared to other energy sources without financial support. The more important question is: why would a government implement feed-in-tariffs/premiums? This could be a *response* to securing energy supply, the need for future-oriented industries and employment and reduction of greenhouse gasses and local pollution (Ydersbond and Korsnes, 2016). It seems that the factors influencing wind energy are part of a larger mechanism in which change happens after a desire is in place.

Jacobsson and Lauber (2006) attempt to describe this system through a case study. In Germany, a lack of oil resources left coal and nuclear as electricity options. Unfortunately, environmental disasters such as forest die-back caused by acid rain and the Chernobyl nuclear accident resulted in strong public opposition to both resources. The emergence of climate change eventually led to the green movement. The political response to reach the desired level of environmental care and electricity security was to promote renewable energy,

such as wind energy. This highlights the importance of the comparison of the desired state with the existing state, taking action to implement measures to affect change, compensate for disturbances and follow the feedback loop to adjust control measures to reach the desired state.

In view of the evidence reviewed, this current study proposes a closed-loop feedback system to conceptualize the mechanism between input, output, controller, disturbance and feedback (Figure 8) in wind energy diffusion systems. Closed-loop feedback systems are used to control the change of a system from an existing state to the desired state. Examples of applications can be found in elevators or cruise controls in vehicles. In an elevator, the operator presses the button to express the desired destination and the controller and electrical hoist ensure that the elevator accelerates. Disturbances occur if children are jumping in the elevator. The controller needs to adjust the speed of the hoist to ensure a stable ride. Once the destination is near, the controller and electrical hoist slow down the elevator to stop smoothly at the desired level. Cruise controls work in similar ways. Even though closed-loop control systems are generally used for technical applications, it effectively describes the socio-technical phenomena of wind energy diffusion.

Similar to the diffusion of technology in general, wind energy diffusion often follows an 's-curve' (e.g.(Bento and Fontes, 2016)). The s-curve is also a common response of a closed-loop feedback system, where the specifics depend on the combination of the system, the controller and the feedback loop. However, the remaining questions include: who sets the desired output level and who controls the measures to reach the output? Very simply seen, wind energy is diffused through sellers and buyers of wind turbines. This purchasing process is a result of a mix of policies, technology and market demand. Meaning, the public, government and private businesses play important roles in the mechanism. It highlights the important role of private and public partnerships (Dinica, 2008b).

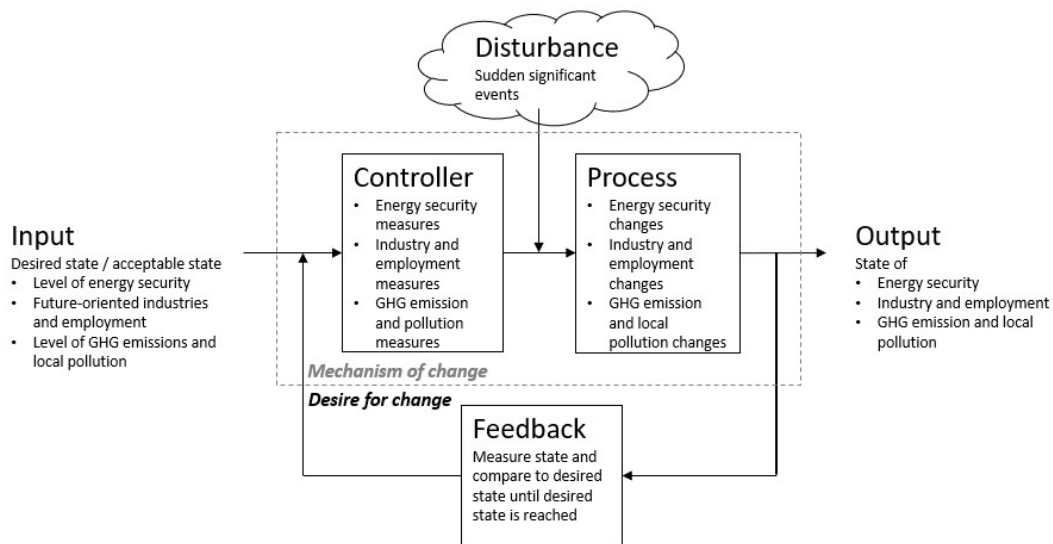


Figure 8 Closed-loop feedback system of 2 types of factors (desire for change and mechanism of change) influencing diffusion of wind energy. Input and output based on Ydersbond and Korsnes (2016).

Figure 8 explains this framework of general wind power diffusion. It also clarifies why there are differences between diffusion levels of different technology or country groups. The desire for change is related to the differences between the desired state and current state for all three levels of energy security, industry and employment level and emission and pollution level (as measured by the feedback loop). The disturbances are a form of external drivers or barriers. The drivers or barriers that are controller and process-related (such as feed-in-tariffs/premiums or R&D) are called mechanism of change factors. The mechanism of change is a response to the desire for change and determines the efficiency and effectiveness of the change of the output (a large body of research can be found for example on determining policy efficiency (Baudry and Bonnet, 2019)). As wind energy has a different contribution to the 3 outputs of energy security, industry and employment and greenhouse gasses and pollution levels compared to renewable energy in general, this also explains why there is a difference in diffusion drivers. For developing and emerging countries, the factors related to the desire for change are very likely to be different from advanced economies. The feedback loop will focus on the largest differences and will seek the most cost-effective option. This partly explains the global differences between wind diffusion. Secondly, the disturbances that result in the changes in the system

differ between the country groups. For example, corruption could create additional barriers.

4.2 Applying the framework to understand state of the art global differences in wind power diffusion

A summary of the different country groups and the elements of the closed-loop feedback system is found in Table 5. The output is the current state (based on (International Renewable Energy Agency, 2019; The World Bank, 2019a, 2019b, 2020), for details see Appendix C), the input (desired state) is derived by adding the feedback loop to the current state. The feedback loop prioritization differs per country group, as described below

Reading Table 5 horizontally, focussing on the feedback loop in comparison to output and input allows an understanding of the variations between the country groups. Advanced economies focus on environmental improvement that further supports the technical potential and economic factors (feedback loop) to move from the current to the desired state. Developing and emerging markets aim to improve economic conditions, followed by the technological potential of energy security. The environmental feedback loop is negative, indicating that environmental factors are not drivers for wind energy. China and India's focus is on improving energy security, together with the economic situation. Social factors can reinforce or block the feedback. However, the direction is unclear for all country groups because of a lack of data. Driven by the total magnitude of the feedback loop, the controller introduces measures to evolve to the desired level. For advanced economies, the most important driving measures are regulatory, followed by political factors. For developing and emerging economies, political factors are the most important drivers. For China and India, regulatory measures are the drivers and technological measures are barriers (for example lack of infrastructure). Disturbances influence the impact of the measures on the changes. In advanced economies, the disaster of Chernobyl was found to influence wind energy diffusion. For developing and emerging economies, armed conflict, corruption, economic stability and climate change were important factors.

For China and India, a lack of financial resources was mentioned. The specific sub-categories, including the disturbances, are listed in Appendix B.

Table 5 Closed-loop feedback system of drivers for wind energy. FD% (Table 2) for advanced economies are based on advanced economies, for developing and emerging economies are based on all studies that included emerging and developing economies, also as part of a larger group and for China and India are based on China and/or India. Current state based on (International Renewable Energy Agency, 2019; The World Bank, 2019a, 2019b, 2020), for details see Appendix C. Disturbances are listed in Appendix B.

	Desire for change			Disturbances	Mechanism of change	
	Input (desired state)	Output (current state)	Feedback (output vs desired state)	Disturbances (external)	Controller (measures)	Process (changes)
Advanced economies	Technical potential: High level of energy security Economic: Keep high level of industry and employment opportunities Environment: Low level GHG and local pollution	Technical potential: Medium secure energy supply Economic: High industry and employment opportunities Environment: High GHG, low local pollution	Tech pot 33%: Important driver Economic 5%* Least important driver Environmental 100% Strongest driver, but low amount of data Social -60% Social resistance, but low amount of data	Disasters (Chernobyl)	Regulatory 25%* Most important driving measures Political 14%* Least Important driving measures Technological 0%* Measures with zero impact	High increase of wind energy installed. Establishment of wind industry
Developing and emerging economies	Technical potential: Reasonable secure energy supply Economic: Medium industry and employment opportunities Environment: Subordinate to economic and technical potential factors	Technical potential: Low-medium energy security Economic: Low level of industry and employment opportunities Environment: Low GHG, medium local pollution	Tech pot: 27%* Least important driver Economic: 69%* Most important driver Environmental: -11%* Clear barrier Social 60% Social reinforcement, but low amount of data	Armed conflict, corruption, monetary instability, insTable economic environment, climate change	Regulatory 14%* Least important driving measures Political 20%* Most important driving measures Technological 0% Measures with zero impact, but low amount of data	No or small increase of wind energy installed
China and India	Technical potential: High level of energy security Economic: Keep high level of industry and employment opportunities Environment: Unknown	Technical potential: Low-medium energy security Economic: High industry and employment opportunities Environment: Low-medium GHG, medium-high local pollution	Tech potential: 67%* Most important driver Economic: 43%* Least important driver Environmental: NA No data Social -100%: Social resistance, but low amount of data		Regulatory 29%* Most important driving measures Political NA No data Technological -78%* Most important blocking measures	High increase of wind energy installed. Establishment of wind industry

The model is different from the DPSIR framework (Smeets and Weterings, 1999) in a way that it has a clear input and output and that it is able to deal with disturbances. It is holistic in a way that it can explain drivers in previously identified phenomena in sustainability transitions, such as experimenting (a specific type of controller measures) (Sengers, Wieczorek and Raven, 2019), stop-and-go mechanisms (non-functional controller, disturbances or no feedback loop) and alignment between policies (controller effectiveness) (Grubler, 2012).

From an OEM point of view, a rather re-active form of business development is to respond to the mechanism of change related factors, such as Feed-In-Tariff. The framework as presented in Table 5 allows OEMs to understand the desire behind wind energy demand, enabling them to create long term business development strategies focussing on shaping the energy transition. This makes the closed-loop feedback system attractive for OEM strategy building.

4.3 Implications for further research

The proposed research agenda follows the limitations of this meta-analysis. In the initial selection, sectorial papers were excluded to support the focus on global diffusion. This resulted in the exclusion of several papers on early wind diffusion in California. However, the 74 papers resulted in a sufficiently large dataset of 259 global factors. The sample size, however, for the factor level was in some categories rather low. Because of these sample size limitations, the data for emerging and advanced economies in the conceptual model (Table 5) was based on studies that also included other country groups. Another limitation is the grouping per sub-categories, even though it was based on Can Şener et al (2018) (2018), it has subjective elements. Therefore, the conceptual model that is developed describes a logic mechanism to distinguish factors related to the desire of change and factors related to the mechanism of change. Further analysis is needed to increase the understanding of which factors fall into which category.

Table 6 states an overview of the academic field and areas addressed. The area of path creation deserves further research, especially in emerging and developing economies. The number of regression studies in the field has significantly increased since 2005. However, within the current sample no study, using regression, has been found to include path creation. Regression has the advantage of being able to compare the model fit of several models (for example Grafström and Lindman (2017)) and to objectively show the impact direction and magnitude of factors influencing wind energy growth (for instance Marques et al (2019)). These insights appear to be missing for path creation. Especially for the wind OEMs, having quantitate data on path creation helps with taking strategic

decisions on when to focus on which country for market entry, how much growth can be expected or what to do to influence this. With the availability of panel data on installed wind energy across the world, it would be interesting to explore this avenue. Overall, the barriers identified in the meta-analysis using interviews/surveys were not confirmed by regression and model fitting. Introducing a subjective intermediate resulted in different outcomes compared to direct measurement, confirming Bertrand and Mullainathan (2001).

To date, multi-perspective wind power diffusion research has not addressed the OEM perspective. As the wind industry has a significant contribution to the diffusion of wind power, this viewpoint should be included. Not only do policymakers benefit from academic research, also business developers and technology specialists in OEM firms could improve their practices based on tested theories. This paper evaluated existing evidence from an OEM perspective and identified areas that are valuable to an OEM. However, specific research from a wind power OEM point of view would be needed to confirm or reject the conclusions presented in this study. Factors influencing the desire for wind energy seem in particularly relevant for OEMs, as they can alter their offerings to meet the specific desire. More research is needed to quantify the different factors related to the desire per country.

Table 6 Overview of academic field and areas addressed (ADV = Advanced Economies. EDE = Emerging and Developing Economies (not including China and India), $\sqrt{}$ = 6 or more journal papers identified in this study, x = 1-5 journal papers identified in this study, xx = no journal papers identified in this study).

		Path creation	Wind energy growth
Countries considered	ADV	$\sqrt{}$	$\sqrt{}$
	EDE & Group incl. EDE	X	$\sqrt{}$
Method considered	Fitting of theoretical model	X	$\sqrt{}$
	Regression	XX	$\sqrt{}$
	Historical descriptive	$\sqrt{}$	$\sqrt{}$
	Interview / survey	$\sqrt{}$	$\sqrt{}$
Viewpoint of study	Policymakers	$\sqrt{}$	$\sqrt{}$
	Multi actor	$\sqrt{}$	$\sqrt{}$
	Developers, Financers, Investors, Utilities	X	$\sqrt{}$
	Wind Power OEM	XX	XX

5. Conclusions and implications for wind power OEMs

This study aims to contribute to the literature by providing a wind-specific systematic literature review, focusing on global diffusion and separately considering developing countries. It is novel in highlighting the different perspectives literature has to offer (for instance investor, policymaker). It aims to enhance understanding of wind energy diffusion from a wind power OEM perspective.

In the 74 articles selected through the systematic review, 259 dependent factors influencing wind diffusion were identified, sorted into 8 factors categories and 170 factor sub-categories. The most popular viewpoint used in literature was policymakers. Other perspectives included: public-private networks, investors, financiers and developers. No study was found addressing the OEM point of view. A novel closed-loop feedback system was developed to describe wind energy diffusion, contributing to the academic field of technology diffusion. This framework allowed to distinguish factors related to the desire for change and factors related to the mechanism of change. Many emerging and developing economies have very limited wind energy installed, despite having significant wind resources. Before wind energy is diffused, it is the desire for wind energy that drives the change. The mechanism of change (for instance efficiency and effectiveness of regulations) are only relevant once there is desire. Understanding the level of desire helps wind power OEMs to alter their offerings to fit specific developing and emerging markets stimulate deployment. The meta-analysis in this paper highlights that different country groups have different factors influencing wind diffusion. The analysis also shows indications that economic factors are of key importance in emerging and developing countries, significantly more important compared to advanced economies. Environmental factors do not seem to be drivers for wind energy growth in emerging and developing countries, contrary to expectations. This has implications for OEMs. First of all, a one size fits all approach to promote wind energy globally is not likely to result in the highest deployment of wind turbines. Secondly, a rebranding of wind turbine

technology from “green technology” to “job-creating technology” might be needed to stimulate a transition to a more sustainable society in many emerging and developing markets. Further research on wind energy diffusion from a wind power OEM perspective is needed to accelerate a sustainable transition in emerging and developing markets.

Appendices

Appendix A Search strings

Table A-1 Search strings and number of results of search executed on 04/08/2019.

Database	Number of results	Search string
Scopus	1477	(barrier* OR consumption OR driver* OR investment* OR adoption OR diffusion OR transition OR determinant* OR "panel data") PRE/10 ("wind energy" OR "wind power" OR "wind technology" OR "wind sector" OR "wind electricity" OR "wind turbine*" OR "wind industr*") AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "ECON")) AND (LIMIT-TO (LANGUAGE , "English"))
Wos	896	((barrier* OR consumption OR driver* OR investment* OR adoption OR diffusion OR transition OR determinant* OR "panel data") NEAR/10 ("wind energy" OR "wind power" OR "wind technology" OR "wind sector" OR "wind electricity" OR "wind turbine*" OR "wind industr*")) Filter: DOCUMENT TYPES: (ARTICLE) AND LANGUAGES: (ENGLISH)
ABI Inform (proquest)	219	noft(("barrier*" OR "consumption" OR "driver*" OR "investment*" OR "adoption" OR "diffusion" OR "transition" OR "determinant*" OR "panel data") NEAR/10 ("wind energy" OR "wind power" OR "wind technology" OR "wind sector" OR "wind electricity" OR "wind turbine*" OR "wind industr*")) Filter: peer reviewed, English
EBSCO (BSC)	253	("barrier*"OR"consumption"OR"driver*"OR"investment*"OR"adoption"OR"diffusion"OR"transition"OR"determinant*"OR"panel data")N10("wind energy"OR"wind power"OR"wind technology"OR"wind sector"OR"wind electricity"OR"wind turbine*"OR"wind industr*")) Filter: peer reviewed, English

Appendix B Factors categories, sub-categories and direction

Table B-1 number of drivers and barriers found per factor category and sub-category, sorted by country group. ADV = Advanced economies, CN & IN = China and / or India, EDE = Emerging and developing economies (excl. CN & IN). Definition of Advanced and emerging and developing economies according to (International Monetary Fund, 2018).

Factor categories, subcategories	Driver	Barrier	Total
ADV	56	39	95
Technological	5	4	9
Knowledge spill-overs combined with local absorptive capacity	1		1
Lack of transmission network infrastructure		3	3
Limited experience in wind farm development		1	1
R&D: government run R&D in wind power	1		1
R&D: grants	1		1
Relevant competences	2		2
Technical potential	2	1	3
Electricity consumption	1		1
Total energy import dependency		1	1
Wind resource	1		1
Social	2	4	6
Financial institutions unfamiliarity with renewable energy tech		1	1
Interest in wind technology	1		1
Lack of investor interest from public sector		1	1
Local opposition to the construction of wind farms		1	1
Misinformation of local communities, regarding RES benefits		1	1
Pioneering inventors and innovators	1		1
Regulatory	23	13	36
Feed-In-Tariff / Premium	9		9
Feed-in-Tariff / Premium: change in FIT / P		2	2
Feed-in-Tariff / Premium: price driven policies, not capacity driven policies	1		1
Grid: lack of priority grid access		1	1
Installation subsidies	1		1
Land-use: lack of integrated special planning		1	1
Land-use: regulations		1	1
Policy package: policy to stimulate utilities in direction of hybridization	1		1
Policy package: public-private partnerships stimulating policies	1		1
Policy package: short-term focus, unpredictable, stop-go, no demand side measures		1	1
Policy package: State support niche technology in response to energy security concerns	1		1
Policy support	1		1
Policy uncertainty		3	3
Power Purchase Agreement: delay in definition		1	1
Subsidies to renewable energy and emission trading scheme to fossil-fuels	1		1
Targets: renewable energy targets	1		1
Targets: wind energy targets	1		1
Policy package: lack of policy coherence in support for key resource formation process		1	1
Policy package: mostly long-term focus, predictable, broad portfolio combining supply and demand-side measures from the start, periods of no predictability	1		1
Feed-in-Tariff / Premium: incl. tradable green certificate	2		2
Feed-In-Tariff / Premium: long term FIT / P	2		2
Building permits: delay in issuance		1	1
Fossil fuel subsidy		1	1
Political	5	3	8
Complexity of administrative procedures		2	2
Dual strategy of political lobbying and end user campaigning	1		1
Political uncertainty		1	1
Pro-wind interest advocate for strongly support feed-in-tariff	1		1
Inter-ministry coordination	1		1
Existence of a system builder	1		1
Utilities lobby to shape regulatory environment in favour of wind	1		1
Environmental	3		3
Climate change	2		2
Environmental benefits of wind energy	1		1
Economic	11	13	24
Carbon price	1		1
Construction costs		1	1
Diversification of electricity production	1		1

Electricity price volatility	1		1
Firm age		1	1
Gas price	1		1
International learning spill over	1		1
Investment costs		1	1
Investor experience	2		2
Investors need for revenue growth	1		1
Lack of financial resources		1	1
Negative path interdependence with the dynamics of established paths		1	1
No equilibrium between incentives and contributions		1	1
Non-core country (being a follower country)	1	1	2
Price of electricity		1	1
Raising prices of fuel oil, natural gas and coal due to changes in taxes	1		1
Steel price		2	2
Vested Interests: Wind located outside of the vested interest structure		1	1
Comparative price advantage wind energy	1		1
Poor alignment between technology developers and investors		1	1
Competition resulting in large cost reductions		1	1
Combination	5	1	6
Formation of alliances	1		1
Leadership provided by main energy utility	2		2
Loss of control over major industrial inputs & cognitive change about need to control			
uncertainties & national + EU policy RET goals	1		1
Misalignment policy support and firm strategy on innovation and knowledge creation		1	1
Lack of oil resources, anti-nuclear movement, strong environmental movement, Chernobyl, forest die-back (acid rain), emergence of climate change.	1		1
ADV and CN/IN	4	1	5
Regulatory	3		3
Feed-In-Tariff / Premium	1		1
Installation subsidies	1		1
Mandatory requirements by government: obligations for utility to purchase power	1		1
Economic	1	1	2
Vested Interests: Increasing leverage vested interests		1	1
Vested interests: weakening vested interests	1		1
CN/IN	23	19	42
Technological	1	8	9
Construction quality control		1	1
Country wind technology capacity	1		1
Grid connection technology		1	1
Grid stability		1	1
Lack of transmission network infrastructure		1	1
Operation & maintenance		1	1
Process quality control		1	1
Wind resource survey		1	1
Wind turbine technology		1	1
Technical potential	5	1	6
Coal consumption	1		1
Solar PV installed capacity	1	1	2
Wind resource	3		3
Social		2	2
Preference for thermal and hydro power		1	1
Willingness of consulting and insurance companies to work with wind industry		1	1
Regulatory	12	6	18
Clean Development Mechanism	1		1
Feed-In-Tariff / Premium	2	1	3
Grid: plans		1	1
Grid: policy to reduce grid and transmission risk	1		1
Peak regulations power stations		1	1
Policy package: coherent catch-up strategy by the government	1		1
Policy package: matching policy initiatives, sectoral goals and macro policy	1		1
Policy to improve financing availability	1		1
Policy to improve resource and technology availability	1		1
Policy to reduce counterparty risk	1		1
Policy to reduce power market risk	1		1
Policy to reduce project implementation risk	1		1
Policy to support financial returns	1		1
Policy uncertainty		1	1
Taxes		1	1

Wind power plans		1	1
Economic	5	2	7
Electricity intensity (economic efficiency)	1		1
GDP per capita	2		2
Investment costs		1	1
Lack of financial resources		1	1
Market share of domestic wind turbine manufacturer	1		1
Net present value of wind energy project	1		1
EDE	6	9	15
Technological		1	1
Lack of transmission network infrastructure		1	1
Technical potential	1	1	2
Seasonal variation in wind speeds		1	1
Electricity security	1		1
Social	1	1	2
Environmental awareness	1		1
Unequal access to education		1	1
Regulatory	1		1
Financial support from European Union (cohesion policy)	1		1
Political		2	2
Armed conflict		1	1
Corruption		1	1
Environmental	1		1
Climate change	1		1
Economic	2	4	6
Diversification of electricity production	1		1
GDP	1		1
Lack of financial resources		1	1
Levelized cost of wind electricity		1	1
Unstable macroeconomic environment		1	1
Unattractive loan conditions		1	1
Group incl. EDE	69	33	102
Technological	2	1	3
Infrastructure investments	1	1	2
Knowledge stock (patent count)	1		1
Technical potential	6	4	10
Annual added wind power generation (market share indicator)	1		1
Electricity consumption	1		1
Electricity consumption intensity (index)		1	1
Energy consumption	1		1
Share of gas energy in electricity generation		1	1
Share of hydro power in electricity generation	1	1	2
Share of nuclear power in electricity generation		1	1
Share of wind energy in electricity generation	1		1
Total energy import dependency	1		1
Social	3		3
ArCo tech index (patents, diffusion, human capital) (Archibugi and Coco 2004)	1		1
information and education related to energy use or emission performance	2		2
Regulatory	23	18	41
Codes and standards	1	2	3
Economic support	1		1
Feed-In-Tariff / Premium	7		7
Funds to sub-national governments		2	2
Grants and subsidies		1	1
Kyoto ratification	1	1	2
Loans	2		2
Mandatory requirements by government, other than codes & standards / obligation schemes			
for energy	1		1
Mandatory requirements by government: obligation scheme		1	1
Market Based Instruments	1	3	4
Obligation scheme		1	1
Policy package: support programs for technology deployment and diffusion		1	1
Policy support	4		4
Procurement rules		1	1
Regulatory support	1		1
Support scheme change: major change		1	1
Support scheme change: minor change		1	1
Tax relief	2		2

Taxes		1	1
Voluntary approaches		2	2
Grid: favourable grid access regulations	2		2
Political	6	2	8
Corruption		1	1
Globalization: political participation	1		1
Lead time of administrative procedure		1	1
Rule of law	2		2
Predictability of public authorities	1		1
Simple administrative process	2		2
Environmental	3	5	8
CO2 emission	3	2	5
Solar intensity		1	1
Sunshine hours		2	2
Economic	24	3	27
Access to finance, trade openness, investment freedom	1		1
Business Competitiveness Index	1		1
Carbon price	1		1
Developing vs Advanced economies		1	1
Domestic private debt divided by GDP	1		1
Economic Integration (Bilateral country pairings)	1		1
FDI stock	1		1
GDP	2		2
GDP per capita	4		4
Interest rates		1	1
Involvement of international developers	1		1
Levelized cost of wind electricity	1	1	2
Market size	1		1
Price of electricity	1		1
Primary energy intensity	1		1
Private credit divided by GDP	2		2
Share price of local indices	1		1
Strength of multilateral development banks	1		1
Unstable macroeconomic environment	1		1
Insurance assets divided by GDP	1		1
De-institutionalisation (challenging a fossil fuel-based economy)	1		1
Combination	2		2
Leadership provided by main energy utility	1		1
Enhancing energy security, creating future oriented industry that provides job opportunities, environmental protection	1		1
Total	158	101	259

Table B-2 number of drivers and barriers found per factor category and sub-category, sorted by country group, filtered for dependent variable 'Wind energy growth'. ADV = Advanced economies, CN & IN = China and / or India, EDE = Emerging and developing economies (excl. CN & IN). Definition of Advanced and emerging and developing economies according to (International Monetary Fund, 2018).

Factor categories, subcategories	Driver	Barrier	Total
ADV	47	34	81
Technological	4	4	8
Knowledge spill-overs combined with local absorptive capacity	1		1
Lack of transmission network infrastructure		3	3
Limited experience in wind farm development		1	1
R&D: government run R&D in wind power	1		1
R&D: grants	1		1
Relevant competences	1		1
Technical potential	2	1	3
Electricity consumption	1		1
Total energy import dependency		1	1
Wind resource	1		1
Social	1	4	5
Financial institutions unfamiliarity with renewable energy tech		1	1
Interest in wind technology	1		1
Lack of investor interest from public sector		1	1
Local opposition to the construction of wind farms		1	1
Misinformation of local communities, regarding RES benefits		1	1
Regulatory	20	12	32
Feed-In-Tariff / Premium	9		9
Feed-in-Tariff / Premium: change in FIT / P		2	2
Feed-in-Tariff / Premium: price driven policies, not capacity driven policies	1		1
Grid: lack of priority grid access		1	1
Installation subsidies	1		1
Land-use: lack of integrated special planning		1	1
Land-use: regulations		1	1
Policy package: public-private partnerships stimulating policies	1		1
Policy package: short-term focus, unpredictable, stop-go, no demand side measures		1	1
Policy uncertainty		3	3
Power Purchase Agreement: delay in definition		1	1
Subsidies to renewable energy and emission trading scheme to fossil-fuels	1		1
Targets: renewable energy targets	1		1
Targets: wind energy targets	1		1
Policy package: mostly long-term focus, predictable, broad portfolio combining supply and demand-side measures from the start, periods of no predictability	1		1
Feed-in-Tariff / Premium: incl. tradable green certificate	2		2
Feed-In-Tariff / Premium: long term FIT / P	2		2
Building permits: delay in issuance		1	1
Fossil fuel subsidy		1	1
Political	4	3	7
Complexity of administrative procedures		2	2
Political uncertainty		1	1
Pro-wind interest advocate for strongly support feed-in-tariff	1		1
Inter-ministry coordination	1		1
Existence of a system builder	1		1
Utilities lobby to shape regulatory environment in favour of wind	1		1
Environmental	3		3
Climate change	2		2
Environmental benefits of wind energy	1		1
Economic	11	10	21
Carbon price	1		1
Construction costs		1	1
Diversification of electricity production	1		1
Electricity price volatility	1		1
Firm age		1	1
Gas price	1		1
International learning spill over	1		1
Investment costs		1	1
Investor experience	2		2
Investors need for revenue growth	1		1

Lack of financial resources		1	1
Non-core country (being a follower country)	1		1
Price of electricity		1	1
Raising prices of fuel oil, natural gas and coal due to changes in taxes	1		1
Steel price		2	2
Vested Interests: Wind located outside of the vested interest structure		1	1
Comparative price advantage wind energy	1		1
Poor alignment between technology developers and investors		1	1
Competition resulting in large cost reductions		1	1
Combination	2		2
Formation of alliances	1		1
Leadership provided by main energy utility	1		1
ADV and CN/IN	4	1	5
Regulatory	3		3
Feed-In-Tariff / Premium	1		1
Installation subsidies	1		1
Mandatory requirements by government: obligations for utility to purchase power	1		1
Economic	1	1	2
Vested Interests: Increasing leverage vested interests		1	1
Vested interests: weakening vested interests	1		1
CN/IN	22	19	41
Technological	1	8	9
Construction quality control		1	1
Country wind technology capacity	1		1
Grid connection technology		1	1
Grid stability		1	1
Lack of transmission network infrastructure		1	1
Operation & maintenance		1	1
Process quality control		1	1
Wind resource survey		1	1
Wind turbine technology		1	1
Technical potential	5	1	6
Coal consumption	1		1
Solar PV installed capacity	1	1	2
Wind resource	3		3
Social		2	2
Preference for thermal and hydro power		1	1
Willingness of consulting and insurance companies to work with wind industry		1	1
Regulatory	11	6	17
Clean Development Mechanism	1		1
Feed-In-Tariff / Premium	2	1	3
Grid: plans		1	1
Grid: policy to reduce grid and transmission risk	1		1
Peak regulations power stations		1	1
Policy package: coherent catch-up strategy by the government	1		1
Policy package: matching policy initiatives, sectoral goals and macro policy	1		1
Policy to improve financing availability	1		1
Policy to reduce counterparty risk	1		1
Policy to reduce power market risk	1		1
Policy to reduce project implementation risk	1		1
Policy to support financial returns	1		1
Policy uncertainty		1	1
Taxes		1	1
Wind power plans		1	1
Economic	5	2	7
Electricity intensity (economic efficiency)	1		1
GDP per capita	2		2
Investment costs		1	1
Lack of financial resources		1	1
Market share of domestic wind turbine manufacturer	1		1
Net present value of wind energy project	1		1
EDE	6	6	12
Technological		1	1
Lack of transmission network infrastructure		1	1
Technical potential	1		1
Electricity security	1		1
Social	1	1	2
Environmental awareness	1		1

Unequal access to education		1	1
Regulatory	1		1
Financial support from European Union (cohesion policy)	1		1
Political		2	2
Armed conflict		1	1
Corruption		1	1
Environmental	1		1
Climate change	1		1
Economic	2	2	4
Diversification of electricity production	1		1
GDP	1		1
Unstable macroeconomic environment		1	1
Unattractive loan conditions		1	1
Group incl. EDE	65	32	97
Technological	2	1	3
Infrastructure investments	1	1	2
Knowledge stock (patent count)	1		1
Technical potential	6	4	10
Annual added wind power generation (market share indicator)	1		1
Electricity consumption	1		1
Electricity consumption intensity (index)		1	1
Energy consumption	1		1
Share of gas energy in electricity generation		1	1
Share of hydro power in electricity generation	1	1	2
Share of nuclear power in electricity generation		1	1
Share of wind energy in electricity generation	1		1
Total energy import dependency	1		1
Social	3		3
ArCo tech index (patents, diffusion, human capital) (Archibugi and Coco 2004)	1		1
information and education related to energy use or emission performance	2		2
Regulatory	23	18	41
Codes and standards	1	2	3
Economic support	1		1
Feed-In-Tariff / Premium	7		7
Funds to sub-national governments		2	2
Grants and subsidies		1	1
Kyoto ratification	1	1	2
Loans	2		2
Mandatory requirements by government, other than codes & standards / obligation schemes for energy	1		1
Mandatory requirements by government: obligation scheme		1	1
Market Based Instruments	1	3	4
Obligation scheme		1	1
Policy package: support programs for technology deployment and diffusion		1	1
Policy support	4		4
Procurement rules		1	1
Regulatory support	1		1
Support scheme change: major change		1	1
Support scheme change: minor change		1	1
Tax relief	2		2
Taxes		1	1
Voluntary approaches		2	2
Grid: favourable grid access regulations	2		2
Political	6	2	8
Corruption		1	1
Globalization: political participation	1		1
Lead time of administrative procedure		1	1
Rule of law	2		2
Predictability of public authorities	1		1
Simple administrative process	2		2
Environmental	3	5	8
CO2 emission	3	2	5
Solar intensity		1	1
Sunshine hours		2	2
Economic	20	2	22
Access to finance, trade openness, investment freedom	1		1
Business Competitiveness Index	1		1
Carbon price	1		1

Domestic private debt divided by GDP	1		1
Economic Integration (Bilateral country pairings)	1		1
FDI stock	1		1
GDP	2		2
GDP per capita	3		3
Interest rates		1	1
Levelized cost of wind electricity	1	1	2
Price of electricity	1		1
Primary energy intensity	1		1
Private credit divided by GDP	2		2
Share price of local indices	1		1
Strength of multilateral development banks	1		1
Unstable macroeconomic environment	1		1
Insurance assets divided by GDP	1		1
Combination	2		2
Leadership provided by main energy utility	1		1
Enhancing energy security, creating future oriented industry that provides job opportunities, environmental protection	1		1
Total	144	92	236

Appendix C Current state of energy security, industry and emission levels

Table C-1 current state of energy security, industry and employment level and emission and local pollution levels.

	Energy security (The World Bank, 2019a) (Import as % of consumption)	Industry level and employment (International Renewable Energy Agency, 2019) (Number of jobs in wind industry)	Level of greenhouse gasses (The World Bank, 2020) (Annual metric ton CO ₂ / cap)	Local pollution (The World Bank, 2019b) (Micro gram PM _{2.5} / cubic meter)
Advanced economies	21% (high income countries)	428.000 (US and EU)	10.9 (high income countries)	15 (high income countries)
	Medium secure	High level	High level	Low level
Emerging and developing economies	28% (low and middle income countries)	164.000 (world minus (US + EU + China + India)	3.5 (low and middle income)	51 (low and middle income)
	Low-medium secure	Low level	Low level	Medium level
China & India	15% (China) 34% (India)	568.000 (China + India)	7.5 (China) 1.7 (India)	53 (China) 91 (India)
	Low-medium secure	High level	Low-medium level	Medium-high level

References

- Abdmouleh, Z., Alammari, R. A. M. and Gastli, A. (2015) 'Review of policies encouraging renewable energy integration & best practices', *Renewable and Sustainable Energy Reviews*. doi: 10.1016/j.rser.2015.01.035.
- Barradale, M. J. (2010) 'Impact of public policy uncertainty on renewable energy investment: wind power and the production tax credit', *Energy Policy*. Elsevier, 38(12), pp. 7698–7709. doi: 10.1016/j.enpol.2010.08.021.
- Bass, F. M. (1969) 'A New Product Growth for Model Consumer Durables', *Management Science*, 15(5), pp. 215–227. doi: 10.1287/mnsc.15.5.215.
- Baudry, M. and Bonnet, C. (2019) 'Demand-pull instruments and the development of wind power in Europe: a counterfactual analysis', *Environmental and Resource Economics*. Springer Netherlands, 73(2), pp. 385–429. doi: 10.1007/s10640-018-0267-3.
- Bento, N. and Fontes, M. (2015a) 'Spatial diffusion and the formation of a technological innovation system in the receiving country: the case of wind energy in Portugal', *Environmental Innovation and Societal Transitions*. Elsevier B.V., 15, pp. 158–179. doi: 10.1016/j.eist.2014.10.003.
- Bento, N. and Fontes, M. (2015b) 'The construction of a new technological innovation system in a follower country: wind energy in Portugal', *Technological Forecasting and Social Change*. Elsevier B.V., 99, pp. 197–210. doi: 10.1016/j.techfore.2015.06.037.
- Bento, N. and Fontes, M. (2016) 'The capacity for adopting energy innovations in Portugal: historical evidence and perspectives for the future', *Technological Forecasting and Social Change*. Elsevier Inc., 113, pp. 308–318. doi: 10.1016/j.techfore.2015.09.003.
- Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008) 'Analyzing the functional dynamics of technological innovation systems: a scheme of analysis', *Research Policy*, 37(3), pp. 407–429. doi: <https://doi.org/10.1016/j.respol.2007.12.003>.

- Bergek, A. and Mignon, I. (2017) 'Motives to adopt renewable electricity technologies: evidence from Sweden', *Energy Policy*, 106, pp. 547–559. doi: 10.1016/j.enpol.2017.04.016.
- Bertrand, M. and Mullainathan, S. (2001) 'Do people mean what they say? Implications for subjective survey data', *American Economic Review*, 91(2), pp. 67–72. doi: 10.1257/aer.91.2.67.
- Best, R. and Burke, P. J. (2018) 'Adoption of solar and wind energy: the roles of carbon pricing and aggregate policy support', *Energy Policy*. Elsevier Ltd, 118(April), pp. 404–417. doi: 10.1016/j.enpol.2018.03.050.
- Binz, C., Gosens, J., Hansen, T. and Hansen, U. E. (2017) 'Toward technology-sensitive catching-up policies: insights from renewable energy in China', *World Development*, 96, pp. 418–437. doi: 10.1016/j.worlddev.2017.03.027.
- Biresselioglu, M. E., Kilinc, D., Onater-Isberk, E. and Yelkenci, T. (2016) 'Estimating the political, economic and environmental factors' impact on the installed wind capacity development: a system GMM approach', *Renewable Energy*. Elsevier Ltd, 96, pp. 636–644. doi: 10.1016/j.renene.2016.05.034.
- Blindheim, B. (2013) 'Implementation of wind power in the Norwegian market; the reason why some of the best wind resources in Europe were not utilised by 2010', *Energy Policy*. Elsevier, 58(1), pp. 337–346. doi: 10.1016/j.enpol.2013.03.033.
- Buen, J. (2006) 'Danish and Norwegian wind industry: The relationship between policy instruments, innovation and diffusion', *Energy Policy*, 34(18), pp. 3887–3897. doi: 10.1016/j.enpol.2005.09.003.
- Can Şener, Ş. E., Sharp, J. L. and Anctil, A. (2018) 'Factors impacting diverging paths of renewable energy: A review', *Renewable and Sustainable Energy Reviews*, 81(March 2017), pp. 2335–2342. doi: 10.1016/j.rser.2017.06.042.
- Cárdenas Rodríguez, M., Haščič, I., Johnstone, N., Silva, J. and Ferey, A. (2015) 'Renewable energy policies and private sector investment: evidence from financial microdata', *Environmental and Resource Economics*, 62(1), pp. 163–188. doi: 10.1007/s10640-014-9820-x.

Cherp, A., Vinichenko, V., Jewell, J., Suzuki, M. and Antal, M. (2017) 'Comparing electricity transitions: a historical analysis of nuclear, wind and solar power in Germany and Japan', *Energy Policy*. Elsevier, 101(May 2016), pp. 612–628. doi: 10.1016/j.enpol.2016.10.044.

Chodkowska-Miszczuk, J., Biegańska, J., Środa-Murawska, S., Grzelak-Kostulska, E. and Rogatka, K. (2016) 'European Union funds in the development of renewable energy sources in Poland in the context of the cohesion policy', *Energy and Environment*, 27(6–7), pp. 713–725. doi: 10.1177/0958305X16666963.

Craig, R. (2019) *Suzlon joins Enercon and Servion on OEM crisis list*, *Wind Power Monthly*. Available at: <https://www.windpowermonthly.com/article/1665921/suzlon-joins-enercon-servion-oem-crisis-list> (Accessed: 5 December 2020).

Criscuolo, C. and Menon, C. (2015) 'Environmental policies and risk finance in the green sector: cross-country evidence', *Energy Policy*, 83, pp. 38–56. doi: 10.1016/j.enpol.2015.03.023.

Dai, Y. and Xue, L. (2015) 'China's policy initiatives for the development of wind energy technology', *Climate Policy*. Taylor & Francis, 15(1), pp. 30–57. doi: 10.1080/14693062.2014.863549.

Darmani, A., Niesten, E. M. M. I. and Hekkert, M. P. (2017) 'Characteristics of investors in onshore wind power in Sweden', *Environmental Innovation and Societal Transitions*. Elsevier B.V., 24, pp. 67–82. doi: 10.1016/j.eist.2016.10.005.

Davies, S. W. (1979) *The diffusion of process innovations*. Cambridge, UK: Cambridge University Press.

Davies, S. W. and Diaz-Rainey, I. (2011) 'The patterns of induced diffusion: evidence from the international diffusion of wind energy', *Technological Forecasting and Social Change*. Elsevier Inc., 78(7), pp. 1227–1241. doi: 10.1016/j.techfore.2011.03.012.

- Dinica, V. (2008a) 'Greening electricity production: A success story of multi-level governance convergence and innovation', *Energy and Environment*, 19(6), pp. 787–801. doi: 10.1260/095830508785363596.
- Dinica, V. (2008b) 'Initiating a sustained diffusion of wind power: the role of public-private partnerships in Spain', *Energy Policy*, 36(9), pp. 3562–3571. doi: 10.1016/j.enpol.2008.06.008.
- Diógenes, J. R. F., Claro, J. and Rodrigues, J. C. (2019) 'Barriers to onshore wind farm implementation in Brazil', *Energy Policy*. Elsevier Ltd, 128(January), pp. 253–266. doi: 10.1016/j.enpol.2018.12.062.
- Dovi, V. G., Friedler, F., Huisingh, D. and Klemeš, J. J. (2009) 'Cleaner energy for sustainable future', *Journal of Cleaner Production*. doi: 10.1016/j.jclepro.2009.02.001.
- Du, Y., Song, B., Duan, H., Tsvetanov, T. G. and Wu, Y. (2019) 'Multi-renewable management: interactions between wind and solar within uncertain technology ecological system', *Energy Conversion and Management*. Elsevier, 187(January), pp. 232–247. doi: 10.1016/j.enconman.2019.01.032.
- Edmondson, A. C. and Mcmanus, S. E. (2007) 'Methodological fit in management field research', *Academy of Management Review*, 32(4), pp. 1246–1264. doi: 10.5465/amr.2007.26586086.
- Edsand, H. E. (2017) 'Identifying barriers to wind energy diffusion in Colombia: a function analysis of the technological innovation system and the wider context', *Technology in Society*. Elsevier Ltd, 49, pp. 1–15. doi: 10.1016/j.techsoc.2017.01.002.
- Eleftheriadis, I. M. and Anagnostopoulou, E. G. (2015) 'Identifying barriers in the diffusion of renewable energy sources', *Energy Policy*. Elsevier, 80, pp. 153–164. doi: 10.1016/j.enpol.2015.01.039.
- Ericsson, K., Nilsson, L. J. and Nilsson, M. (2011) 'New energy strategies in the Swedish pulp and paper industry-The role of national and EU climate and energy policies', *Energy Policy*. Elsevier, 39(3), pp. 1439–1449. doi:

10.1016/j.enpol.2010.12.016.

Espinoza, J. L. and Vredenburg, H. (2010) 'Towards a model of wind energy industry development in industrial and emerging economies', *Global Business and Economics Review*, 12(3), pp. 203–229. doi: 10.1504/GBER.2010.034894.

Friebe, C. A., Von Flotow, P. and Täube, F. A. (2014) 'Exploring technology diffusion in emerging markets - the role of public policy for wind energy', *Energy Policy*. Elsevier, 70, pp. 217–226. doi: 10.1016/j.enpol.2014.03.016.

Furman, J. L. and Hayes, R. (2004) 'Catching up or standing still?: National innovative productivity among "follower" countries, 1978–1999', *Research Policy*, 33(9), pp. 1329–1354. doi: 10.1016/j.respol.2004.09.006.

Gavard, C. (2016) 'Carbon price and wind power support in Denmark', *Energy Policy*. Elsevier, 92, pp. 455–467. doi: 10.1016/j.enpol.2016.01.031.

Geels, F. W. (2002) 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study', *Research Policy*, 31(8), pp. 1257–1274. doi: [https://doi.org/10.1016/S0048-7333\(02\)00062-8](https://doi.org/10.1016/S0048-7333(02)00062-8).

Gonzalez, A. and Laudette, C.-L. (2019) *UPDATE 2-Turbine maker Siemens Gamesa shares plummet on delayed margin goals*, *Reuters*. Available at: <https://www.reuters.com/article/siemens-gamesa-r-results/update-2-turbine-maker-siemens-gamesa-shares-plummet-on-delayed-margin-goals-idUSL8N27L1CD> (Accessed: 5 December 2020).

Grafström, J. and Lindman, Å. (2017) 'Invention, innovation and diffusion in the European wind power sector', *Technological Forecasting and Social Change*. Elsevier Inc., 114, pp. 179–191. doi: 10.1016/j.techfore.2016.08.008.

Griliches, Z. (1957) 'Hybrid corn: an exploration in the economics of technological change', *Econometrica*. doi: 10.2307/1905380.

Grubler, A. (2012) 'Energy transitions research : insights and cautionary tales', *Energy Policy*. Elsevier, 50, pp. 8–16. doi: 10.1016/j.enpol.2012.02.070.

Halleck-Vega, S. and Mandel, A. (2018) 'Technology diffusion and climate policy:

a network approach and its application to wind energy', *Ecological Economics*, 145(November 2016), pp. 461–471. doi: 10.1016/j.ecolecon.2017.11.023.

Halleck-Vega, S., Mandel, A. and Millock, K. (2018) 'Accelerating diffusion of climate-friendly technologies: a network perspective', *Ecological Economics*, 152, pp. 235–245. doi: 10.1016/j.ecolecon.2018.05.007.

Heiskanen, E., Jalas, M., Juntunen, J. K. and Nissilä, H. (2017) 'Small streams, diverse sources: who invests in renewable energy in Finland during the financial downturn?', *Energy Policy*. Elsevier Ltd, 106(March), pp. 191–200. doi: 10.1016/j.enpol.2017.03.013.

Huang, Y. H. and Wu, J. H. (2009) 'A transition toward a market expansion phase: policies for promoting wind power in Taiwan', *Energy*, 34(4), pp. 437–447. doi: 10.1016/j.energy.2008.12.003.

Hübner, A. and Martin, M. (2019) *German wind turbine maker Senvion files for insolvency*, *Reuters*. Available at: <https://www.reuters.com/article/us-germany-senvion/german-wind-turbine-maker-senvion-files-for-insolvency-idUSKCN1RL271> (Accessed: 5 December 2020).

Hvelplund, F. (2006) 'Renewable energy and the need for local energy markets', *Energy*, 31(13), pp. 2293–2302. doi: 10.1016/j.energy.2006.01.016.

Ibenholt, K. (2002) 'Explaining learning curves for wind power', *Energy Policy*, 30(13), pp. 1181–1189. doi: 10.1016/S0301-4215(02)00014-9.

Inoue, Y. and Miyazaki, K. (2008) 'Technological innovation and diffusion of wind power in Japan', *Technological Forecasting and Social Change*, 75(8), pp. 1303–1323. doi: 10.1016/j.techfore.2008.01.001.

International Energy Agency (2019) *World Energy Investment 2019*. Paris. Available at: <https://www.iea.org/wei2019>.

International Monetary Fund (2018) *World Economic Outlook - Database - WEO Groups and Aggregates Information*. Available at: <https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/groups.htm>

(Accessed: 5 November 2018).

International Renewable Energy Agency (2018) *Renewable capacity statistics 2018*. Abu Dhabi: International Renewable Energy Agency (IRENA). doi: 10.1016/S2255-4971(15)30126-9.

International Renewable Energy Agency (2019) *Renewable Energy and Jobs: Annual Review 2019*. Masdar City.

Jacobsson, S. and Lauber, V. (2006) 'The politics and policy of energy system transformation - explaining the German diffusion of renewable energy technology', *Energy Policy*, 34(3), pp. 256–276. doi: 10.1016/j.enpol.2004.08.029.

Jung, C., Schindler, D. and Laible, J. (2018) 'National and global wind resource assessment under six wind turbine installation scenarios', *Energy Conversion and Management*. doi: 10.1016/j.enconman.2017.11.059.

Kabouris, J. and Perrakis, K. (2000) 'Wind electricity in Greece: recent developments, problems and prospects', *Renewable Energy*, 21(3–4), pp. 417–432. doi: 10.1016/S0960-1481(00)00004-5.

Karltorp, K. (2016) 'Challenges in mobilising financial resources for renewable energy - The cases of biomass gasification and offshore wind power', *Environmental Innovation and Societal Transitions*. Elsevier B.V., 19(2016), pp. 96–110. doi: 10.1016/j.eist.2015.10.002.

Keeley, A. R. and Ikeda, Y. (2017) 'Determinants of foreign direct investment in wind energy in developing countries', *Journal of Cleaner Production*. Elsevier, 161, pp. 1451–1458. doi: 10.1016/J.JCLEPRO.2017.05.106.

Keeley, A. R. and Matsumoto, K. (2018) 'Investors' perspective on determinants of foreign direct investment in wind and solar energy in developing economies – Review and expert opinions', *Journal of Cleaner Production*, 179, pp. 132–142. doi: 10.1016/j.jclepro.2017.12.154.

Kern, F., Verhees, B., Raven, R. and Smith, A. (2015) 'Empowering sustainable

niches: comparing UK and Dutch offshore wind developments', *Technological Forecasting and Social Change*. Elsevier Inc., 100, pp. 344–355. doi: 10.1016/j.techfore.2015.08.004.

Kim, S. E. and Urpelainen, J. (2013) 'When and how can advocacy groups promote new technologies? Conditions and strategies for effectiveness', *Journal of Public Policy*, 33(3), pp. 259–293. doi: 10.1017/S0143814X13000159.

Knight, S. (2019) *Enercon braced for change following dramatic German collapse*, *Wind Power Monthly*. Available at: <https://www.windpowermonthly.com/article/1581941/enercon-braced-change-following-dramatic-german-collapse> (Accessed: 5 December 2020).

Lehtovaara, M., Karvonen, M., Kapoor, R., Kässi, T. S. and Pyrhönen, J. (2014) 'Major factors contributing to wind power diffusion', *Foresight*, 16(3), pp. 250–269. doi: 10.1108/FS-03-2013-0012.

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J. and Moher, D. (2009) 'The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration', *Journal of clinical epidemiology*, 62(10), pp. e1–e34. doi: 10.1016/j.jclinepi.2009.06.006.

Liu, W.-Q., Zhang, X.-L. and Gan, L. (2002) 'Wind energy development in China: institutional dynamics and policy incentives', *International Journal of Energy Technology and Policy*, 1(1/2), p. 145. doi: 10.1504/IJETP.2002.000807.

Liu, Y. (2015) 'CDM and national policy: Synergy or conflict? Evidence from the wind power sector in China', *Climate Policy*, 15(6), pp. 767–783. doi: 10.1080/14693062.2014.968764.

Liu, Y. and Wei, T. (2016) 'Market and non-market policies for renewable energy diffusion: a unifying framework and empirical evidence from China's wind power sector', *Energy Journal*, 37, pp. 195–210. doi: 10.5547/01956574.37.SI1.1yan.

Lu, X., McElroy, M. B. and Kiviluoma, J. (2009) 'Global potential for wind-

generated electricity', *Proceedings of the National Academy of Sciences*. doi: 10.1073/pnas.0904101106.

Lund, P. D. (2015) 'Energy policy planning near grid parity using a price-driven technology penetration model', *Technological Forecasting and Social Change*. Elsevier Inc., 90(PB), pp. 389–399. doi: 10.1016/j.techfore.2014.05.004.

Lüthi, S. and Prässler, T. (2011) 'Analyzing policy support instruments and regulatory risk factors for wind energy deployment-A developers' perspective', *Energy Policy*, 39(9), pp. 4876–4892. doi: 10.1016/j.enpol.2011.06.029.

Marques, A. C., Fuinhas, J. A. and Pereira, D. S. (2019) 'The dynamics of the short and long-run effects of public policies supporting renewable energy: A comparative study of installed capacity and electricity generation', *Economic Analysis and Policy*. Elsevier B.V., 63, pp. 188–206. doi: 10.1016/j.eap.2019.06.004.

Meyer, N. I. (2006) 'Influence of government policy on the promotion of wind power', *International Journal of Global Energy Issues*, 25(3/4), p. 204. doi: 10.1504/IJGEI.2006.008992.

Meyer, N. I. (2007) 'Learning from wind energy policy in the EU: Lessons from Denmark, Sweden, and Spain', *European Environment*, 17(5), pp. 347–362. doi: 10.1002/eet.463.

Mignon, I. and Bergek, A. (2016) 'System- and actor-level challenges for diffusion of renewable electricity technologies: an international comparison', *Journal of Cleaner Production*. Elsevier Ltd, 128, pp. 105–115. doi: 10.1016/j.jclepro.2015.09.048.

Moe, E. (2012) 'Vested interests, energy efficiency and renewables in Japan', *Energy Policy*. Elsevier, 40(1), pp. 260–273. doi: 10.1016/j.enpol.2011.09.070.

Moe, E. (2017) *Does politics matter? Explaining swings in wind power installations*, *AIMS Energy*. doi: 10.3934/energy.2017.3.341.

Montalvo, C. and Kemp, R. (2008) 'Cleaner technology diffusion: case studies,

modeling and policy', *Journal of Cleaner Production*. doi: 10.1016/j.jclepro.2006.06.005.

Mulder, A. (2008) 'Do economic instruments matter? Wind turbine investments in the EU(15)', *Energy Economics*, 30(6), pp. 2980–2991. doi: 10.1016/j.eneco.2008.02.005.

Negro, S. O., Alkemade, F. and Hekkert, M. P. (2012) 'Why does renewable energy diffuse so slowly? A review of innovation system problems', *Renewable and Sustainable Energy Reviews*. doi: 10.1016/j.rser.2012.03.043.

Nelson, R. and Winter, S. (1982) *An evolutionary theory of economic change*. London: Belknap Press of Harvard University.

Nordensvärd, J. and Urban, F. (2015) 'The stuttering energy transition in Germany: wind energy policy and feed-in tariff lock-in', *Energy Policy*. Elsevier, 82(1), pp. 156–165. doi: 10.1016/j.enpol.2015.03.009.

Panse, R. and Kathuria, V. (2015) 'Modelling diffusion of wind power across countries', *International Journal of Innovation Management*, 19(4). doi: 10.1142/S1363919615500371.

Peña, I., Azevedo, I. and Marcelino Ferreira, L. A. F. (2017) 'Lessons from wind policy in Portugal', *Energy Policy*. Elsevier, 103(January), pp. 193–202. doi: 10.1016/j.enpol.2016.11.033.

Phillips, F. (2007) 'On S-curves and tipping points', *Technological Forecasting and Social Change*, 74(6), pp. 715–730. doi: <https://doi.org/10.1016/j.techfore.2006.11.006>.

Pittaway, L., Robertson, M., Munir, K., Denyer, D. and Neely, A. (2004) 'Networking and innovation: a systematic review of the evidence', *International Journal of Management Reviews*, 5–6(3–4), pp. 137–168. doi: 10.1111/j.1460-8545.2004.00101.x.

Polzin, F., Egli, F., Steffen, B. and Schmidt, T. S. (2019) 'How do policies mobilize private finance for renewable energy?—A systematic review with an investor

perspective', *Applied Energy*, 236, pp. 1249–1268. doi: 10.1016/j.apenergy.2018.11.098.

Polzin, F., Migendt, M., Täube, F. A. and von Flotow, P. (2015) 'Public policy influence on renewable energy investments-A panel data study across OECD countries', *Energy Policy*, 80(June), pp. 98–111. doi: 10.1016/j.enpol.2015.01.026.

Popp, D., Hascic, I. and Medhi, N. (2011) 'Technology and the diffusion of renewable energy', *Energy Economics*. Elsevier B.V., 33(4), pp. 648–662. doi: 10.1016/j.eneco.2010.08.007.

Quintana-Rojo, C., Callejas-Albiñana, F. E., Tarancón, M. A. and Del Río, P. (2019) 'Identifying the drivers of wind capacity additions: the case of Spain. A multiequational approach', *Energies*, 12(10), pp. 1–19. doi: 10.3390/en12101944.

del Río, P. and Tarancón, M. A. (2012) 'Analysing the determinants of on-shore wind capacity additions in the EU: An econometric study', *Applied Energy*. Elsevier Ltd, 95, pp. 12–21. doi: 10.1016/j.apenergy.2012.01.043.

Schumpeter, J. A. (1934) *The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle*. Cambridge, MA: Harvard University Press.

Sengers, F., Wieczorek, A. J. and Raven, R. (2019) 'Change Experimenting for sustainability transitions: a systematic literature review', *Technological Forecasting & Social Change*. Elsevier Inc., 145, pp. 153–164. doi: 10.1016/j.techfore.2016.08.031.

Shah, A. N., Palacios, M. and Ruiz, F. (2013) 'Strategic rigidity and foresight for technology adoption among electric utilities', *Energy Policy*, 63, pp. 1233–1239. doi: 10.1016/j.enpol.2013.08.013.

She, Z. Y., Cao, R., Xie, B. C., Ma, J. J. and Lan, S. (2019) 'An analysis of the wind power development factors by Generalized Bass Model: A case study of China's eight bases', *Journal of Cleaner Production*. Elsevier Ltd, 231, pp. 1503–

1514. doi: 10.1016/j.jclepro.2019.05.255.

Simmie, J., Sternberg, R. and Carpenter, J. (2014) 'New technological path creation: evidence from the British and German wind energy industries', *Journal of Evolutionary Economics*, 24(4), pp. 875–904. doi: 10.1007/s00191-014-0354-8.

Sisodia, G. S. and Soares, I. (2015) 'Panel data analysis for renewable energy investment determinants in Europe', *Applied Economics Letters*, 22(5), pp. 397–401. doi: 10.1080/13504851.2014.946176.

Sisodia, G. S., Soares, I. and Ferreira, P. (2016) 'The effect of sample size on European Union's renewable energy investment drivers', *Applied Economics*. Routledge, 48(53), pp. 5129–5137. doi: 10.1080/00036846.2016.1173176.

Smeets, E. and Weterings, R. (1999) *Environmental indicators: typology and overview*, *Technical report No 25*. Copenhagen. Available at: <http://www.eea.europa.eu/publications/TEC25>.

Steen, M. and Hansen, G. H. (2018) 'Barriers to path creation: the case of offshore wind power in Norway', *Economic Geography*, 94(2), pp. 188–210. doi: 10.1080/00130095.2017.1416953.

Steffen, B., Matsuo, T., Steinemann, D. and Schmidt, T. S. (2018) 'Opening new markets for clean energy: the role of project developers in the global diffusion of renewable energy technologies', *Business and Politics*, pp. 1–35. doi: 10.1017/bap.2018.17.

Stenzel, T. and Frenzel, A. (2008) 'Regulating technological change-The strategic reactions of utility companies towards subsidy policies in the German, Spanish and UK electricity markets', *Energy Policy*, 36(7), pp. 2645–2657. doi: 10.1016/j.enpol.2008.03.007.

Strantzali, E. and Aravossis, K. (2016) 'Decision making in renewable energy investments: A review', *Renewable and Sustainable Energy Reviews*. doi: 10.1016/j.rser.2015.11.021.

Surana, K. and Anadon, L. D. (2015) 'Public policy and financial resource mobilization for wind energy in developing countries: a comparison of approaches and outcomes in China and India', *Global Environmental Change*. Elsevier Ltd, 35, pp. 340–359. doi: 10.1016/j.gloenvcha.2015.10.001.

The World Bank (2019a) *Electricity production from nuclear sources (% of total)*. Available at: <https://data.worldbank.org/indicator/EG.ELC.NUCL.ZS> (Accessed: 20 March 2020).

The World Bank (2019b) *PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)*. Available at: <https://data.worldbank.org/indicator/EN.ATM.PM25.MC.M3> (Accessed: 1 October 2020).

The World Bank (2020) *CO2 emissions (metric tons per capita)*. Available at: <https://data.worldbank.org/indicator/EN.ATM.CO2E.PC> (Accessed: 17 July 2020).

Tranfield, D., Denyer, D. and Smart, P. (2003) 'Towards a methodology for developing evidence-informed management knowledge by means of systematic review', *British Journal of Management*, 14(3), pp. 207–222. doi: 10.1111/1467-8551.00375.

United Nations (2018) *Sustainable Development Goal 7*. Available at: <https://sustainabledevelopment.un.org/sdg7> (Accessed: 26 October 2018).

van der Vleuten, E. and Raven, R. (2006) 'Lock-in and change: Distributed generation in Denmark in a long-term perspective', *Energy Policy*, 34(18), pp. 3739–3748. doi: 10.1016/j.enpol.2005.08.016.

Werner, L. and Scholtens, B. (2017) 'Firm Type, Feed-in Tariff, and Wind Energy Investment in Germany: An Investigation of Decision Making Factors of Energy Producers Regarding Investing in Wind Energy Capacity', *Journal of Industrial Ecology*, 21(2), pp. 402–411. doi: 10.1111/jiec.12443.

Wijayatunga, P. D. C., Siriwardena, K., Fernando, W. J. L. S., Shrestha, R. M. and Attalage, R. A. (2006) 'Strategies to overcome barriers for cleaner generation

technologies in small developing power systems: Sri Lanka case study', *Energy Conversion and Management*, 47(9–10), pp. 1179–1191. doi: 10.1016/j.enconman.2005.07.003.

Ydersbond, I. M. and Korsnes, M. S. (2016) 'What drives investment in wind energy? A comparative study of China and the European Union', *Energy Research and Social Science*. Elsevier Ltd, 12, pp. 50–61. doi: 10.1016/j.erss.2015.11.003.

Zhang, R. X. X., Ni, M., Shen, G. Q. P. and Wong, J. K. W. (2019) 'An analysis on the effectiveness and determinants of the wind power Feed-in-Tariff policy at China's national-level and regional-grid-level', *Sustainable Energy Technologies and Assessments*. Elsevier, 34(April), pp. 87–96. doi: 10.1016/j.seta.2019.04.010.

Zhao, Z.-Y., Chang, R.-D. and Chen, Y.-L. (2016) 'What hinder the further development of wind power in China?—A socio-technical barrier study', *Energy Policy*. Elsevier Ltd, 88, pp. 465–476. doi: 10.1016/j.enpol.2015.11.004.

4 RESEARCH DESIGN

“You haven't seen a tree until you've seen its shadow from the sky”

--- Amalia Earhart

Abstract

The UN created the 17 Sustainable Development Goals to increase the prosperity of people and planet by 2030. Goal 7 focusses on affordable, reliable, sustainable and modern energy access for all. Significant progress has been made over the last decade: since 2007, the annual investment in renewable energy exceeded the combined investment in fossil and nuclear energy. However, for many developing countries, the balance is still in favour of conventional energy.

The literature study showed four areas worth of further exploration: explaining differences in wind diffusion between emerging and developing economies and advanced economies, understanding path creation using quantitative data, measuring the desire-related factors that influence wind energy diffusion and describing wind diffusion from a wind energy Original Equipment Manufacturers point of view.

The appropriate research method to address the identified field of study was chosen to be panel based binary logistic regression. The chosen philosophical position was critical rationalism. Following the importance of desire for wind energy in early stages of wind power path creations, three research questions were defined, and the dependent, independent and controlling variables were selected.

Keywords: Wind Energy, Diffusion, Developing and Emerging Economies, Drivers, Barriers, Path Creation, Research Design

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1 Introduction

In 2015, the UN created the 17 Sustainable Development Goals (SDGs) to increase the prosperity of people and the planet by 2030. SDG number 7 aims to “ensure access to affordable, reliable, sustainable and modern energy for all” (United Nations, 2018). Global investment in power generation was approximately 480 USD billion in 2018. Since 2007, the annual investment in renewable energy exceeded the combined investment in fossil and nuclear energy, however in many developing and emerging economies, investments in conventional energy are still dominant (International Energy Agency, 2019b). The annual investment in power generation is decreasing in high income countries but has been increasing in emerging markets since 2011 (International Energy Agency, 2019b). Understanding the reasons why there is relatively little investment in renewable energy in certain developing and emerging markets could help turn the balance in favour of renewable energy and support achievement of SDG 7.

Within the field of renewable energy, solar PV and wind together formed the largest share of total investments in 2018 (International Energy Agency, 2019b). Solar PV and wind technologies are technically and operationally very different, hence the barriers and drivers for these technologies will most likely differ. To focus, this study will consider wind energy only.

The relatively low investment in wind energy in many developing and emerging markets is not a consequence of a lack of wind. Lu et al (2009) and Jung et al (2018) provide country level perspectives of technical wind potential. With 23GW installed wind power by the end of 2017, Spain is one of Europe’s leading markets regarding installed wind power (International Renewable Energy Agency, 2018). Taking the wind potential of Spain as the threshold, Lu et al (2009) and Jung et al (2018) identify respectively 59 and 53 high wind potential countries. Combining both studies, result in 68 unique high wind potential countries. Table 1 displays these countries, sorted by the amount of accumulative wind energy installed. Despite having high wind potential, the total accumulative wind energy installed

in many developing and emerging economies is very low. This demonstrates the scale of the potential opportunity in developing and emerging countries.

Table 1 High wind potential countries, derived from Lu et al (2009) and Jung et al (2018), grouped by installed wind power capacity by end of 2017 (International Renewable Energy Agency, 2018). Underlined: developing and emerging economies (definition by International Monetary Fund (2018)).

0 GW	0-0.1GW	0.1-1GW	1-10GW	>10GW
<u>Afghanistan</u>	Chad	Mongolia	<u>Morocco</u>	Brazil
<u>Angola</u>	<u>Eritrea</u>	<u>Kazakhstan</u>	Norway	Canada
<u>Congo</u>	<u>Indonesia</u>	<u>Iran</u>	<u>Chile</u>	France
<u>Iraq</u>	<u>Syria</u>	<u>Tunisia</u>	<u>Uruguay</u>	United Kingdom
<u>Libya</u>	Iceland	<u>Argentina</u>	<u>South Africa</u>	Spain
<u>Madagascar</u>	<u>Nigeria</u>	Czech Republic	Japan	<u>India</u>
Mali	<u>Saudi Arabia</u>	<u>Ethiopia</u>	Ireland	Germany
<u>Mozambique</u>	<u>Somalia</u>	<u>Ukraine</u>	<u>Mexico</u>	United States
<u>Niger</u>	<u>Namibia</u>	New Zealand	Netherlands	<u>China</u>
<u>Oman</u>	<u>Algeria</u>	<u>Egypt</u>	Australia	
<u>Paraguay</u>	<u>Russia</u>	<u>Pakistan</u>	Denmark	
<u>Sudan</u>	<u>Colombia</u>		<u>Poland</u>	
Tanzania	<u>Kenya</u>		<u>Turkey</u>	
<u>Turkmenistan</u>	<u>Bolivia</u>		Sweden	
<u>Uzbekistan</u>	<u>Mauritania</u>			
<u>Zambia</u>	<u>Venezuela</u>			
Greenland ¹	<u>Belarus</u>			

For several Original Equipment Manufacturers (OEMs) in the wind industry, stagnating markets and increased competition resulted in financial problems (Craig, 2019; Hübner and Martin, 2019; Knight, 2019). In certain developing countries, fossil-based power generation is attracting more investments than wind. Turning this balance in favour of wind, would create new business opportunities for the wind industry.

The purpose of this chapter is to summarize the specific literature on wind power diffusion, highlight the area worth further research and determine the research method in detail.

The structure of the research design is as follows. Section 2 provides a summary of the literature. The purpose of the research and the research questions are described in section 3. Section 4 elaborates on the philosophical position. The

¹ No data available on Greenland in International Renewable Energy Agency (2018) (International Renewable Energy Agency, 2018)

following section details the research method. The ethical and practical considerations are described in section 6.

2 Summary of literature

Global differences in wind energy investment can be viewed from the perspective of general technology diffusion. This perspective is explained in literature through different theoretical constructs. Global adoption and diffusion of technology by means of epidemic S-curves is described by, for instance, Griliches (1957), Bass (1969), Davies (1979) and Phillips (2007). Technological transitions based on evolutionary economics are conceptualized by, among others, Nelson and Winter (1982), Geels (2002) and Rogers (2003). A socio-technical view consisting of a multi-function approach, Technological Innovation Systems, is further detailed by, exempli gratia, Jacobsson and Bergek (2004), Jacobsson and Lauber (2006), Hekkert et al (2007) and Bergek et al (2008).

Answering the review on global diffusion of all renewable energy types (Can Şener, Sharp and Anctil, 2018), a meta-analysis and systematic literature review (SLR) was created by the author focussing on wind energy specifically (Zwarteveen *et al.*, 2021). Special attention was paid to differences between advanced economies and developing and emerging economies. Using the PRISMA method (Liberati *et al.*, 2009), 2905 field specific articles were reduced to 74 relevant manuscripts. In this final selection of papers, 259 dependent factors influencing wind diffusion were identified, and were sorted into 8 factor categories and 170 factor sub-categories.

2.1 Descriptive results

The literature review (Zwarteveen *et al.*, 2021) identified two dependent variables:

- Wind energy growth: factors that explain capacity *growth* measured in increase of MW installed (e.g. (Popp, Hascic and Medhi, 2011)).
- Path creation: factor that explain the *start* of wind energy in a country, measured in the transition from absence of wind into wind energy installed (e.g (Steen and Hansen, 2018)).

Re-iterating the findings from Zwarteven et al (2021), a descriptive overview of the selection of manuscripts is shown in Table 2. The table highlights that the area of path creation is not as frequently studied as wind energy growth, especially for emerging and developing economies. Regression is commonly used as a research method in this field. However, within the current sample no study, using regression, has been found to focussing on path creation. Policy makers seem to be well addressed in academic research, whereas the industry actors are not that often targeted.

Table 2 Overview of academic field and areas addressed (ADV = Advanced Economies. EDE = Emerging and Developing Economies (not including China and India), √ = 6 or more journal papers identified in the SLR, x = 1-5 journal papers in identified in the SLR, xx = no journal papers identified in the SLR). Table copied from the SLR (Zwarteven *et al.*, 2021).

Areas	Details	Path creation	Wind energy growth
Countries considered	ADV	√	√
	Studies including EDE	X	√
Method considered	Fitting of theoretical model	X	√
	Regression	XX	√
	Historical descriptive	√	√
	Interview / survey	√	√
Viewpoint of study	Policy makers	√	√
	Multi actor	√	√
	Developers, Financers, Investors, Utilities	X	√
	Wind Power OEM	XX	XX

2.2 Meta-analysis

The 259 factors influencing wind energy diffusion were identified and clustered into 8 categories (Table 3). Using the Factor Direction (as defined in the previous chapter, (Zwarteven *et al.*, 2021)), economic and technical potential factors appeared to be the strongest drivers of wind energy diffusion. Social factors and technological factors formed the strongest barriers.

Within wind energy growth, country groups show different results. Studies that included emerging and developing economies showed that economic factors are an important driver, the magnitude was significantly lower for advanced economies. Environmental factors play a more important role in advanced economies versus emerging and developing economies. Lastly, social factors

seem to drive wind energy in emerging and developing economies, whereas it is a barrier in advanced economies.

Table 3 Drivers and barriers of wind energy diffusion, summarized from the literature study (Zwarteveen *et al.*, 2021). In bold, the factor groups with largest factor direction differences between advanced and emerging and developing economies.

Factor	Explanation	Role in wind energy diffusion (Factor Direction %)	
		Studies focussing on advanced economies	Studies including emerging and developing economies
Technological	R&D, Wind turbine and infra tech	Neutral (0%)	Neutral (0%)
Technical potential	Natural wind supply and electricity demand	Minor driver (33%)	Minor driver (27%)
Social	Opinions, knowledge, education	Strong barrier (-60%)	Strong driver (60%)
Regulatory	Governmental measures, e.g. Feed-in-Tarif	Minor driver (25%)	Minor driver (14%)
Political	Governmental practices, e.g. rule of law	Minor driver (14%)	Minor driver (20%)
Environmental	Emissions and climate change	Major driver (100%)	Minor barrier (-11%)
Economic	GDP, capital, prices, vested interests	Minor driver (5%)	Strong driver (69%)
Combination	Amalgam of above, from which the impact was only measured in a combined manner	Strong driver (100%)	Strong driver (100%)

A closed loop feedback model was proposed to understand the mechanism of wind energy diffusion and the differences between country groups. This model introduced 3 types of factors:

- The desire-related factors that influence wind energy diffusion (why does a country want wind energy).
- The mechanism-related factors that influence wind energy diffusion (how does wind energy diffusion take place).
- Factors disturbing the changes in wind energy diffusion.

The second group of factors is a response to the desire for wind energy. A large group of literature can be found addressing for example policy efficiency (Meyer, 2007; Liu, 2015; Peña, Azevedo and Marcelino Ferreira, 2017). However, an efficient policy will only be put in place if there is a desire for wind energy.

According to Ydersbond and Korsnes (2016), the desire to adopt wind energy is driven by the need for energy security (technical potential), the need for future

oriented industries and employment (economic factors) and the need to reduce environmental pollution (environmental factors). The literature review indicated that for advanced economies environmental improvement are important desire-related factors. Developing and emerging markets aim to strongly improve economic conditions with wind energy, followed by the need to increase energy security.

2.3 Research agenda

The proposed research agenda addresses the limitations of the meta-analysis. For instance, the sample size for the factor level was in some categories, rather low. Because of to these limitations, the data for emerging and advanced economies in the conceptual model was based on studies that also included other country groups. The literature indicted a need for a study that analyses different country groups separately and with sufficiently large data sets.

Secondly, the area of path creation deserves further research, especially in emerging and developing economies. Table 2 provides an overview of the academic field and areas addressed. The number of regression studies in the field has increased significantly since 2005. However, within the current sample no study, using regression, has been found to include path creation. Regression has the advantage of being able to compare the model fit of several models and to objectively show the impact direction and magnitude of factors influencing path creation. Especially for the global wind industry, having quantitative data on path creation helps with taking strategic decisions on when to focus on which country, how much growth can be expected or what to do to influence this. Many studies focus on “policy efficiency” (Meyer, 2007; Liu, 2015; Peña, Azevedo and Marcelino Ferreira, 2017), this is assuming a country is already interested in wind energy. Especially in the case of new path creation, the desire creates the first change. With the availability of panel data on installed wind energy across the world, it would be novel to explore this avenue.

Thirdly, the review only briefly touches on which wind energy diffusion factors are desire related. Further research is needed to identify if more variables can be defined to be desire related.

Lastly, no studies were found addressing the viewpoint of a wind OEM. As the wind industry has a significant contribution to the diffusion of wind, this viewpoint is worth to be considered in future research.

3 Research purpose and research questions

This research aims to develop knowledge relevant to both academia and practitioners.

The academic contribution is:

- The further validation of the technology diffusion feedback model (Zwarteveen *et al.*, 2021) to describe new path creation for wind power.
- Quantitatively understanding factors influencing path creation.
- Exploring how much of the wind power diffusion can be explained by measuring the desire-related factors only.
- Understanding differences between new path creation in developing and advanced economies.

The practical contribution is:

- Estimating the potential size of new markets to inform market entry strategies.
- Understanding how to influence the desire related factors for wind energy at different stages of wind energy diffusion.
- Rebranding / reshaping offering of wind energy to fit the needs of markets with limited installed wind energy.
- Developing a method for designing the fitting market entry strategy for new markets.

Before wind energy is diffused, it is the desire for wind energy that drives the change. The efficiency and effectiveness of regulations are only relevant once the desire is there. Hence, the purpose of the research is to understand which are the desire related factors and how this influence wind energy path creation. Understanding the level of desire helps the OEM industry and other actors in the wind industry to alter their offerings to make it country fitting to stimulate the deployment of it.

Summarizing, the overarching theme is to understand path creation in wind energy in developing and emerging economies by looking at the desire related factors. Accordingly, the research questions of this study are:

- RQ1: How much of the wind energy path creation can be explained by looking at desire related factors only?
- RQ2: What are the differences in desire related factors that influence path creation of wind energy between advanced economies and emerging and developing economies?
- RQ3: What are the differences in desire related factors that influence the different stages of new path creation of wind energy?

4 Philosophical position

The philosophical position determines the ontology, the epistemology and eventually the methodology (Scotland, 2012). The literature review revealed the use of multiple methodologies in the field of wind energy diffusion. The overview, and their corresponding philosophical foundations are shown in Table 4.

Table 4 Different philosophical positions, based on Blaikie (2007), present in the field of wind energy diffusion research.

Philosophical position	Ontology What is reality?	Epistemology How is knowledge created?	Methodology examples in wind energy diffusion field	Motivation for selection
Positivism				
Measurement is the exclusive basis for reality	Objective observation	Knowledge is created by measuring	Regression (del Río and Tarancón, 2012) Analytical Hierarchy Process (AHP) (Wijayatunga <i>et al.</i> , 2006) Curve-fitting (s-curve) (Bento and Fontes, 2016)	<ul style="list-style-type: none"> Provides quantitative insight in the relation (correlation, not causality) between dependent and independent variables (del Río and Tarancón, 2012) Determines direction and magnitude. Distinguishes significant and insignificant. Allows comparison of models, which one fits better? (del Río and Tarancón, 2012) Quantitative data is used in mature research fields (Edmondson and Mcmanus, 2007) AHP: Helps rational decision making (Wijayatunga <i>et al.</i>, 2006) No subjective intermediate (Bertrand and Mullainathan, 2001)
Interpretivism				
Meaning is only relevant in context	Mental state, denial of existence of external world	Abduction, reality is to be discovered	In depth interviews (Kern <i>et al.</i> , 2015)	<ul style="list-style-type: none"> In dept understanding, triangulation (Kern <i>et al.</i>, 2015) Understand multiple viewpoints (Kern <i>et al.</i>, 2015) Fits well to nascent state of research (Edmondson and Mcmanus, 2007)
Realism				
Only part of reality can be understood and some of it may not be quantifiable	Empirical, actual and real	Object of interest occur independently of social scientist, causal explanatory	Historical descriptive (van der Vleuten and Raven, 2006; Surana and Anadon, 2015; Cherp <i>et al.</i> , 2017)	<ul style="list-style-type: none"> Qualitative data to provide an explanatory of how and why (Cherp <i>et al.</i>, 2017) Chronological explanation of trajectories (van der Vleuten and Raven, 2006) Analyse relationship in a qualitative way (Surana and Anadon, 2015)

Finding the right methodological fit is important for creating a high-quality field research (Edmondson and Mcmanus, 2007). The research questions provide the starting point.

The questions for this study are related to identifying factors and the magnitude of their impact. It also aims to fill the gap in literature by using quantitative data to explain new path creation. Hence, from all 3 philosophical options listed in Table 4, positivism fits the best.

Positivism can be further detailed in three categories (Blaikie, 2007):

- Pure positivism:
The view is that natural science shares the same principles as social science. Everything is observable and observations are not influenced by the observer. Universal laws are not possible, since they cannot be verified in its completeness. Instead, theories are tested.
- Standard positivism:
It is based on pure positivism, but universal laws are possible due to the existence of causation.
- Critical rationalism:
It is based on standard positivism; however the observations might be influenced by shortcomings in the senses. The reality is external, but the researcher needs to be critical in selection of measurement tools.

For this study, many assumptions must be made by the author to measure the external reality. Hence, the best suitable philosophical viewpoint is critical rationalism. This philosophical view determines the detailed research method design, which is explored in the next section.

5 Research method

5.1 Detailed research method

As explained in 2.2, this study is focussed on the desire for wind energy during new path creation. Warm glow - the reward from pro-social behaviour - is an important driver of pro-environment behaviour (Hartmann and Apaolaza-Ibáñez, 2012; Hartmann *et al.*, 2017). Meaning, interviews / surveys might not reveal the actual reason for wind energy diffusion because of the incentive to mention the pro-environmental side over, for example, economic reasons. The study of Bertrand and Mullainathan (2001) also shows that there is a difference between what people say and what they mean. Multiple methods exist to explore the hidden needs (Goffin and Lemke, 2004). Among others, observation is one. Although Goffin and Lemke (2004) recommend anthropological exploration as 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 were important to drive wind energy diffusion.

Path creation is generally measured qualitatively in the literature (see Table 2), through interviews or historical descriptive analysis. Multiple studies explained the boundaries of new path creations and the different steps within the boundaries. Simmy et al (2014) link path creation to path establishment:

- Path creation as the introduction of wind power for the first time.
- Path establishment as the process of innovation and diffusion.

Using the concept of Technology Innovation Systems, Surana and Anadon (2015) present similar 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 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 annual capacity increase of greater than or equal to 10%) and widespread diffusion (three consecutive years increase less than 10%, ceiling of S-curve).

Table 5 Stages in wind diffusion path creation.

Stage	Total installed capacity in China and India [MW] (Surana and 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

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 bandwidths chosen for this research are based on previous research (Surana and Anadon, 2015) and verified by translating it into number of wind farms, as shown in Table 5.

The chosen method to analyse the different factors influencing the desire in the different stages of path creation is regression. Regression can quantify impacts of factors as well as explaining the model fit of models. This is needed to answer the research questions.

Regression models take a variety of forms (Tabachnick and Fidell, 2013). Ordinary regression deals with drawing a line through a multidimensional space of dots, determining the model fit by calculating Pearson correlation coefficient. However, if data is put into the categories shown in Table 5, the data becomes categorical, or bounded. For continuous, but bounded data, Tobit regression can be used. In this study, the data categories are considered as main data points (nominal data), not the data in the groups (continuous data). The reason is to analyse the path creation by looking at thresholds rather than the increase of wind energy between different boundaries. For this type of nominal data, two methods can be applied: binary logistic regression and multinomial logistic regression (Tabachnick and Fidell, 2013). Binary logistic considers a dependent variable with two possible 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 (e.g. for the case of winning or losing: age, gender, hours of training, diet). With a multinomial logistic regression where the

stage positions represent the multiple nominal outcomes, it would not be possible to understand the differences between the stage transitions. The downside of binary logistic regression is however that it only takes 2 possible outcomes into account, whereas the dependent variable as shown in table 5 has 4 possible outcomes. However, by creating a binary regression model for each phase change transition (in total 3 binary models), the research questions as presented earlier will be addressed. Note: alternative to logistic, linear or probit regression can also be applied to binary regression. Binary linear regression is mathematically the simplest alternative but as the probability curve is s-shaped, the linear function is often ruled out (Kutner *et al.*, 2005). Binary probit regression provides in practise similar results compared to binary logit regression (Verbeek, 2004), but provides a less straightforward method of coefficient interpretation (UCLA, 2021a, 2021b).

To determine significance of the independent variables, intercorrelation of the variables and the goodness of fit, statistical tests need to be executed as further detailed by Tabachnick and Fidell (2013).

With the developed models, simulations can be made to predict phase transitions. Considering the transition to commercialization specifically, with the models, a list of promising high wind potentials can be created where commercialization of wind is expected to soon take place.

The model development will be described in chapter 5 whereas the simulation is addressed in chapter 6.

5.2 Sampling and data collection

5.2.1 Dependent variable

The study aims to measure the impact of desire related factors on 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 paragraph 5.2. The capacity levels of installed wind energy globally are tracked since 2000 by IRENA (International Renewable Energy Agency, 2015, 2020).

5.2.2 Independent variables

In the literature study (Zwarteveen *et al.*, 2021), 170 sub-category factors were identified to influence wind energy diffusion. It was assumed in the literature study that the categories of economic, environmental and technical potential factors were influencing the desire for wind. In order to review this in detail, all 170 sub-category factors were screened according to the process shown in Figure 1. The details of the selection can be found in Appendix A. 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 6.

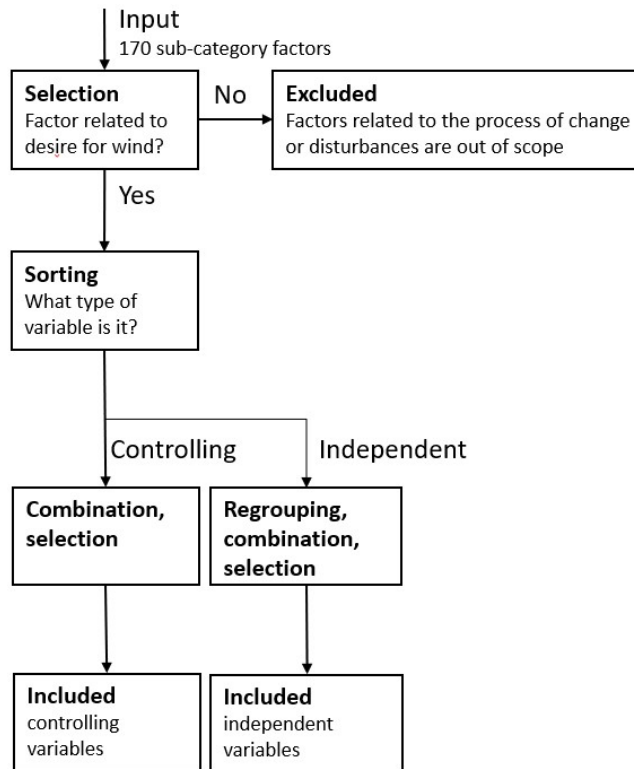


Figure 1 Selection method for relevant controlling and independent variables.

Table 6 The independent variables, their groups, the measurement unit and their data sources.

Group	Description	Variables	How to measure	Available sources and years studied
Business case	Price advantage of wind energy compared to electricity price	Price of electricity	Price of electricity per country in year <i>i</i>	(Global Petrol Prices, 2020) 2019 / (International Energy Agency, 2019c) ² / (Passport, 2020) ³ 1985-2019 / (Fitch Solutions, 2020) 1990-2020 ⁴ / (Statistica, 2015) 2015 ⁵
		– LCoE wind	– Global LCoE of wind in year <i>i</i>	(Wiser, Seel and Paulos, 2016) 1980-2015 (International Renewable Energy Agency, 2019b) 2010-2018
Economic contribution	The state of industrialization and requirement for creating jobs	Industrialization state	Industrialization intensity index	(The World Bank, 2014) 1990-2014 (International Monetary Fund, 2019) 1948-2019
		Unemployment level	Unemployment rate	(The World Bank, 2019g) 1991-2019
Education	Educational level to influence the choice of electricity source	Education level	Education index	(UNDP, 2013) 1980-2013 (OECD, 2018a) 2000-2018
Energy security	Security of providing the required electricity	Energy import dependency	Total energy import dependency	(The World Bank, 2019d) 1960-2015 (International Energy Agency, 2019a) 1971-2018
		Energy consumption	Total energy consumption	(The World Bank, 2019e) 1960-2015 (United Nations, 2020g) 1990-2018
		Energy consumption increase	Total energy consumption rate of change	(The World Bank, 2019e) 1960-2015 (United Nations, 2020g) 1990-2018
Environmental	Greenhouse gas and smog	Greenhouse gas emission	CO2 emission	(The World Bank, 2020) 1960-2014 (United Nations, 2020b) 1990-2017
		Particle emission	PM2.5 emission	(The World Bank, 2019f) 1960-2015 (OECD, 2018b) 1990-2017
Spill over	The effect of having neighbours or partners with wind energy. Knowledge and products might spill over across borders	Neighbour influence	Wind energy installed in neighbouring countries (yes/no)	(International Renewable Energy Agency, 2019a) 2008-2018
		Globalization participation	KOF index of globalization	(Dreher, 2006) 1970-2000 (ETH, 2020) 1970-2017
Vested interests	Existing interests and their impact on wind energy	Vested interests in conventional fossil	% electricity from oil / gas / coal	(The World Bank, 2019c) 1960-2015 (United Nations, 2020f) 1990-2018 (The World Bank, 2019b) 1960-2015 (United Nations, 2020d) 1990-2018
		Vested interests in nuclear	% electricity from nuclear	(The World Bank, 2019a) 1960-2015 (International Renewable Energy Agency, 2019a) 2008-2018 (United Nations, 2020a)
		Vested interests in green alternatives	% electricity from solar / hydro	(United Nations, 2020g) (United Nations, 2020c) (United Nations, 2020e) 1990-2018

² No access via Cranfield University³ Electricity price paid by industrial user, excl. VAT, incl. non-refundable taxes⁴ Electricity costs for the industrial end user⁵ Levelized cost of electricity per country, only 19 countries considered

5.2.3 Controlling variables

The research questions address two different areas:

- The difference of factors influencing wind power path creation between advanced and emerging and developing economies.
- The difference of factors influencing wind power path creation in the stages in path creation.

The controlling variables for the regression models are shown in Table 7.

Table 7 Controlling variables, the measurement unit and their data sources.

Variable	Description	How to measure	Sources, years and countries
Installed capacity	Different levels of installed capacity are used to control the dependent variable	Installed capacity of wind power in MW, for categories see 5.2	(International Renewable Energy Agency, 2015) 2000-2014, 117 countries (International Renewable Energy Agency, 2020) 2010-2019, 150 countries
Emerging, developing or advanced economies	To understand if different country classifications have an influence on factors influencing the wind diffusion	IMF category of different countries	(International Monetary Fund, 2018), 39 advanced economies, 158 developing and emerging economies
Wind potential in country	Only countries with high wind potential are included		(Lu, McElroy and Kiviluoma, 2009) (Jung, Schindler and Laible, 2018), 68 high wind countries

6 Ethical and practical considerations

6.1 Ethical considerations

This study is not using a subjective intermediate to retrieve the data. No surveys or interviews will be used. Hence personal data and related ethical considerations are not relevant.

However, since the author has a strict positivist view on life, it is relevant to realize that not everyone shares this view. Especially when using the research outcome in a business context, being aware of philosophical difference will help to increase the impact.

This research is subsidized by the employer of the author. This has a risk of introducing a bias in favour of wind power diffusion or a bias to use the developed knowledge make the wind industry more successful. Also, when publishing, commercial confidential information must be excluded.

6.2 Practical considerations

The quality of panel-based regression methods is directly related to the quality and availability of the data. Hence the practical considerations are:

- Data gaps in the panel data (both in years considered as countries included).
- Difficulties of sorting the data because of different names of categories in different databases (e.g. different and changing names of countries).
- Intercorrelated variables.
- Unquantifiable data.

The recommendations of Tabachnick and Fidell (2013) will be applied to deal with missing data. Also, intercorrelation tests will be executed.

7 Conclusion

In many developing countries, wind energy diffusion is lagging compared to advanced economies. The general aim of this study is to understand factors that influence wind energy diffusion differences between emerging and developing economies and advanced economies.

The literature study showed four areas worth of further exploration:

- Explaining differences in wind diffusion between emerging and developing economies and advanced economies using sufficient data.
- Understanding path creation, especially in a quantitative way.
- Measuring the impact of desire related factors on wind energy path creation, not the effectiveness and efficiency of the mechanism of change.
- Describing wind diffusion from a wind energy OEM point of view, not from a policy maker point of view.

Three research questions were defined to address these areas:

- RQ1: How much of the wind energy path creation can be explained by looking at desire related factors only?
- RQ2: What are the differences in desire related factors that influence path creation of wind energy between advanced economies and emerging and developing economies?
- RQ3: What are the differences in desire related factors that influence the different stages of new path creation of wind energy?

The chosen philosophical position was critical rationalism, to fit the quantitative nature of the questions. Binary regression method was chosen as the research method. Based on the literature study, the dependent, independent and controlling variables were selected.

Appendices

Appendix A Factor sub-categories

Table A-1 Factor sub-categories evaluated for desire and grouped.

Factor category	Factor sub-category	Desire	Group
Combination	Loss of control over major industrial inputs & cognitive change about need to control uncertainties & national + EU policy RET goals	Yes	Business case
Combination	Enhancing energy security, creating future oriented industry that provides job opportunities, environmental protection	Yes	Economic contribution, Energy security, Environmental
Combination	Lack of oil resources, anti-nuclear movement, strong environmental movement, Chernobyl, forest die-back (acid rain), emergence of climate change.	Yes	Energy security, Environmental
Combination	Formation of alliances	Yes	Spill over
Combination	Leadership provided by main energy utility	No	
Combination	Misalignment policy support and firm strategy on innovation and knowledge creation	No	
Economic	Comparative price advantage wind energy	Yes	Business case
Economic	Competition resulting in large cost reductions	Yes	Business case
Economic	Construction costs	Yes	Business case
Economic	Electricity price volatility	Yes	Business case
Economic	Investment costs	Yes	Business case
Economic	Investors need for revenue growth	Yes	Business case
Economic	Lack of financial resources	Yes	Business case
Economic	Levelized cost of wind electricity	Yes	Business case
Economic	Net present value of wind energy project	Yes	Business case
Economic	Price of electricity	Yes	Business case
Economic	Steel price	Yes	Business case
Economic	Diversification of electricity production	Yes	Energy security
Economic	Electricity intensity (economic efficiency)	Yes	Energy security
Economic	GDP	Yes	Energy security
Economic	Market size	Yes	Energy security
Economic	Primary energy intensity	Yes	Energy security
Economic	Economic Integration (Bilateral country pairings)	Yes	Spill over
Economic	International learning spill over	Yes	Spill over
Economic	Non-core country (being a follower country)	Yes	Spill over
Economic	Negative path interdependence with the dynamics of established paths	Yes	Vested interests
Economic	Vested Interests: Increasing leverage vested interests	Yes	Vested interests
Economic	Vested Interests: weakening vested interests	Yes	Vested interests
Economic	Vested Interests: Wind located outside of the vested interest structure	Yes	Vested interests
Economic	Access to finance, trade openness, investment freedom	No	
Economic	Business Competitiveness Index	No	
Economic	Carbon price	No	
Economic	De-institutionalisation (challenging a fossil fuel-based economy)	No	
Economic	Domestic private debt divided by GDP	No	
Economic	FDI stock	No	
Economic	Firm age	No	
Economic	Gas price	No	
Economic	Insurance assets divided by GDP	No	
Economic	Interest rates	No	
economic	Investor experience	No	
Economic	Involvement of international developers	No	
Economic	Market share of domestic wind turbine manufacturer	No	
Economic	No equilibrium between incentives and contributions	No	
Economic	Poor alignment between technology developers and investors	No	
Economic	Private credit divided by GDP	No	
economic	Raising prices of fuel oil, natural gas and coal due to changes in taxes	No	

Economic	Share price of local indices	No	
Economic	Strength of multilateral development banks	No	
Economic	Unattractive loan conditions	No	
Economic	Unstable macroeconomic environment	No	
Economic	Developing vs Advanced economies	Controlling variable	
Economic	GDP per capita	Controlling variable	
Environmental	Solar intensity	Yes	Energy security
Environmental	Sunshine hours	Yes	Energy security
Environmental	Climate change	Yes	Environmental
Environmental	CO2 emission	Yes	Environmental
Environmental	Environmental benefits of wind energy	Yes	Environmental
Political	Globalization: political participation	Yes	Spill over
Political	Armed conflict	No	
Political	Complexity of administrative procedures	No	
Political	Corruption	No	
Political	Dual strategy of political lobbying and end user campaigning	No	
Political	Existence of a system builder	No	
Political	Inter-ministry coordination	No	
Political	Lead time of administrative procedure	No	
Political	Political uncertainty	No	
Political	Predictability of public authorities	No	
Political	Pro-wind interest advocate for strongly support feed-in-tariff	No	
Political	Rule of law	No	
Political	Simple administrative process	No	
Political	Utilities lobby to shape regulatory environment in favour of wind	No	
Regulatory	Building permits: delay in issuance	No	
Regulatory	Clean Development Mechanism	No	
Regulatory	Codes and standards	No	
Regulatory	Economic support	No	
Regulatory	Feed-In-Tariff / Premium	No	
Regulatory	Feed-in-Tariff / Premium: change in FIT / P	No	
Regulatory	Feed-in-Tariff / Premium: incl. tradable green certificate	No	
Regulatory	Feed-In-Tariff / Premium: long term FIT / P	No	
Regulatory	Feed-in-Tariff / Premium: price driven policies, not capacity driven policies	No	
Regulatory	Financial support from European Union (cohesion policy)	No	
Regulatory	Fossil fuel subsidy	No	
Regulatory	Funds to sub-national governments	No	
Regulatory	Grants and subsidies	No	
Regulatory	Grid: favourable grid access regulations	No	
Regulatory	Grid: lack of priority grid access	No	
Regulatory	Grid: plans	No	
Regulatory	Grid: policy to reduce grid and transmission risk	No	
Regulatory	Installation subsidies	No	
Regulatory	Kyoto ratification	No	
Regulatory	Land-use: lack of integrated special planning	No	
Regulatory	Land-use: regulations	No	
Regulatory	Loans	No	
Regulatory	Mandatory requirements by government, other than codes & standards / obligation schemes for energy	No	
Regulatory	Mandatory requirements by government: obligation scheme	No	
Regulatory	Mandatory requirements by government: obligations for utility to purchase power	No	
Regulatory	Market Based Instruments	No	
Regulatory	Obligation scheme	No	
Regulatory	Peak regulations power stations	No	
Regulatory	Policy package: coherent catch-up strategy by the government	No	
Regulatory	Policy package: lack of policy coherence in support for key resource formation process	No	
Regulatory	Policy package: matching policy initiatives, sectoral goals and macro policy	No	

Regulatory	Policy package: mostly long-term focus, predictable, broad portfolio combining supply and demand-side measures from the start, periods of no predictability	No	
Regulatory	Policy package: policy to stimulate utilities in direction of hybridization	No	
Regulatory	Policy package: public-private partnerships stimulating policies	No	
Regulatory	Policy package: short-term focus, unpredictable, stop-go, no demand side measures	No	
Regulatory	Policy package: State support niche technology in response to energy security concerns	No	
Regulatory	Policy package: support programs for technology deployment and diffusion	No	
Regulatory	Policy support	No	
Regulatory	Policy to improve financing availability	No	
Regulatory	Policy to improve resource and technology availability	No	
Regulatory	Policy to reduce counterparty risk	No	
Regulatory	Policy to reduce power market risk	No	
Regulatory	Policy to reduce project implementation risk	No	
Regulatory	Policy to support financial returns	No	
Regulatory	Policy uncertainty	No	
Regulatory	Power Purchase Agreement: delay in definition	No	
Regulatory	Procurement rules	No	
Regulatory	Regulatory support	No	
Regulatory	Subsidies to renewable energy and emission trading scheme to fossil-fuels	No	
Regulatory	Support scheme change: major change	No	
Regulatory	Support scheme change: minor change	No	
Regulatory	Targets: renewable energy targets	No	
Regulatory	Targets: wind energy targets	No	
Regulatory	Tax relief	No	
Regulatory	Taxes	No	
Regulatory	Voluntary approaches	No	
Regulatory	Wind power plans	No	
Social	Environmental awareness	Yes	Education
Social	Unequal access to education	Yes	Education
Social	ArCo tech index (patents, diffusion, human capital) (Archibugi and Coco 2004)	No	
Social	Financial institutions unfamiliarity with renewable energy tech information and education related to energy use or emission performance	No	
Social	Misinformation of local communities, regarding RES benefits	No	
Social	Pioneering inventors and innovators	No	
social	Willingness of consulting and insurance companies to work with wind industry	No	
Social	Interest in wind technology	Controlling variable	
Social	Lack of investor interest from public sector	Controlling variable	
Social	Local opposition to the construction of wind farms	Controlling variable	
Social	Preference for thermal and hydro power	Controlling variable	
Technical potential	Coal consumption	Yes	Energy security
Technical potential	Electricity consumption	Yes	Energy security
Technical potential	Electricity consumption intensity (index)	Yes	Energy security
Technical potential	Electricity security	Yes	Energy security
Technical potential	Energy consumption	Yes	Energy security
Technical potential	Seasonal variation in wind speeds	Yes	Energy security
Technical potential	Share of hydro power in electricity generation	Yes	Energy security

Technical potential	Share of nuclear power in electricity generation	Yes	Energy security
Technical potential	Solar PV installed capacity	Yes	Energy security
Technical potential	Total energy import dependency	Yes	Energy security
Technical potential	Share of gas energy in electricity generation	No	
Technical potential	Annual added wind power generation (market share indicator)	Dependent variable	
Technical potential	Share of wind energy in electricity generation	Dependent variable	
Technical potential	Wind resource	Controlling variable	
Technological	Knowledge spill overs combined with local absorptive capacity	Yes	Spill over
Technological	Construction quality control	No	
Technological	Country wind technology capacity	No	
Technological	Grid connection technology	No	
Technological	Grid stability	No	
Technological	Infrastructure investments	No	
Technological	Knowledge stock (patent count)	No	
Technological	Lack of transmission network infrastructure	No	
Technological	Limited experience in wind farm development	No	
Technological	Operation & maintenance	No	
Technological	Process quality control	No	
Technological	R&D: government run R&D in wind power	No	
Technological	R&D: grants	No	
Technological	Relevant competences	No	
Technological	Wind resource survey	No	
Technological	Wind turbine technology	No	

References

- Bass, F. M. (1969) 'A New Product Growth for Model Consumer Durables', *Management Science*, 15(5), pp. 215–227. doi: 10.1287/mnsc.15.5.215.
- Bento, N. and Fontes, M. (2016) 'The capacity for adopting energy innovations in Portugal: historical evidence and perspectives for the future', *Technological Forecasting and Social Change*. Elsevier Inc., 113, pp. 308–318. doi: 10.1016/j.techfore.2015.09.003.
- Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008) 'Analyzing the functional dynamics of technological innovation systems: a scheme of analysis', *Research Policy*, 37(3), pp. 407–429. doi: <https://doi.org/10.1016/j.respol.2007.12.003>.
- Bertrand, M. and Mullainathan, S. (2001) 'Do people mean what they say? Implications for subjective survey data', *American Economic Review*, 91(2), pp. 67–72. doi: 10.1257/aer.91.2.67.
- Blaikie, N. (2007) 'Approaches to social enquiry: Advancing knowledge (2nd edition)', *Contemporary Sociology*. doi: 10.2307/2076918.
- Can Şener, Ş. E., Sharp, J. L. and Anctil, A. (2018) 'Factors impacting diverging paths of renewable energy: A review', *Renewable and Sustainable Energy Reviews*, 81(March 2017), pp. 2335–2342. doi: 10.1016/j.rser.2017.06.042.
- Cherp, A., Vinichenko, V., Jewell, J., Suzuki, M. and Antal, M. (2017) 'Comparing electricity transitions: a historical analysis of nuclear, wind and solar power in Germany and Japan', *Energy Policy*. Elsevier, 101(May 2016), pp. 612–628. doi: 10.1016/j.enpol.2016.10.044.
- Craig, R. (2019) *Suzlon joins Enercon and Senvion on OEM crisis list*, *Wind Power Monthly*. Available at: <https://www.windpowermonthly.com/article/1665921/suzlon-joins-enercon-senvion-oem-crisis-list> (Accessed: 5 December 2020).
- Davies, S. W. (1979) *The diffusion of process innovations*. Cambridge, UK:

Cambridge University Press.

Dreher, A. (2006) 'Does globalization affect growth? Evidence from a new index of globalization', *Applied Economics*, 38(10), pp. 1091–1110. doi: 10.1080/00036840500392078.

Edmondson, A. C. and Mcmanus, S. E. (2007) 'Methodological fit in management field research', *Academy of Management Review*, 32(4), pp. 1246–1264. doi: 10.5465/amr.2007.26586086.

ETH (2020) *KOF Globalisation Index*. Available at: <https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html> (Accessed: 20 March 2020).

Fitch Solutions (2020) *Fitch Connect*. Available at: <https://app.fitchconnect.com/> (Accessed: 10 April 2020).

Geels, F. W. (2002) 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study', *Research Policy*, 31(8), pp. 1257–1274. doi: [https://doi.org/10.1016/S0048-7333\(02\)00062-8](https://doi.org/10.1016/S0048-7333(02)00062-8).

Global Petrol Prices (2020) *Electricity prices*. Available at: https://www.globalpetrolprices.com/electricity_prices/ (Accessed: 12 December 2020).

Goffin, K. and Lemke, F. (2004) 'Uncovering your customer's hidden needs', *European Business Forum*, 18 summer, pp. 45–47.

Griliches, Z. (1957) 'Hybrid corn: an exploration in the economics of technological change', *Econometrica*. doi: 10.2307/1905380.

Hartmann, P. and Apaolaza-Ibáñez, V. (2012) 'Consumer attitude and purchase intention toward green energy brands: The roles of psychological benefits and environmental concern', *Journal of Business Research*. Elsevier Inc., 65(9), pp. 1254–1263. doi: 10.1016/j.jbusres.2011.11.001.

Hartmann, P., Eisend, M., Apaolaza, V. and D'Souza, C. (2017) 'Warm glow vs. altruistic values: How important is intrinsic emotional reward in proenvironmental

behavior?', *Journal of Environmental Psychology*. Elsevier Ltd, 52, pp. 43–55. doi: 10.1016/j.jenvp.2017.05.006.

Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S. and Smits, R. E. H. M. (2007) 'Functions of innovation systems: a new approach for analysing technological change', *Technological Forecasting and Social Change*, 74(4), pp. 413–432. doi: <https://doi.org/10.1016/j.techfore.2006.03.002>.

Hübner, A. and Martin, M. (2019) *German wind turbine maker Senvion files for insolvency*, *Reuters*. Available at: <https://www.reuters.com/article/us-germany-senvion/german-wind-turbine-maker-senvion-files-for-insolvency-idUSKCN1RL271> (Accessed: 5 December 2020).

International Energy Agency (2019a) *Headline global energy data*. Available at: https://iea.blob.core.windows.net/assets/fffa1b7d-b0c5-4e64-86aa-5c9421832d73/IEA_HeadlineEnergyData.xlsx (Accessed: 20 March 2020).

International Energy Agency (2019b) *World Energy Investment 2019*. Paris. Available at: <https://www.iea.org/wei2019>.

International Energy Agency (2019c) *World energy prices*. Available at: www.iea.org (Accessed: 10 April 2020).

International Monetary Fund (2018) *World Economic Outlook - Database - WEO Groups and Aggregates Information*. Available at: <https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/groups.htm> (Accessed: 5 November 2018).

International Monetary Fund (2019) *Economic Activity, Industrial Production, Manufacturing, Index*. Available at: <https://data.imf.org/> (Accessed: 20 March 2020).

International Renewable Energy Agency (2015) *Renewable Capacity Statistics 2015*. Abu Dhabi. doi: 10.1016/j.renene.2014.09.059.

International Renewable Energy Agency (2018) *Renewable capacity statistics 2018*. Abu Dhabi: International Renewable Energy Agency (IRENA). doi:

10.1016/S2255-4971(15)30126-9.

International Renewable Energy Agency (2019a) *Renewable capacity statistics 2019*. Abu Dhabi. Available at: <https://www.irena.org/publications/2019/Mar/Renewable-Capacity-Statistics-2019>.

International Renewable Energy Agency (2019b) *Renewable Power Generation Costs in 2018*, International Renewable Energy Agency. Abu Dhabi. doi: 10.1007/SpringerReference_7300.

International Renewable Energy Agency (2020) *Renewable capacity statistics 2020*. Abu Dhabi. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_RE_Capacity_Statistics_2020.pdf.

Jacobsson, S. and Bergek, A. (2004) 'Transforming the energy sector: the evolution of technological systems in renewable energy technology', *Industrial and Corporate Change*, 13(5), pp. 815–849. doi: 10.1093/icc/dth032.

Jacobsson, S. and Lauber, V. (2006) 'The politics and policy of energy system transformation - explaining the German diffusion of renewable energy technology', *Energy Policy*, 34(3), pp. 256–276. doi: 10.1016/j.enpol.2004.08.029.

Jung, C., Schindler, D. and Laible, J. (2018) 'National and global wind resource assessment under six wind turbine installation scenarios', *Energy Conversion and Management*. doi: 10.1016/j.enconman.2017.11.059.

Kern, F., Verhees, B., Raven, R. and Smith, A. (2015) 'Empowering sustainable niches: comparing UK and Dutch offshore wind developments', *Technological Forecasting and Social Change*. Elsevier Inc., 100, pp. 344–355. doi: 10.1016/j.techfore.2015.08.004.

Knight, S. (2019) *Enercon braced for change following dramatic German collapse*, *Wind Power Monthly*. Available at: <https://www.windpowermonthly.com/article/1581941/enercon-braced-change->

following-dramatic-german-collapse (Accessed: 5 December 2020).

Kutner, M., Nachtsheim, C., Neter, J. and Li, W. (2005) *Applied linear statistical models*. 5th edn. New York: McGraw-Hill/Irwin.

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J. and Moher, D. (2009) 'The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration', *Journal of clinical epidemiology*, 62(10), pp. e1–e34. doi: 10.1016/j.jclinepi.2009.06.006.

Liu, Y. (2015) 'CDM and national policy: Synergy or conflict? Evidence from the wind power sector in China', *Climate Policy*, 15(6), pp. 767–783. doi: 10.1080/14693062.2014.968764.

Lu, X., McElroy, M. B. and Kiviluoma, J. (2009) 'Global potential for wind-generated electricity', *Proceedings of the National Academy of Sciences*. doi: 10.1073/pnas.0904101106.

Meyer, N. I. (2007) 'Learning from wind energy policy in the EU: Lessons from Denmark, Sweden, and Spain', *European Environment*, 17(5), pp. 347–362. doi: 10.1002/eet.463.

Nelson, R. and Winter, S. (1982) *An evolutionary theory of economic change*. London: Belknap Press of Harvard University.

OECD (2018a) *Adult education level*. Available at: <https://data.oecd.org/eduatt/adult-education-level.htm> (Accessed: 20 March 2020).

OECD (2018b) *Exposure to PM_{2.5} in countries and regions*. Available at: <https://stats.oecd.org/> (Accessed: 20 March 2020).

Passport (2020) *Euromonitor*. Available at: <https://www.portal.euromonitor.com/portal/magazine/homemain> (Accessed: 10 April 2020).

Peña, I., Azevedo, I. and Marcelino Ferreira, L. A. F. (2017) 'Lessons from wind policy in Portugal', *Energy Policy*. Elsevier, 103(January), pp. 193–202. doi: 10.1016/j.enpol.2016.11.033.

Phillips, F. (2007) 'On S-curves and tipping points', *Technological Forecasting and Social Change*, 74(6), pp. 715–730. doi: <https://doi.org/10.1016/j.techfore.2006.11.006>.

Popp, D., Hascic, I. and Medhi, N. (2011) 'Technology and the diffusion of renewable energy', *Energy Economics*. Elsevier B.V., 33(4), pp. 648–662. doi: 10.1016/j.eneco.2010.08.007.

del Río, P. and Tarancón, M. A. (2012) 'Analysing the determinants of on-shore wind capacity additions in the EU: An econometric study', *Applied Energy*. Elsevier Ltd, 95, pp. 12–21. doi: 10.1016/j.apenergy.2012.01.043.

Rogers, E. M. (2003) *Diffusion of innovations*. New York: Fifth Edition Free Press.

Scotland, J. (2012) 'Exploring the Philosophical Underpinnings of Research: Relating Ontology and Epistemology to the Methodology and Methods of the Scientific, Interpretive, and Critical Research Paradigms', *English Language Teaching*, 5(9). doi: 10.5539/elt.v5n9p9.

Simmie, J., Sternberg, R. and Carpenter, J. (2014) 'New technological path creation: evidence from the British and German wind energy industries', *Journal of Evolutionary Economics*, 24(4), pp. 875–904. doi: 10.1007/s00191-014-0354-8.

Statistica (2015) *Global LCOE projection by key country 2015-2020 Published by Statista Research Department, Feb 27, 2015 The levelized cost of electricity (LCOE) varies around the world and was about 23 U.S. cents in 2015 in the United Kingdom, compared to 10 cents in Ind.* Available at: www.statistica.com (Accessed: 10 April 2020).

Steen, M. and Hansen, G. H. (2018) 'Barriers to path creation: the case of offshore wind power in Norway', *Economic Geography*, 94(2), pp. 188–210. doi: 10.1080/00130095.2017.1416953.

Surana, K. and Anadon, L. D. (2015) 'Public policy and financial resource mobilization for wind energy in developing countries: a comparison of approaches and outcomes in China and India', *Global Environmental Change*. Elsevier Ltd, 35, pp. 340–359. doi: 10.1016/j.gloenvcha.2015.10.001.

Tabachnick, B. G. and Fidell, L. S. (2013) *Using multivariate statistics*. 6th edn. Harlow: Pearson Education Ltd.

The World Bank (2014) *Industrialization intensity index*. Available at: https://tcdata360.worldbank.org/indicators/mva.ind.int?country=BRA&indicator=3793&viz=line_chart&years=1990,2014 (Accessed: 20 March 2020).

The World Bank (2019a) *Electricity production from hydroelectric sources (% of total)*. Available at: <https://data.worldbank.org/indicator/EG.ELC.HYRO.ZS> (Accessed: 20 March 2020).

The World Bank (2019b) *Electricity production from nuclear sources (% of total)*. Available at: <https://data.worldbank.org/indicator/EG.ELC.NUCL.ZS> (Accessed: 20 March 2020).

The World Bank (2019c) *Electricity production from oil, gas and coal sources (% of total)*. Available at: <https://data.worldbank.org/indicator/EG.ELC.FOSL.ZS> (Accessed: 20 March 2020).

The World Bank (2019d) *Energy imports, net (% of energy use)*. Available at: <https://data.worldbank.org/indicator/EG.IMP.CON.S.ZS> (Accessed: 6 October 2020).

The World Bank (2019e) *Energy use (kg of oil equivalent per capita)*. Available at: <https://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE> (Accessed: 20 March 2020).

The World Bank (2019f) *PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)*. Available at: <https://data.worldbank.org/indicator/EN.ATM.PM25.MC.M3> (Accessed: 1 October 2020).

The World Bank (2019g) *Unemployment, total (% of total labor force)*. Available at: <https://data.worldbank.org/indicator/SL.UEM.TOTL.ZS> (Accessed: 20 March 2020).

The World Bank (2020) *CO2 emissions (metric tons per capita)*. Available at: <https://data.worldbank.org/indicator/EN.ATM.CO2E.PC> (Accessed: 17 July 2020).

UCLA (2021a) *How do I interpret odds ratios in logistic regression?*, *Statistical Consulting Group*. Available at: <https://stats.idre.ucla.edu/other/mult-pkg/faq/general/faq-how-do-i-interpret-odds-ratios-in-logistic-regression/> (Accessed: 12 May 2021).

UCLA (2021b) *Probit regression*, *Statistical Consulting Group*. Available at: <https://stats.oarc.ucla.edu/stata/output/probit-regression/#:~:text=A positive coefficient means that,decrease in the predicted probability.> (Accessed: 1 April 2022).

UNDP (2013) *Education index*. Available at: <http://hdr.undp.org/en/content/education-index> (Accessed: 20 March 2020).

United Nations (2018) *Sustainable Development Goal 7*. Available at: <https://sustainabledevelopment.un.org/sdg7> (Accessed: 26 October 2018).

United Nations (2020a) *Electricity, net installed capacity of electric power plants*. Available at: <http://data.un.org/Data.aspx?d=EDATA&f=cmID%3AEC> (Accessed: 20 March 2020).

United Nations (2020b) *Greenhouse Gas (GHGs) Emissions, including Indirect CO2, without LULUCF, in kilotonne CO2 equivalent*. Available at: <http://data.un.org/Data.aspx?q=Emissions+&d=GHG&f=seriesID%3AGH2> (Accessed: 20 March 2020).

United Nations (2020c) *Hydro, UNdata*. Available at: <http://data.un.org/Data.aspx?q=hydro&d=EDATA&f=cmID:EH%0A> (Accessed: 17 July 2020).

United Nations (2020d) *Nuclear Electricity*. Available at: <http://data.un.org/Data.aspx?q=Electricity&d=EDATA&f=cmID%3AEN> (Accessed: 20 March 2020).

United Nations (2020e) *Solar Electricity*. Available at: <http://data.un.org/Data.aspx?q=Electricity&d=EDATA&f=cmID%3AES> (Accessed: 17 July 2020).

United Nations (2020f) *Thermal Electricity*. Available at: <http://data.un.org/Data.aspx?q=Electricity&d=EDATA&f=cmID%3AET> (Accessed: 20 March 2020).

United Nations (2020g) *Total Electricity, UNdata*. Available at: <http://data.un.org/Data.aspx?q=Total+Electricity+&d=EDATA&f=cmID%3AEL> (Accessed: 7 October 2020).

Verbeek, M. (2004) *A guide to modern econometrics*. 2nd edn. West Sussex: John Wiley & Sons, Ltd.

van der Vleuten, E. and Raven, R. (2006) 'Lock-in and change: Distributed generation in Denmark in a long-term perspective', *Energy Policy*, 34(18), pp. 3739–3748. doi: 10.1016/j.enpol.2005.08.016.

Wijayatunga, P. D. C., Siriwardena, K., Fernando, W. J. L. S., Shrestha, R. M. and Attalage, R. A. (2006) 'Strategies to overcome barriers for cleaner generation technologies in small developing power systems: Sri Lanka case study', *Energy Conversion and Management*, 47(9–10), pp. 1179–1191. doi: 10.1016/j.enconman.2005.07.003.

Wiser, R., Seel, J. and Paulos, B. (2016) *Are we understating the potential for (and uncertainty in) wind energy cost reductions ?*, *Electricity Markets & Policy Group, Berkeley Lab*.

Ydersbond, I. M. and Korsnes, M. S. (2016) 'What drives investment in wind energy? A comparative study of China and the European Union', *Energy Research and Social Science*. Elsevier Ltd, 12, pp. 50–61. doi: 10.1016/j.erss.2015.11.003.

Zwarteveen, J. W., Figueira, C., Zawwar, I. and Angus, A. (2021) 'Barriers and drivers of the global imbalance of wind energy diffusion: A meta-analysis from a wind power Original Equipment Manufacturer perspective', *Journal of Cleaner Production*, 290, p. 125636. doi: 10.1016/j.jclepro.2020.125636.

5 EMPIRICAL STUDY

“While technology is important, it’s what we do with it that truly matters”

--- Muhammad Yunus

The empirical study was published in 2021 in the Business Strategy and Development journal.

The co-authors had a purely supervisory role.

The last submitted version of the published paper is shown in this section,

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Zwarteveen, J. W., Zawwar, I. and Angus, A. (2021) ‘Market entry for wind energy: Strategic approaches for the original equipment manufacturer’, Business Strategy & Development. doi: 10.1002/bsd2.188.

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

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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 and 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, Zwarteven 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 (Tan, 2013; Curran, Lv and Spigarelli, 2017; Keeley and Matsumoto, 2018) and increasing access to clean and affordable energy, which is Sustainable Development Goal (SDG) number 7 (United Nations, 2015)). Through interlinked effects (Mantlana and 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 and 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 (Mulder, 2008; del Río and Tarancón, 2012) and qualitative studies (Moe, 2012; Zhao, Chang and Chen, 2016) have used this measurement. Zwarteven 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 and Carpenter, 2014)(Simmie, Sternberg and Carpenter, 2014). Compared to wind energy growth, far less is known about wind energy path creation. Factors influencing path creation are regulatory (Bento and Fontes, 2015), the business case (Wijayatunga *et al.*, 2006; Inoue and Miyazaki, 2008), the environment (Jacobsson and Lauber, 2006), education (Bento and Fontes, 2015), spillover (Bento and Fontes, 2016; Steffen *et al.*, 2018), vested interests (Espinoza and Vredenburg, 2010; Steen and Hansen, 2018) and energy security (Cherp *et al.*, 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 (Zwarteven *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 and Mcmanus, 2007).

Wind energy diffusion is also a multi-stakeholder process. Previous studies have considered the perspective of actors related to wind energy: policymakers (Mulder, 2008; Friebe, Von Flotow and Täube, 2014; Nordensvärd and Urban, 2015) energy planners (Ioannou *et al.*, 2019), financiers and investors (Keeley and Ikeda, 2017; Steffen, 2018, 2020), developers (Lüthi and Prässler, 2011;

Steffen *et al.*, 2018) and utilities (Wijayatunga *et al.*, 2006; Shah, Palacios and Ruiz, 2013). Another notable gap in the literature is that, given the importance of wind technology in the process of path creation (Popp, Hascic and 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 and 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 and 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 and 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 (Blanford, 2009; Arent, Wise and Gelman, 2011; Baudry and Bonnet, 2019).

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), Zwarteven 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 and Rutherford, 2009), or more pragmatically, a combination of both (Newell, Jaffe and Stavins, 2006). Global adoption and diffusion of technology have been frequently modelled using epidemic S-curves (Griliches, 1957; Bass, 1969; Davies, 1979). However, path creation is generally described through a multi-level approach (Geels, 2002), based on evolutionary economics (Schumpeter, 1934; Nelson and Winter, 1982). 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 *et al.*, 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, legitimization, entrepreneurial experimentation, and development of external economies. Sustainable Innovation Systems (SIS), is the sustainable application of TIS (Zartha Sossa, López Montoya and Acosta Prado, 2021). SIS follows the same functions as TIS but places sustainability in the centre.

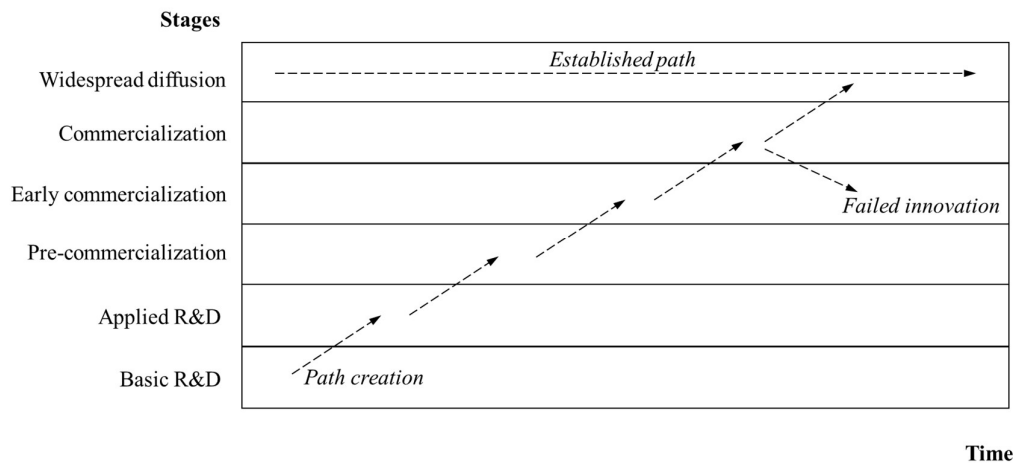


Figure 1 Paths and stages in path creation. Based on (Geels, 2002; Surana and Anadon, 2015; Polzin, 2017).

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 and 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, (van der Vleuten and Raven, 2006; Inoue and Miyazaki, 2008; Bento and Fontes, 2015), there is only limited mixed methods and quantitative research (for example, (Halleck-Vega and Mandel, 2018; Steen and 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 and 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 *et al.*, 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 ($\mathbf{x}_i$).

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

Following the concept of Zwartveen 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 (van der Vleuten and Raven, 2006; Inoue and Miyazaki, 2008; Ericsson, Nilsson and Nilsson, 2011). 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.

Table 1 Stages in wind diffusion path creation.

Stage	Total installed capacity in China and India [MW] (Surana and 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

Warm glow, the psychological reward from pro-social behaviour, is an important driver of pro-environment behaviour (Hartmann and Apaolaza-Ibáñez, 2012; Hartmann *et al.*, 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 and 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, (Mulder, 2008; Shrimali and Kniefel, 2011; Polzin *et al.*, 2015; Sisodia and Soares, 2015; Best and Burke, 2018)), 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 and 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) β_j .

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

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 p_j for **PCSP = 1** for a change in variable $x_{i,j}$ follows equation 3 (UCLA, 2021).

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

The marginal effect can be calculated consequently. One unit change of $x_{i,j}$ results in $\exp(\beta_j)$ 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 and Filippini, 2010; Ruokamo *et al.*, 2019), McFadden's pseudo-R squared (McFadden, 1974) (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)**):

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

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.

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 <i>et al.</i> , 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)

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 and 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. 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.

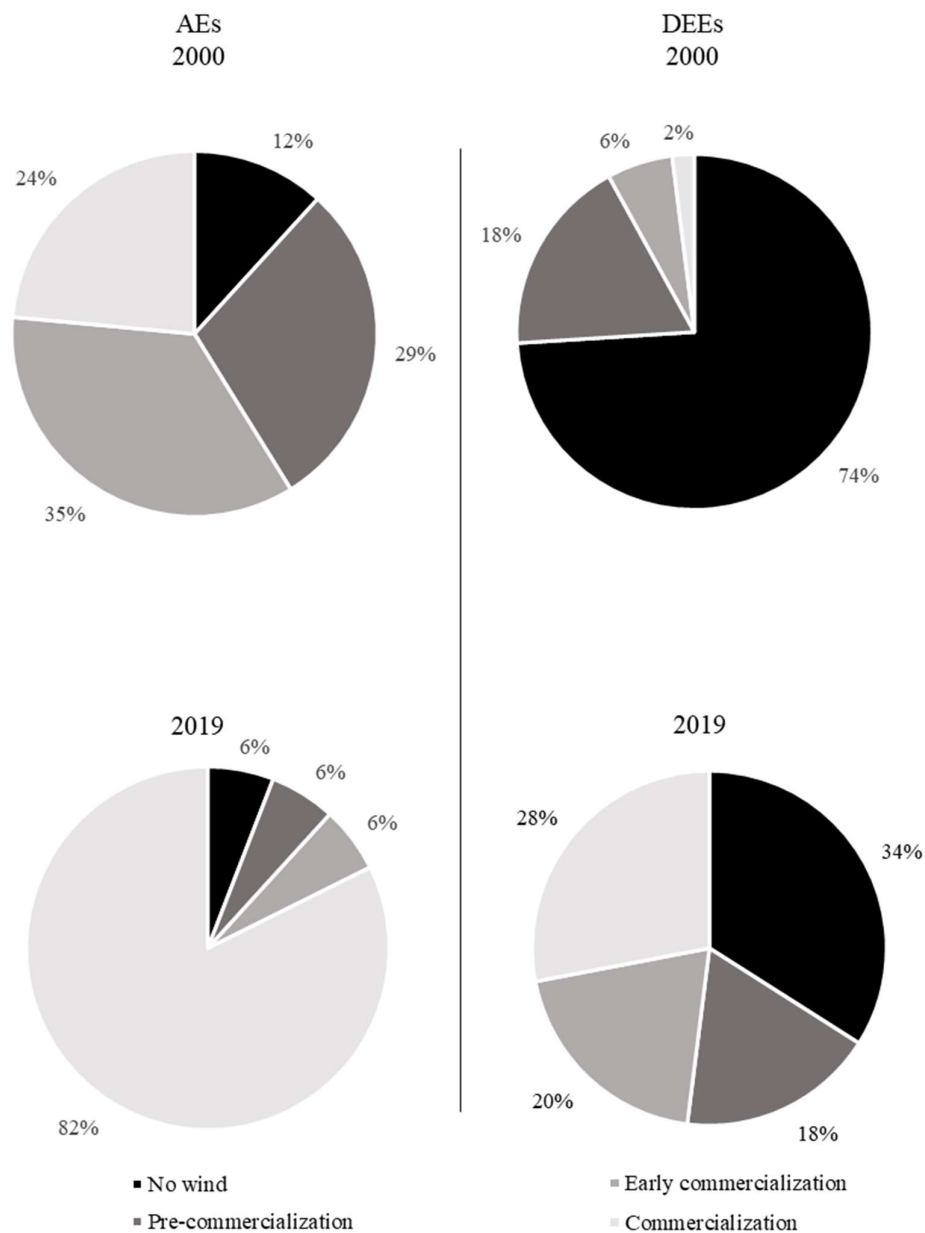


Figure 2 Path creation status anno 2000 and 2019, expressed as a share of the total number of AEs and DEEs.

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.

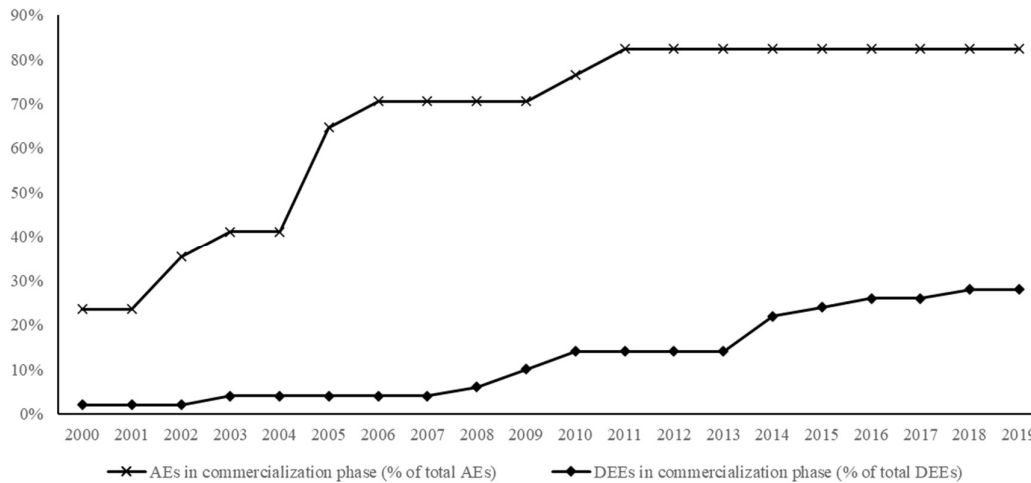


Figure 3 Commercial stage development over the years, expressed as share of the total number of AEs and DEEs.

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 and 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.

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

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 ($\text{Prob} > \chi^2 = 0.000$). Also, the choice for a binary panel model is justified ($\text{Prob} > \chi^2 = 0.000$). 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 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 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 and 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.

Table 8 Qualitative and quantitative research results comparison.

Theme	Qualitative and mixed methods research (‡ = mixed methods)		Quantitative research (¶ = this study)	
	Driver	Barrier	Driver	Barrier
Business case	High and volatile electricity price (Ericsson, Nilsson and Nilsson, 2011)	Disequilibrium between incentives and contributions (Inoue and Miyazaki, 2008)	Positive business case potential ¶	High LCoE (Wijayatunga <i>et al.</i> , 2006) Negative business case potential ¶
Economic contribution	Export potential, job creation (Jacobsson and Lauber, 2006)		Unemployment rate ¶	
Education	Available competences for wind energy (Bento and Fontes, 2015)		Education index ¶	
Energy security	Security of supply (Jacobsson and Lauber, 2006) Energy security concerns (Cherp <i>et al.</i> , 2017)		Electricity import ¶ Energy import ¶	Energy import ¶
Environment	Forest die-back, climate change prevention (Jacobsson and Lauber, 2006)		Smog ¶	GHG ¶
Spill over	First wind project coming from international private developer (Steffen <i>et al.</i> , 2018)‡		Neighbour influence Globalization index ¶	
Vested interests	De-institutionalization of fossil fuel sector, dependence on only Hydropower (Espinoza and Vredenburg, 2010)	Strong fossil fuel sectors (Espinoza and Vredenburg, 2010) Negative path interdependence with dynamics of established paths (hydro lock-in) (Steen and 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 <i>et al.</i> , 2018)‡ Solving energy crisis is based on socio-economic issues, environment important yet secondary (Espinoza and 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 <i>et al.</i> , 2006)	

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 and 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 and Vredenburg, 2010). The benefits of wind are that it provides decentralized electricity, is water-independent (for more about water-energy nexus (Teotónio *et al.*, 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 and Johnson, 2019). Moreover, human-caused GHG emissions are not the only factors influencing climate change (Cohen and 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.

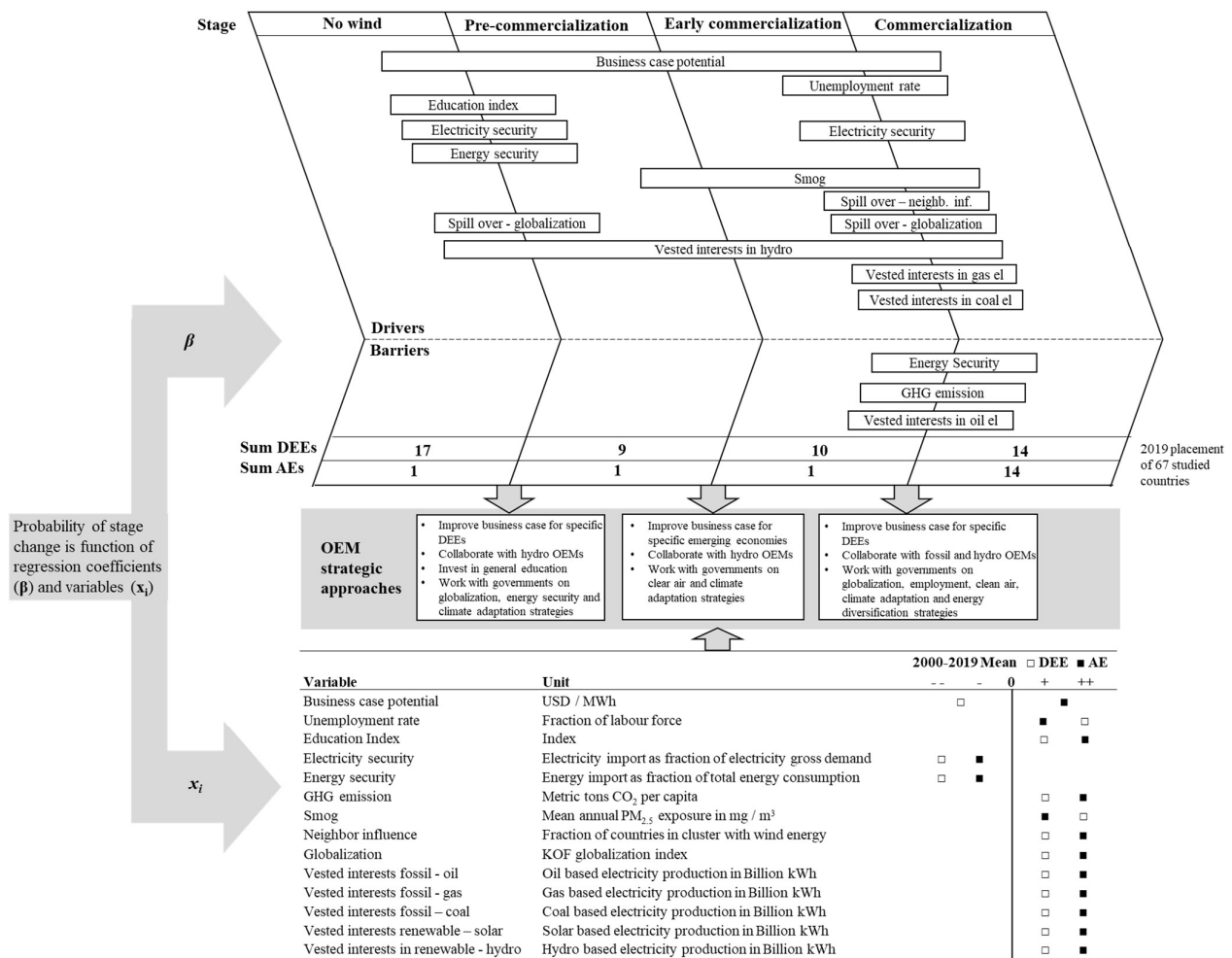
4.4.2 Wind power OEM strategy implications

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 *et al.*, 2018; Chen *et al.*, 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.

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.



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, López Montoya and Acosta Prado, 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 and Kutcherov, 2021) or South Africa (Leigland and 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 quantitatively: 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 and Dastidar, 2021)). The question is to which level exploitation of wind energy is desirable (Tabassum-Abbasi *et al.*, 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, López Montoya and Acosta Prado, 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.

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

References

- Apergis, N., Mustafa, G. and Dastidar, S. G. (2021) 'An analysis of the impact of unconventional oil and gas activities on public health: New evidence across Oklahoma counties', *Energy Economics*, 97, p. 105223. doi: 10.1016/j.eneco.2021.105223.
- Arent, D. J., Wise, A. and Gelman, R. (2011) 'The status and prospects of renewable energy for combating global warming', *Energy Economics*, 33(4), pp. 584–593. doi: 10.1016/j.eneco.2010.11.003.
- Arnold, M. G. (2018) 'Sustainability value creation in frugal contexts to foster Sustainable Development Goals', *Business Strategy & Development*, 1(4), pp. 265–275. doi: 10.1002/bsd2.36.
- Barasa, M., Bogdanov, D., Oyewo, A. S. and Breyer, C. (2018) 'A cost optimal resolution for Sub-Saharan Africa powered by 100% renewables in 2030', *Renewable and Sustainable Energy Reviews*, 92, pp. 440–457. doi: 10.1016/j.rser.2018.04.110.
- Barradale, M. J. (2010) 'Impact of public policy uncertainty on renewable energy investment: wind power and the production tax credit', *Energy Policy*. Elsevier, 38(12), pp. 7698–7709. doi: 10.1016/j.enpol.2010.08.021.
- Bass, F. M. (1969) 'A New Product Growth for Model Consumer Durables', *Management Science*, 15(5), pp. 215–227. doi: 10.1287/mnsc.15.5.215.
- Baudry, M. and Bonnet, C. (2019) 'Demand-pull instruments and the development of wind power in Europe: a counterfactual analysis', *Environmental and Resource Economics*. Springer Netherlands, 73(2), pp. 385–429. doi: 10.1007/s10640-018-0267-3.
- Bento, N. and Fontes, M. (2015) 'The construction of a new technological innovation system in a follower country: wind energy in Portugal', *Technological Forecasting and Social Change*. Elsevier B.V., 99, pp. 197–210. doi: 10.1016/j.techfore.2015.06.037.
- Bento, N. and Fontes, M. (2016) 'The capacity for adopting energy innovations in

Portugal: historical evidence and perspectives for the future', *Technological Forecasting and Social Change*. Elsevier Inc., 113, pp. 308–318. doi: 10.1016/j.techfore.2015.09.003.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008) 'Analyzing the functional dynamics of technological innovation systems: a scheme of analysis', *Research Policy*, 37(3), pp. 407–429. doi: <https://doi.org/10.1016/j.respol.2007.12.003>.

Best, R. and Burke, P. J. (2018) 'Adoption of solar and wind energy: the roles of carbon pricing and aggregate policy support', *Energy Policy*. Elsevier Ltd, 118(April), pp. 404–417. doi: 10.1016/j.enpol.2018.03.050.

Blaikie, N. (2007) 'Approaches to social enquiry: Advancing knowledge (2nd edition)', *Contemporary Sociology*. doi: 10.2307/2076918.

Blanford, G. J. (2009) 'R&D investment strategy for climate change', *Energy Economics*, 31, pp. S27–S36. doi: 10.1016/j.eneco.2008.03.010.

Böhringer, C., Mennel, T. P. and Rutherford, T. F. (2009) 'Technological change and uncertainty in environmental economics', *Energy Economics*, 31, pp. S1–S3. doi: 10.1016/j.eneco.2009.05.006.

Bowerman, B. L. and O'Connell, R. (1990) *Linear Statistical Models: An Applied Approach*. Boston: PWS-Kent Publishing Company.

Brunel, C. and Johnson, E. P. (2019) 'Two birds, one stone? Local pollution regulation and greenhouse gas emissions', *Energy Economics*, 78, pp. 1–12. doi: 10.1016/j.eneco.2018.10.011.

Chappin, E. J. L. and Van der Lei, T. (2014) 'Adaptation of interconnected infrastructures to climate change: A socio-technical systems perspective', *Utilities Policy*, 31, pp. 10–17. doi: 10.1016/j.jup.2014.07.003.

Chen, X., McElroy, M. B., Wu, Q., Shu, Y. and Xue, Y. (2019) 'Transition towards higher penetration of renewables: an overview of interlinked technical, environmental and socio-economic challenges', *Journal of Modern Power Systems and Clean Energy*, 7(1), pp. 1–8. doi: 10.1007/s40565-018-0438-9.

- Cherp, A., Vinichenko, V., Jewell, J., Suzuki, M. and Antal, M. (2017) 'Comparing electricity transitions: a historical analysis of nuclear, wind and solar power in Germany and Japan', *Energy Policy*. Elsevier, 101(May 2016), pp. 612–628. doi: 10.1016/j.enpol.2016.10.044.
- Ciscar, J.-C. and Dowling, P. (2014) 'Integrated assessment of climate impacts and adaptation in the energy sector', *Energy Economics*, 46, pp. 531–538. doi: 10.1016/j.eneco.2014.07.003.
- Cohen, S. and Stanhill, G. (2021) 'Changes in the Sun's radiation', in *Climate Change*. Elsevier, pp. 687–709. doi: 10.1016/B978-0-12-821575-3.00032-3.
- Curran, L., Lv, P. and Spigarelli, F. (2017) 'Chinese investment in the EU renewable energy sector: Motives, synergies and policy implications', *Energy Policy*. Elsevier, 101, pp. 670–682. doi: 10.1016/j.enpol.2016.09.018.
- Damert, M. and Baumgartner, R. J. (2018) 'Intra-Sectoral Differences in Climate Change Strategies: Evidence from the Global Automotive Industry', *Business Strategy and the Environment*, 27(3), pp. 265–281. doi: 10.1002/bse.1968.
- Davies, S. W. (1979) *The diffusion of process innovations*. Cambridge, UK: Cambridge University Press.
- DiBella, J. (2020) 'The spatial representation of business models for climate adaptation: An approach for business model innovation and adaptation strategies in the private sector', *Business Strategy & Development*, 3(2), pp. 245–260. doi: 10.1002/bsd2.92.
- Dorman, L. I. (2021) 'Space weather and cosmic ray effects', in *Climate Change*. Elsevier, pp. 711–768. doi: 10.1016/B978-0-12-821575-3.00033-5.
- Edenhofer, O., Pichs-Madruga, R., Youba, S., Seyboth, K., Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schloemer, S. and Von Stechow, C. (2011) *Renewable energy sources and climate change mitigation*. Cambridge, UK: Cambridge University Press.
- Edmondson, A. C. and Mcmanus, S. E. (2007) 'Methodological fit in management field research', *Academy of Management Review*, 32(4), pp. 1246–1264. doi:

10.5465/amr.2007.26586086.

Ender, P. B. (2010) *STATA programs for data analysis, UCLA Office of Academic Computing, Statistical Computing and Consulting*. Available at: <https://stats.idre.ucla.edu/stata/ado/analysis/> (Accessed: 9 April 2021).

Ericsson, K., Nilsson, L. J. and Nilsson, M. (2011) 'New energy strategies in the Swedish pulp and paper industry-The role of national and EU climate and energy policies', *Energy Policy*. Elsevier, 39(3), pp. 1439–1449. doi: 10.1016/j.enpol.2010.12.016.

Espinoza, J. L. and Vredenburg, H. (2010) 'Towards a model of wind energy industry development in industrial and emerging economies', *Global Business and Economics Review*, 12(3), pp. 203–229. doi: 10.1504/GBER.2010.034894.

Euromonitor International (2020) *Passport, economies and consumers annual data*. Available at: <https://www.portal.euromonitor.com/portal/statisticsevolution/index%0A> (Accessed: 5 February 2021).

Fetz, A. and Filippini, M. (2010) 'Economies of vertical integration in the Swiss electricity sector', *Energy Economics*, 32(6), pp. 1325–1330. doi: 10.1016/j.eneco.2010.06.011.

Friebe, C. A., Von Flotow, P. and Täube, F. A. (2014) 'Exploring technology diffusion in emerging markets - the role of public policy for wind energy', *Energy Policy*. Elsevier, 70, pp. 217–226. doi: 10.1016/j.enpol.2014.03.016.

Geels, F. W. (2002) 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study', *Research Policy*, 31(8), pp. 1257–1274. doi: [https://doi.org/10.1016/S0048-7333\(02\)00062-8](https://doi.org/10.1016/S0048-7333(02)00062-8).

Global Petrol Prices (2020) *Electricity prices*. Available at: https://www.globalpetrolprices.com/electricity_prices/ (Accessed: 12 December 2020).

Goffin, K. and Lemke, F. (2004) 'Uncovering your customer's hidden needs', *European Business Forum*, 18 summer, pp. 45–47.

Griliches, Z. (1957) 'Hybrid corn: an exploration in the economics of technological change', *Econometrica*. doi: 10.2307/1905380.

Gupta, J., Pouw, N. R. M. and Ros-Tonen, M. A. F. (2015) 'Towards an Elaborated Theory of Inclusive Development', *The European Journal of Development Research*, 27(4), pp. 541–559. doi: 10.1057/ejdr.2015.30.

Gygli, S., Haelg, F., Potrafke, N. and Sturm, J.-E. (2019) 'The KOF Globalisation Index – revisited', *The Review of International Organizations*, 14(3), pp. 543–574. doi: 10.1007/s11558-019-09344-2.

Halleck-Vega, S. and Mandel, A. (2018) 'Technology diffusion and climate policy: a network approach and its application to wind energy', *Ecological Economics*, 145(November 2016), pp. 461–471. doi: 10.1016/j.ecolecon.2017.11.023.

Hartmann, P. and Apaolaza-Ibáñez, V. (2012) 'Consumer attitude and purchase intention toward green energy brands: The roles of psychological benefits and environmental concern', *Journal of Business Research*. Elsevier Inc., 65(9), pp. 1254–1263. doi: 10.1016/j.jbusres.2011.11.001.

Hartmann, P., Eisend, M., Apaolaza, V. and D'Souza, C. (2017) 'Warm glow vs. altruistic values: How important is intrinsic emotional reward in proenvironmental behavior?', *Journal of Environmental Psychology*. Elsevier Ltd, 52, pp. 43–55. doi: 10.1016/j.jenvp.2017.05.006.

Hausman, J. A. (1978) 'Specification Tests in Econometrics', *Econometrica*, 46(6), p. 1251. doi: 10.2307/1913827.

Haywood, J. (2021) 'Atmospheric aerosols and their role in climate change', in *Climate Change*. Elsevier, pp. 645–659. doi: 10.1016/B978-0-12-821575-3.00030-X.

Henze, V. (2020) *Vestas Still Rules Turbine Market, But Challengers Are Closing In*, *Bloomberg New Energy Finance*. Available at: <https://about.bnef.com/blog/vestas-still-rules-turbine-market-but-challengers-are-closing-in/> (Accessed: 16 June 2021).

Henze, V. (2021) *Energy Transition Investment Hit \$500 Billion in 2020 – For First*

Time, *Bloomberg New Energy Finance*. London and New York. Available at: <https://about.bnef.com/blog/energy-transition-investment-hit-500-billion-in-2020-for-first-time> (Accessed: 28 April 2021).

Inoue, Y. and Miyazaki, K. (2008) 'Technological innovation and diffusion of wind power in Japan', *Technological Forecasting and Social Change*, 75(8), pp. 1303–1323. doi: 10.1016/j.techfore.2008.01.001.

International Monetary Fund (2018) *World Economic Outlook - Database - WEO Groups and Aggregates Information*. Available at: <https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/groups.htm> (Accessed: 5 November 2018).

International Renewable Energy Agency (2019) *Renewable Power Generation Costs in 2018*, *International Renewable Energy Agency*. Abu Dhabi. doi: 10.1007/SpringerReference_7300.

International Renewable Energy Agency (2020a) *Renewable electricity capacity and generation statistics, July 2020*. Available at: <https://www.irena.org/Statistics/Download-Data> (Accessed: 7 August 2020).

International Renewable Energy Agency (2020b) *Renewable Power Generation Costs in 2019*, *Irena*. Abu Dhabi. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf.

Ioannou, A., Fuzuli, G., Brennan, F., Yudha, S. W. and Angus, A. (2019) 'Multi-stage stochastic optimization framework for power generation system planning integrating hybrid uncertainty modelling', *Energy Economics*, 80, pp. 760–776. doi: 10.1016/j.eneco.2019.02.013.

Jaber, S. (2014) 'Environmental Impacts of Wind Energy', *Journal of Clean Energy Technologies*, pp. 251–254. doi: 10.7763/JOCET.2013.V1.57.

Jacobsson, S. and Lauber, V. (2006) 'The politics and policy of energy system transformation - explaining the German diffusion of renewable energy technology', *Energy Policy*, 34(3), pp. 256–276. doi: 10.1016/j.enpol.2004.08.029.

- Keeley, A. R. and Ikeda, Y. (2017) 'Determinants of foreign direct investment in wind energy in developing countries', *Journal of Cleaner Production*. Elsevier, 161, pp. 1451–1458. doi: 10.1016/J.JCLEPRO.2017.05.106.
- Keeley, A. R. and Matsumoto, K. (2018) 'Relative significance of determinants of foreign direct investment in wind and solar energy in developing countries – AHP analysis', *Energy Policy*, 123, pp. 337–348. doi: 10.1016/j.enpol.2018.08.055.
- Khan, S. J., Kaur, P., Jabeen, F. and Dhir, A. (2021) 'Green process innovation: Where we are and where we are going', *Business Strategy and the Environment*, p. bse.2802. doi: 10.1002/bse.2802.
- Kudelin, A. and Kutcherov, V. (2021) 'Wind Energy in Russia: The current state and development trends', *Energy Strategy Reviews*, 34, p. 100627. doi: 10.1016/j.esr.2021.100627.
- Kumar, S., Sureka, R., Lim, W. M., Kumar Mangla, S. and Goyal, N. (2021) 'What do we know about business strategy and environmental research? Insights from Business Strategy and the Environment', *Business Strategy and the Environment*, p. bse.2813. doi: 10.1002/bse.2813.
- Lacal-Arántegui, R. (2019) 'Globalization in the wind energy industry: contribution and economic impact of European companies', *Renewable Energy*, 134, pp. 612–628. doi: 10.1016/j.renene.2018.10.087.
- Leigland, J. and Eberhard, A. (2018) 'Localisation barriers to trade: The case of South Africa's renewable energy independent power program', *Development Southern Africa*, 35(4), pp. 569–588. doi: 10.1080/0376835X.2018.1487829.
- Lourens, L. J. (2021) 'The variation of the Earth's movements (orbital, tilt, and precession) and climate change', in *Climate Change*. Elsevier, pp. 583–606. doi: 10.1016/B978-0-12-821575-3.00028-1.
- Lüthi, S. and Prässler, T. (2011) 'Analyzing policy support instruments and regulatory risk factors for wind energy deployment-A developers' perspective', *Energy Policy*, 39(9), pp. 4876–4892. doi: 10.1016/j.enpol.2011.06.029.
- Mantlana, K. B. and Maoela, M. A. (2020) 'Mapping the interlinkages between

sustainable development goal 9 and other sustainable development goals: A preliminary exploration', *Business Strategy & Development*, 3(3), pp. 344–355. doi: 10.1002/bsd2.100.

Mauree, D., Naboni, E., Coccolo, S., Perera, A. T. D., Nik, V. M. and Scartezzini, J.-L. (2019) 'A review of assessment methods for the urban environment and its energy sustainability to guarantee climate adaptation of future cities', *Renewable and Sustainable Energy Reviews*, 112, pp. 733–746. doi: 10.1016/j.rser.2019.06.005.

McFadden, D. (1974) 'Conditional logit analysis of qualitative choice behavior', in Zarembka, *Frontiers in econometrics*. New York: Academic Press, pp. 104–142.

Moe, E. (2012) 'Vested interests, energy efficiency and renewables in Japan', *Energy Policy*. Elsevier, 40(1), pp. 260–273. doi: 10.1016/j.enpol.2011.09.070.

Mulder, A. (2008) 'Do economic instruments matter? Wind turbine investments in the EU(15)', *Energy Economics*, 30(6), pp. 2980–2991. doi: 10.1016/j.eneco.2008.02.005.

Nelson, R. and Winter, S. (1982) *An evolutionary theory of economic change*. London: Belknap Press of Harvard University.

Newell, R. G., Jaffe, A. B. and Stavins, R. N. (2006) 'The effects of economic and policy incentives on carbon mitigation technologies', *Energy Economics*, 28(5–6), pp. 563–578. doi: 10.1016/j.eneco.2006.07.004.

Nordensvärd, J. and Urban, F. (2015) 'The stuttering energy transition in Germany: wind energy policy and feed-in tariff lock-in', *Energy Policy*. Elsevier, 82(1), pp. 156–165. doi: 10.1016/j.enpol.2015.03.009.

Ostrom, E. (2010) 'Polycentric systems for coping with collective action and global environmental change', *Global Environmental Change*, 20(4), pp. 550–557. doi: 10.1016/j.gloenvcha.2010.07.004.

Pansera, M. and Sarkar, S. (2016) 'Crafting Sustainable Development Solutions: Frugal Innovations of Grassroots Entrepreneurs', *Sustainability*, 8(1), p. 51. doi: 10.3390/su8010051.

Polzin, F. (2017) 'Mobilizing private finance for low-carbon innovation – A systematic review of barriers and solutions', *Renewable and Sustainable Energy Reviews*. doi: 10.1016/j.rser.2017.04.007.

Polzin, F., Migendt, M., Täube, F. A. and von Flotow, P. (2015) 'Public policy influence on renewable energy investments-A panel data study across OECD countries', *Energy Policy*, 80(June), pp. 98–111. doi: 10.1016/j.enpol.2015.01.026.

Popp, D., Hascic, I. and Medhi, N. (2011) 'Technology and the diffusion of renewable energy', *Energy Economics*. Elsevier B.V., 33(4), pp. 648–662. doi: 10.1016/j.eneco.2010.08.007.

Redman, A. (2018) 'Harnessing the Sustainable Development Goals for businesses: A progressive framework for action', *Business Strategy & Development*, 1(4), pp. 230–243. doi: 10.1002/bsd2.33.

del Río, P. and Tarancón, M. A. (2012) 'Analysing the determinants of on-shore wind capacity additions in the EU: An econometric study', *Applied Energy*. Elsevier Ltd, 95, pp. 12–21. doi: 10.1016/j.apenergy.2012.01.043.

Ruokamo, E., Kopsakangas-Savolainen, M., Meriläinen, T. and Svento, R. (2019) 'Towards flexible energy demand – Preferences for dynamic contracts, services and emissions reductions', *Energy Economics*, 84, p. 104522. doi: 10.1016/j.eneco.2019.104522.

Schumpeter, J. A. (1934) *The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle*. Cambridge, MA: Harvard University Press.

Shah, A. N., Palacios, M. and Ruiz, F. (2013) 'Strategic rigidity and foresight for technology adoption among electric utilities', *Energy Policy*, 63, pp. 1233–1239. doi: 10.1016/j.enpol.2013.08.013.

Shrimali, G. and Kniefel, J. (2011) 'Are government policies effective in promoting deployment of renewable electricity resources?', *Energy Policy*. Elsevier, 39(9), pp. 4726–4741. doi: 10.1016/j.enpol.2011.06.055.

- Simmie, J., Sternberg, R. and Carpenter, J. (2014) 'New technological path creation: evidence from the British and German wind energy industries', *Journal of Evolutionary Economics*, 24(4), pp. 875–904. doi: 10.1007/s00191-014-0354-8.
- Sisodia, G. S. and Soares, I. (2015) 'Panel data analysis for renewable energy investment determinants in Europe', *Applied Economics Letters*, 22(5), pp. 397–401. doi: 10.1080/13504851.2014.946176.
- Sorrell, S. (2018) 'Explaining sociotechnical transitions: A critical realist perspective', *Research Policy*, 47(7), pp. 1267–1282. doi: 10.1016/j.respol.2018.04.008.
- StataCorp (2019) *Stata 16 Base Reference Manual*. Texas: Stata Press.
- Steen, M. and Hansen, G. H. (2018) 'Barriers to path creation: the case of offshore wind power in Norway', *Economic Geography*, 94(2), pp. 188–210. doi: 10.1080/00130095.2017.1416953.
- Steffen, B. (2018) 'The importance of project finance for renewable energy projects', *Energy Economics*, 69, pp. 280–294. doi: 10.1016/j.eneco.2017.11.006.
- Steffen, B. (2020) 'Estimating the cost of capital for renewable energy projects', *Energy Economics*, 88, p. 104783. doi: 10.1016/j.eneco.2020.104783.
- Steffen, B., Matsuo, T., Steinemann, D. and Schmidt, T. S. (2018) 'Opening new markets for clean energy: the role of project developers in the global diffusion of renewable energy technologies', *Business and Politics*, pp. 1–35. doi: 10.1017/bap.2018.17.
- Stehly, T. and Beiter, P. (2019) *2018 cost of wind energy review*. Golden, CO. Available at: <https://www.nrel.gov/docs/fy20osti/74598.pdf>.
- Stenchikov, G. (2021) 'The role of volcanic activity in climate and global changes', in *Climate Change*. Elsevier, pp. 607–643. doi: 10.1016/B978-0-12-821575-3.00029-3.
- Surana, K. and Anadon, L. D. (2015) 'Public policy and financial resource

mobilization for wind energy in developing countries: a comparison of approaches and outcomes in China and India', *Global Environmental Change*. Elsevier Ltd, 35, pp. 340–359. doi: 10.1016/j.gloenvcha.2015.10.001.

Tabachnick, B. G. and Fidell, L. S. (2013) *Using multivariate statistics*. 6th edn. Harlow: Pearson Education Ltd.

Tabassum-Abbasi, Premalatha, M., Abbasi, T. and Abbasi, S. A. (2014) 'Wind energy: Increasing deployment, rising environmental concerns', *Renewable and Sustainable Energy Reviews*, 31, pp. 270–288. doi: 10.1016/j.rser.2013.11.019.

Tan, X. (2013) 'China's overseas investment in the energy/resources sector: Its scale, drivers, challenges and implications', *Energy Economics*, 36, pp. 750–758. doi: 10.1016/j.eneco.2012.11.019.

Teotónio, C., Rodríguez, M., Roebeling, P. and Fortes, P. (2020) 'Water competition through the "water-energy" nexus: Assessing the economic impacts of climate change in a Mediterranean context', *Energy Economics*, 85, p. 104539. doi: 10.1016/j.eneco.2019.104539.

The World Bank (2019a) *Energy imports, net (% of energy use)*. Available at: <https://data.worldbank.org/indicator/EG.IMP.CON.S.ZS> (Accessed: 6 October 2020).

The World Bank (2019b) *PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)*. Available at: <https://data.worldbank.org/indicator/EN.ATM.PM25.MC.M3> (Accessed: 1 October 2020).

The World Bank (2019c) *Unemployment, total (% of total labor force)*. Available at: <https://data.worldbank.org/indicator/SL.UEM.TOTL.ZS> (Accessed: 20 March 2020).

The World Bank (2020) *CO2 emissions (metric tons per capita)*. Available at: <https://data.worldbank.org/indicator/EN.ATM.CO2E.PC> (Accessed: 17 July 2020).

UCLA (2021) *How do I interpret odds ratios in logistic regression?*, *Statistical*

Consulting Group. Available at: <https://stats.idre.ucla.edu/other/mult-pkg/faq/general/faq-how-do-i-interpret-odds-ratios-in-logistic-regression/> (Accessed: 12 May 2021).

UN News (2021) *Renewable energy access key to climate adaptation in Africa: UN chief, Climate and environment*. Available at: <https://news.un.org/en/story/2021/04/1089122> (Accessed: 13 April 2021).

United Nations (2015) *Transforming our world: the 2030 agenda for sustainable development, A/RES/70/1*. Available at: https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E (Accessed: 28 April 2021).

United Nations (2020a) *Country Savings Assessments, United for Efficiency*. Available at: <https://united4efficiency.org/countries/country-assessments/> (Accessed: 12 December 2020).

United Nations (2020b) *Education Index, United Nations development programme, human development reports*. Available at: <http://hdr.undp.org/en/indicators/103706> (Accessed: 12 December 2020).

United Nations (2020c) *Hydro, UNdata*. Available at: <http://data.un.org/Data.aspx?q=hydro&d=EDATA&f=cmID:EH%0A> (Accessed: 17 July 2020).

United Nations (2020d) *Solar Electricity*. Available at: <http://data.un.org/Data.aspx?q=Electricity&d=EDATA&f=cmID%3AES> (Accessed: 17 July 2020).

United Nations (2020e) *Thermal Electricity*. Available at: <http://data.un.org/Data.aspx?q=Electricity&d=EDATA&f=cmID%3AET> (Accessed: 20 March 2020).

United Nations (2020f) *Total Electricity, UNdata*. Available at: <http://data.un.org/Data.aspx?q=Total+Electricity+&d=EDATA&f=cmID%3AEL> (Accessed: 7 October 2020).

United States Environmental Protection Agency (2010) *Estimating Particulate*

Matter Emissions for eGRID. Available at: https://www.epa.gov/sites/production/files/2020-07/documents/draft_egrid_pm_white_paper_7-20-20.pdf (Accessed: 28 April 2021).

Verbeek, M. (2004) *A guide to modern econometrics*. 2nd edn. West Sussex: John Wiley & Sons, Ltd.

van der Vleuten, E. and Raven, R. (2006) 'Lock-in and change: Distributed generation in Denmark in a long-term perspective', *Energy Policy*, 34(18), pp. 3739–3748. doi: 10.1016/j.enpol.2005.08.016.

Wijayatunga, P. D. C., Siriwardena, K., Fernando, W. J. L. S., Shrestha, R. M. and Attalage, R. A. (2006) 'Strategies to overcome barriers for cleaner generation technologies in small developing power systems: Sri Lanka case study', *Energy Conversion and Management*, 47(9–10), pp. 1179–1191. doi: 10.1016/j.enconman.2005.07.003.

Wu, C.-F., Woodward, A., Li, Y.-R., Kan, H., Balasubramanian, R., Latif, M. T., Sahani, M., Cheng, T.-J., Chio, C.-P., Taneepanichskul, N., Kim, H., Chan, C.-C., Yi, S.-M., Withers, M. and Samet, J. (2017) 'Regulation of fine particulate matter (PM_{2.5}) in the Pacific Rim: perspectives from the APRU Global Health Program', *Air Quality, Atmosphere & Health*, 10(9), pp. 1039–1049. doi: 10.1007/s11869-017-0492-x.

Yusta, J. M. and Lacal-Arántegui, R. (2020) 'Measuring the internationalization of the wind energy industry', *Renewable Energy*, 157, pp. 593–604. doi: 10.1016/j.renene.2020.05.053.

Zartha Sossa, J. W., López Montoya, O. H. and Acosta Prado, J. C. (2021) 'Determinants of a sustainable innovation system', *Business Strategy and the Environment*, 30(2), pp. 1345–1356. doi: 10.1002/bse.2689.

Zhao, Z.-Y., Chang, R.-D. and Chen, Y.-L. (2016) 'What hinder the further development of wind power in China?—A socio-technical barrier study', *Energy Policy*. Elsevier Ltd, 88, pp. 465–476. doi: 10.1016/j.enpol.2015.11.004.

Zwarteveen, J. W., Figueira, C., Zawwar, I. and Angus, A. (2021) 'Barriers and drivers of the global imbalance of wind energy diffusion: A meta-analysis from a wind power Original Equipment Manufacturer perspective', *Journal of Cleaner Production*, 290, p. 125636. doi: 10.1016/j.jclepro.2020.125636.

6 SIMULATION STUDY

*“Life is an unfoldment, and the further we travel the more we can comprehend.
To understand the things that are at our door is the best preparation for
understanding those that lie beyond”*

--- Hypatia (Greek philosopher 350-420 AD)

The simulation study has been accepted for publication in Cleaner Production Letters. The co-author had a purely supervisory role. The last submitted version of the paper is shown in this section. Copyright © 2022 Elsevier Ltd. All rights reserved. Author rights allow content to be included in a thesis or dissertation (provided this is not published commercially).

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Abstract

There is significant under-utilization of wind energy resources, particularly in countries that have high wind potential. From the 67 highest wind potential countries, 39 have installed less than 500 MW of wind power capacity, while the remaining countries have an average installed capacity of 20596 MW. In the lagging countries, there is significant potential for sustainable value creation, however large investment gaps need to be closed. Entering a new market for wind power Original Equipment Manufacturers is complex and requires a prediction of the future market size. Quantitative research to promote wind power internationalization is scarce. The objective of this paper is therefore to estimate the market size by predicting the probability of commercial wind development in the lagging countries. The purpose is to help the Original Equipment Manufacturers in their market entry decisions. The second purpose is to provide an example how to reduce risk required to close the Sustainable Development Goals financing gap. Using a binary logistic regression model based on technological path creation theory, the probability for the 39 lagging countries to enter the wind power commercialization stage was predicted. Results show that 12 of the lagging countries have a high probability to commercialize wind energy. A new simulation-based approach was presented to stimulate wind power market entry. The prediction of adoption probability proves useful to reduce risk required to close the financing gap to achieve the Sustainable Development Goals.

Keywords: Market Entry Strategy, Original Equipment Manufacturer, SDG, Financing Gap, Wind Energy

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1. Introduction

Renewable energy resources are more equally distributed globally compared to fossil and nuclear resources (UNDP, 2000). There are many countries with significant wind resources, however large shares of this capacity remain unexploited. From the 67 highest wind potential countries defined by Zwarteveen et al. (Zwarteveen *et al.*, 2021; Zwarteveen, Zawwar and Angus, 2021), 39 have less than 500 MW wind power installed and, the remaining 28 countries have an average installed wind energy of 20596 MW (International Renewable Energy Agency, 2020a). The technical potential in these high wind countries is ≥ 1 PWh/yr (Lu, McElroy and Kiviluoma, 2009), which represents a generating capacity of on average ≥ 114000 MW, or ≥ 380000 MW of installed wind power with an assumed capacity factor of 0.3. It shows that specifically the 39 lagging countries have significant unused potential compared to the 28 frontrunners and that it is not the technical capacity that is limiting them from installing more wind energy. Of the 39 lagging countries, 36 are developing and emerging markets (as defined by the International Monetary Fund (2018)). In the net zero carbon strategy of the International Energy Agency (2021) wind energy is expected to grow 11 fold until 2050 with the majority of growth in emerging markets. This illustrates the importance and potential of sustainable development in the emerging world.

Successful triple bottom line post-pandemic recovery requires evidence-based economic analysis and initiatives to strengthen the local economy (Ranjbari *et al.*, 2021). Increasing wind energy could support the targeted recovery: the job creation per 1 million USD spend under a stimulus program was 2.6 times higher for wind energy compared to oil and gas (Bacon and Kojima, 2011). Local job creation is one of the socioeconomic benefits wind energy brought to Europe (Ortega-Izquierdo and Río, 2020) and it is essential for sustainable development in emerging markets (Arnold, 2018). Increasing the wind power generation capacity in the lagging countries also contributes to achieving Sustainable Development Goal (SDG) 7, which is to ensure global access to affordable, reliable, sustainable, and modern

energy (United Nations, 2018). Attracting significant financial resources is essential to achieve the SDGs (Barua and Chiesa, 2019). The private sector has an important role to achieve the power-related SDGs, yet a large investment gap exists (UNCTAD, 2014). Barua (2020) highlights a less engaged private sector as a high priority and critical challenge to close the investment gap and proposes to create attractive risk-return business models as a solution to promote private investment. The wind power Original Equipment Manufacturers (OEMs) that are the most successful in internationalization, measured in total abroad sales and number of countries covered (Yusta and Lacal-Arántegui, 2020), also suffer from high pressure on their margins resulting in recent profit warnings (Binnie, Steitz and Hübner, 2021; Thomas and Sanderson, 2021). Even though domestic environmental regulations in leading countries resulted for the local wind industry in global competitive advantages (Kuik, Branger and Quirion, 2019), still, prudent market entry strategies are required to capture the global benefits. A reliable estimation of a future risk-return is needed before expansion decisions can be taken. However, unavailability of reliable data is another challenge regarding the gap in financing the SDGs (Barua, 2020). Generating data that can be used by wind power OEMs to estimate future risk-return of their market entry is essential.

Both advanced and emerging economies have reformed their electricity sector in the last decades (Jamassb, 2006). The main reason for privatization of the sector was to establish clear and stable price determination and incentives that restore financial viability (Newbery, 2004). In the process, the number and type of stakeholders involved with energy technology diffusion changed, providing a more important role for the private sector. Policies have an impact on private investment and vice versa (Cárdenas Rodríguez *et al.*, 2015). Besides policy makers and private investors, wind power OEMs play an important role in wind energy diffusion: without their technology, wind energy can not be exploited. However, a market entry for a wind power OEM is an intricate strategic move. Internationalization into a new market can be done through export, licenses, joint ventures, and fully owned foreign investment

(Buckley and Casson, 1998). Wind turbine technology is a complex export product. Localized production, transport, installation, commissioning, operation, and maintenance of wind turbines require the setup of a local company in each country where turbines are sold. Bidding on foreign wind power project supply tenders would be one market entry method, and Lacal-Arantequi (2019) defines five additional approaches to entering new markets specific to the wind power OEMs: joint ventures, licensing, acquisitions, developing wind projects or (partly) financing the wind projects. Based on the market entry of the automotive industry Sivakumaran et al (2015) define two critical success factors: firstly market barrier-induced costs (country specific related entry costs, such as local content requirements) and secondly sales potential and synergies (estimation of future sales volume and potential cross-market synergies). Regarding wind energy, the barrier induced costs can be estimated up front before taking the market entry decision. However, predicting the sales potential is more difficult. Internationalization into a country without significant installed wind capacity means entering a market without noteworthy competition, which could result in first-mover advantages (Agarwal and Gort, 2001). Being a first-mover can also result in disadvantages, especially because of uncertainties in the market and complex green practices (Luan, Tien and Wu, 2013). If the market does not develop, the first-mover has unnecessarily invested in an expensive local setup. Therefore, market entry is only profitable in the long run if the sustainable returns of the sales exceed the barrier-induced costs. This highlights the critical importance of market forecasting for wind power OEMs.

The market size for wind energy can be described along four stages of path creation: pre-commercialization, early commercialization, commercialization, and widespread diffusion (Surana and Anadon, 2015). The objective of this paper is to estimate the market size by predicting the probability of entering commercial wind exploitation for the lagging countries in wind adoption. The purpose is to help OEMs in their market entry decisions. More broadly, the second purpose is to provide an example how to reduce risk required to close the financing gap to achieve the Sustainable

Development Goals. This study uses a dataset created by Zwarteven et al (2021) with the aim to predict the probability of the 39 lagging high wind capacity countries entering the commercialization stage. With today's and future's predicted probability, OEMs can have greater certainty when devising their market entry and market development strategy.

2. Method

Path creation theory explains how a nascent technology comes about, especially relevant in the early stages of diffusion. Paths and stages form the basis of the theory (Geels, 2002; Surana and Anadon, 2015). Alternatively, wind power diffusion can also be measured as 'wind power growth', often used to determine factors influencing the total installed wind capacity measured in MW (e.g. (Popp, Hascic and Medhi, 2011)). Because of the very low amount of wind energy installed in the 39 lagging countries, path creation can help to increase understanding how wind energy can evolve from the niches. Applying path creation theory to nascent wind power diffusion, Zwarteveen et al (2021) created binary logistic regression models to quantitatively model the transition between the stages. The first (*M1*) to model the transition from no wind to pre-commercialization (>1-50 MW installed wind power), the second (*M2*) to model the transition to early commercialization (>50 MW-500 MW installed wind power), and the third (*M3*) to model the transition to commercialization (>500 MW installed wind power). The accumulated wind power installation (International Renewable Energy Agency, 2020b) was transformed into binary the categories for each model. Based on a Systems Control inspired closed loop feedback mechanism, technology diffusion can be described along the 'desire for wind energy' (*why* is a country interested in wind energy), the 'mechanism of change' (*how* does wind diffusion take place) and 'disturbing factors' (such as war) (Zwarteveen *et al.*, 2021). Pioneering wind energy projects are frequently developed without supporting deployment policies (Steffen *et al.*, 2018), hence the focus on the mechanism of change might not bring significant insight in early stages of wind diffusion. Therefore, the research variables of Zwarteveen et al (2021) were chosen to be related to the desire for wind energy (*why* is a country interested in wind energy) as this is particularly relevant in the first stages of path creation. The logic is that a mechanism of change will autonomously follow once the desire of change exists.

The purpose of this paper is to identify commercial opportunities in the lagging countries. Firstly, the binary logistic regression formula for the transition to the

commercialization stage (*M3*) was simplified to predict the probability of commercialization. The model only took desire-related factors that influence wind energy diffusion into account, as this is argued to be the main driver for early path creation. Variables related to the mechanism of change – such as policies and grid connection – were not included. By using backward elimination (Heinze and Dunkler, 2017), non-significant variables were removed until only significant variables remained. This step reduced the original 15 explanatory variables from model *M3* (Zwarteveen, Zawwar and Angus, 2021) to 9, listed in Table 1. Backward elimination excluded 6 of the 15 variables to their non-significance: the education index, electricity import dependency, energy import dependency, vested interests in oil-based electricity production, vested interests in solar energy production and the country classification (advanced economies or developing and emerging economies). The regression results of the simplified model are shown in Table 2. Binary logistic regression is non-linear, hence the regression coefficient (log odd) is not the same as the predicted probability. The size and sign of the coefficient are however related to the size and the sign of the predicted probability. The model fit (measured with the McFadden's pseudo-R squared (McFadden, 1974)) of the original model was 0.7, the simplified also achieved 0.7. This value demonstrates a substantial model fit (Chin, 1998).

Table 1 The variables of the simplified model to predict the transition to commercial wind exploitation, listed with their sources (Source: adapted from (Zwarteveen, Zawwar and Angus, 2021)).

Predictor variables		Explanation	Unit	Reference
Business case	v_4 Business case potential	Price advantage of wind energy compared to electricity price.	USD / MWh	(Euromonitor International, 2020; Global Petrol Prices, 2020; United Nations, 2020a)
		Electricity price – levelized cost of wind energy		(International Renewable Energy Agency, 2019, 2020c)
Economic contribution	v_5 Unemployment rate	Urgency for a country to create jobs, as measured in unemployment rate	Fraction of labour force without work	(The World Bank, 2019b)
Environment	v_9 GHG emission	High CO ₂ levels might influence choice for low CO ₂ energy technology	CO ₂ emissions (metric tons per capita)	(The World Bank, 2020)
	v_{10} Smog	High PM _{2.5} levels might influence choice for low PM _{2.5} energy technology	PM _{2.5} air pollution, mean annual exposure in mg / m ³	(The World Bank, 2019a)
Spill over	v_{11} Neighbor influence	The effect of having neighbors with wind energy. Knowledge and products might spill over across borders.	Fraction of countries in geographical cluster that has adopted wind energy	(International Renewable Energy Agency, 2020b)
	v_{12} Globalization	Global partners with wind energy. Knowledge and products might spill over through globalized network	KOF globalization index, a composite globalization index including economic, social and political dimensions, measured per country	(Gygli <i>et al.</i> , 2019)
Vested interests	v_{14} Fossil - Gas	Existing fossil interests might have impact on wind exploitation	Gas based electricity production in kWh billion	(United Nations, 2020c)
	v_{15} Fossil - Coal	Existing fossil interests might have impact on wind exploitation	Coal based electricity production in kWh billion	(United Nations, 2020c)
	v_{17} Renewable - Hydro	Existing renewable interests might have impact on wind exploitation	Hydro based electricity production in kWh billion	(United Nations, 2020b)

Table 2 The regression results of the simplified model to predict the transition to commercial wind exploitation.

Variables		Log odds (<i>b</i>)
<i>a</i>	Constant	-167.060***
	Business case	
<i>V</i> ₄	Business case potential	0.409***
	Economic contribution	
<i>V</i> ₅	Unemployment rate	106.740***
	Environment	
<i>V</i> ₉	GHG emission	-1.441**
<i>V</i> ₁₀	Smog	0.861***
	Spill over	
<i>V</i> ₁₁	Neighbor influence	38.539***
<i>V</i> ₁₂	Globalization	1.568***
	Vested interests	
<i>V</i> ₁₄	Fossil – Gas	0.148***
<i>V</i> ₁₅	Fossil – Coal	0.020**
<i>V</i> ₁₇	Renewable - Hydro	0.121***
Specifications		Value
	Number of Observations	431
	Number of Groups	36
	LR chi ² (9)	303.71
	Log likelihood	-68.813
	Prob > chi ²	0.000
	/lnsig2u	5.641
	sigma_u	16.783
	Rho	0.988
	LR test of rho=0: chibar ² (01)	127.76
	Prob >= chibar²	0.000
	Hausman	CNA
	McFadden's pseudo-R squared	0.688

* 0.1, ** 0.05, ***0.01 significant levels, CNA = Convergence not achieved for the fixed effect model

The simplified regression model is used to predict the probability for stage transition to commercial wind (P_{CW}) (UCLA, 2021):

$$P_{CW} = \frac{e^{a+b_4v_4+b_5v_5+b_9v_9+b_{10}v_{10}+b_{11}v_{11}+b_{12}v_{12}+b_{14}v_{14}+b_{15}v_{15}+b_{17}v_{17}}}{1+e^{a+b_4v_4+b_5v_5+b_9v_9+b_{10}v_{10}+b_{11}v_{11}+b_{12}v_{12}+b_{14}v_{14}+b_{15}v_{15}+b_{17}v_{17}}} \quad (1)$$

Where a is the constant, b_i the log odd and v_i the value of the explanatory variable with the number i . The set is screened for missing data and only countries with values for all variables in Table 2 are used. In detail, only Greenland was eliminated, as it

did not have a value for 3 of the 9 considered variables. Calculating the probability for stage transition with 3 missing values would result in inaccurate outcomes. Estimating the missing values is one method of solving the missing data, however dropping cases when the missing data sample is rather small is a recommended method according to Tabachnick and Fidell (2013).

As a second step, the lagging countries are clustered according to their probability for stage transition to commercial wind. Binary logistic models predict an outcome of zero or one. A grid-based clustering approach (Gan, Ma and Wu, 2007) followed by the 1.5 Interquartile Range (IQR) rule to determine outliers of the group (Tabachnick and Fidell, 2013) is used to determine high, low, and in-between probabilities.

Lastly, simulations are executed using the prediction model to calculate the probability for future scenarios.

3. Data and results

The 67 high wind potential countries, as defined in the introduction, and their stage in wind development (based on 2019 installation (International Renewable Energy Agency, 2020a)) are shown in Table 3. Regarding the values for the independent variables (as per Table 1) for all lagging countries, see appendix A.

Table 3 High wind potential countries grouped into different stages of commercialization (International Renewable Energy Agency, 2020a).

Stage	Countries (2019 allocation)	
Wind energy: commercialization (>500 MW installed)	Argentina	Morocco
	Australia	Netherlands
	Brazil	New Zealand
	Canada	Norway
	Chile	Pakistan
	China	Poland
	Denmark	South Africa
	Egypt	Spain
	France	Sweden
	Germany	Turkey
	India	Ukraine
	Ireland	United Kingdom
	Japan	United States
	Mexico	Uruguay
Wind energy before commercialization (<500 MW installed)	Afghanistan	Mali
	Algeria	Mauritania
	Angola	Mongolia
	Belarus	Mozambique
	Bolivia	Namibia
	Chad	Niger
	Colombia	Nigeria
	Congo DR	Oman
	Czech Republic	Paraguay
	Eritrea	Russia
	Ethiopia	Saudi Arabia
	Greenland	Somalia
	Iceland	Syria
	Indonesia	Tanzania
	Iran	Tunisia
	Iraq	Turkmenistan
	Kazakhstan	Uzbekistan
	Kenya	Venezuela
	Libya	Zambia
	Madagascar	

The focus is on the 39 countries before commercialization. Using the simplified prediction model, the probability to exceed 500 MW of wind energy is calculated per country. Greenland was removed because of insufficient data. The results are visualized in Figure 1 (further details, including country numbers are located in Appendix B).

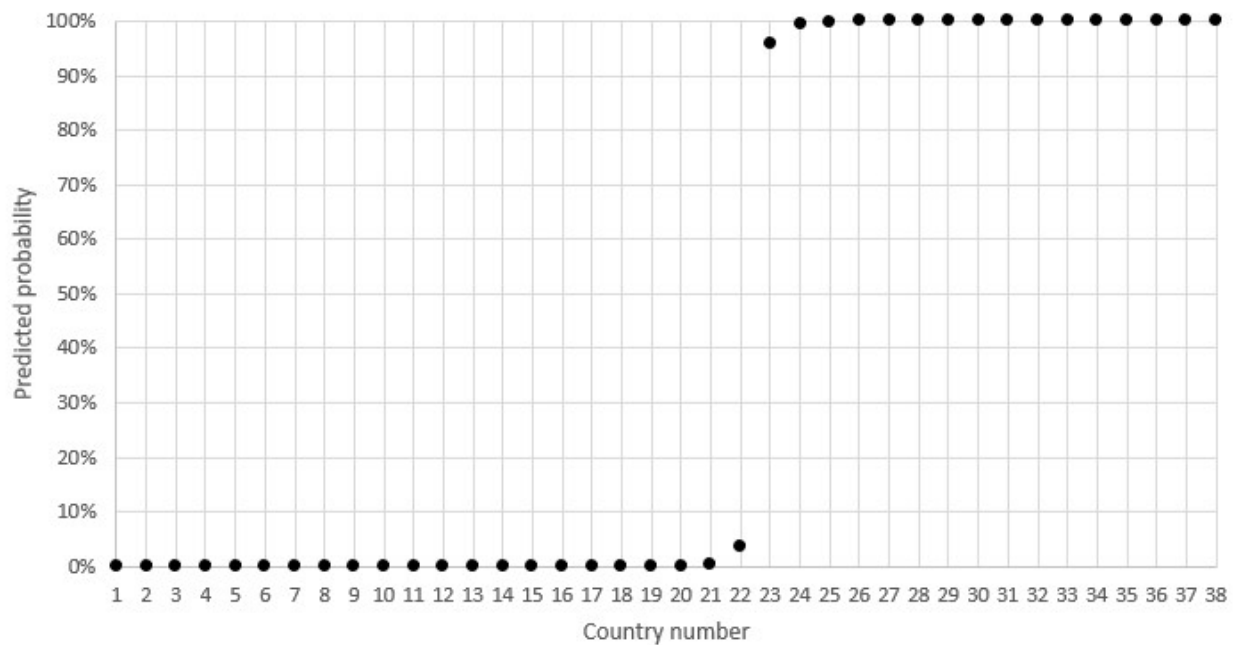


Figure 1 Predicted probability of exceeding 500MW of wind power, visualized per country (country numbers according to Appendix B). Grid based clustering, using steps of 10%, result in 22 countries in the low probability group and 16 countries in the high probability group.

Using grid-based clustering, two rough categories are defined: countries with low probability and countries with high probability (Figure 1). With changing input variables, binary logistic models have output values close to 0 and 1 with a limited tipping phase. Hence, all outliers of both groups are considered to be part of the tipping point group (Table 4). Using the 1.5 IQR method, 9 outliers were identified, 4 from the high probability group and 5 from the low probability group. Two outliers can be visually identified as they are clearly not located on the 0% and 100% line (Figure 1 - country number 22 and 23). The other outliers are closer to the remaining

values (details in Appendix B). This illustrates that only small changes in the values of the explanatory values result in a change from very close to 0% to very close to 100% in predicted probability or vice versa.

Table 4 Outliers of the high and low probability groups determined with the 1.5 IQR method.

Group	Outliers
High probability group	Namibia
	Iceland
	Kenya
	Tunisia
Low probability group	Libya
	Paraguay
	Iran
	Bolivia
	Belarus

The results of both steps in the clustering analysis split all lagging wind adopters into three groups of low, high, and tipping probability to enter full commercial wind (Table 5).

Table 5 Lagging countries and their predicted probability to start wind power commercialization (which is to exceed 500MW of installed capacity).

Low	Tipping point	High
Turkmenistan	Namibia	Indonesia
Angola	Iceland	Eritrea
Ethiopia	Kenya	Nigeria
Kazakhstan	Tunisia	Colombia
Uzbekistan	Libya	Mali
Oman	Paraguay	Saudi Arabia
Syria	Iran	Niger
Venezuela	Bolivia	Chad
Congo DR	Belarus	Somalia
Madagascar		Mauritania
Afghanistan		Russia
Zambia		Czech Republic
Tanzania		
Iraq		
Mongolia		
Mozambique		
Algeria		

4. Discussion

This paper considered 39 high wind potential countries with less than 500 MW wind energy capacity installed. It used a binary prediction model to estimate the probability of breaking this threshold, entering full commercial wind exploitation. After the screening for missing data, 38 countries remained. The 38 countries were split into 3 groups, low, high, and tipping probability. But what are the implications of the distribution of the countries in these groups?

4.1 Low probability

17 countries have a low probability of entering full commercial wind utilization. This is the largest group in Table 5. It contains 8 countries from Africa, 4 from Central Asia, 4 from the Middle East, and 1 from Latin America. It is unlikely that these countries will install wind turbine capacity exceeding 500 MW in the near future. However, some of the countries have already reached the early commercialization stage, for example Ethiopia with 324 MW wind installed in 2019 (International Renewable Energy Agency, 2020a).

4.2 High probability

With 12 countries, the high probability group is the second largest group in Table 5. 7 are from Africa, 2 from Europe, 1 from the Middle East, 1 from Latin America, and 1 from the Indo Pacific region. No country from Central Asia is present in this promising list. The high probability indicates that it is likely that the accumulated installed wind capacity will soon exceed the 500 MW. Signs can already be witnessed, examples are the 1,000 MW signed wind projects in Russia (Lee, 2021), the finalized tender of 400 MW in Saudi Arabia and the plans for a second tender (Aguinaldo, 2020), and the plans to build multiple wind farms exceeding 500 MW in combined capacity in Colombia (Azzopardi, 2021). However, the prediction model has a model fit of 0.7, meaning the chosen explanatory variables only explain 70% of the variation in the dependent variable. There are other factors explaining the remaining 30% in variation of the dependent variable. Some countries in the high

probability list have not installed any wind power yet. As proposed by Zwarteveen et al (2021), it is likely that the ‘mechanism of change’ (e.g. grid availability and feed in tariff policies) and ‘disturbing factors’ (such as war) also influence the probability for significant wind growth.

4.3 Tipping probability

The countries with tipping probability form with a count of 9 the smallest group in Table 5. Depending on how the values of the variables of Table A-1 (Appendix A) change, these countries can quickly develop into either low or high probability countries. Within the group, Iran is the country with the largest population, an indication of total energy demand (Yoo and Lee, 2010) and total environmental impact (Chertow, 2000). To understand the sensitivity, simulation of Iran’s probability to exceed 500 MW of wind energy is shown in Figure 2.

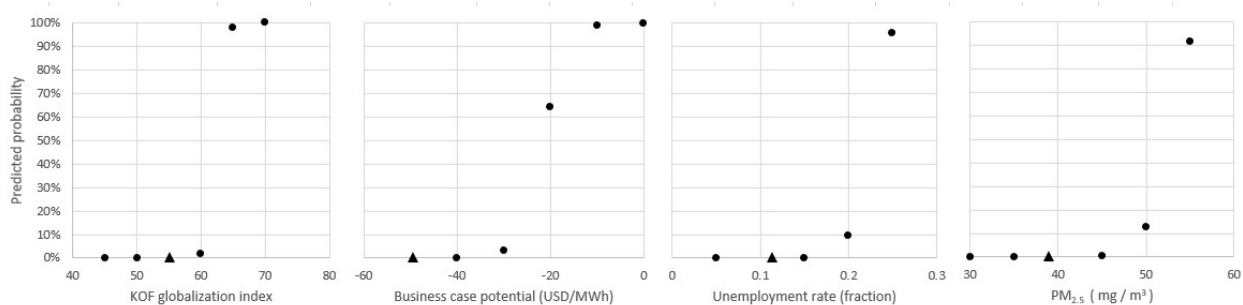


Figure 2 Predicted probability simulation, visualized for the tipping country Iran. The triangles highlight the current value of the variables.

It can be seen that small changes in the individual variables result in disproportionate changes in probability. Table 6 shows two scenarios: globalization of Iran and a further isolation of Iran, scenarios that are potentially the outcome of the US ambitions on reaching a new nuclear deal (Wadhams and Wainer, 2021). For the globalization scenario, higher electricity prices resulting in a better business case, a higher globalization factor, lower unemployment and higher smog caused by higher productivity has been chosen. The rationale is that an increase in globalization results in an uptake of economic activity with an improvement of free-market mechanisms. This scenario results in a high probability. For the opposite scenario,

the isolation scenario, a lower globalization factor, and a higher unemployment has been chosen. This results in a low probability.

Table 6 Simulation scenarios and outcome for Iran.

Scenario	Business case potential	Globalization	Unemployment rate	Smog	Probability	Probability Group
Global	-30	60	0.08	60	99.999999%	High
Isolate	-50	50	0.15	40	0.000027%	Low
Today	-49.3942	55.2214	0.11382	38.9788	0.001072%	Tipping

4.4 Implications for the OEM

Countries with high wind potential and low wind installed capacity form significant business opportunities for wind power OEMs. However, entering new markets comes at a cost. Opening a local business, localization of supply chains, hiring, and training of new employees result in financial barriers. Having certainty about how the market develops is key when taking the decision on market entry and market development. The categorization in Table 5 is a valuable support in taking these decisions. It provides focus on countries that have a high probability of entering full commercial wind utilization. A market entry into these markets is likely to bring volume related benefits. It also provides a list of countries that are less likely to develop a solid wind business in the near future. Entering these markets comes at a risk of potentially winning one project, without a succession of other projects. This would be costly. The tipping countries in the middle indicate that given the right circumstances, the group of the high probability countries can grow. Being a first mover could bring some competitive benefits. The downside is that, if the circumstances change, these countries can also become low probability countries. It is worth noting that Table 6 is the categorization with the latest available data. However, next year, the explanatory variables will have different values and therefore the consistency of the 3 groups is likely to be different. To determine the fitting market entry and market development strategy, up-to-date values are to be used for a country specific simulation, combined with an understanding of the factors

‘mechanism of change’ and ‘disturbing factors’ (section 4.2). The complete decision model is shown in Figure 3.

A market entry strategy should take the existence of potential competitors into account (Buckley and Casson, 1998). A first mover market entry results in a monopoly position, however it can introduce a high cost. As such the OEM growth strategy should consider the competitive strategy related to market entries. Based on the country analysis and the OEM growth strategy, the two decisions (market entry today yes / no, wind market development yes / no) can be made. Together, these two decisions shape the OEM country strategy, as further detailed in Figure 4.

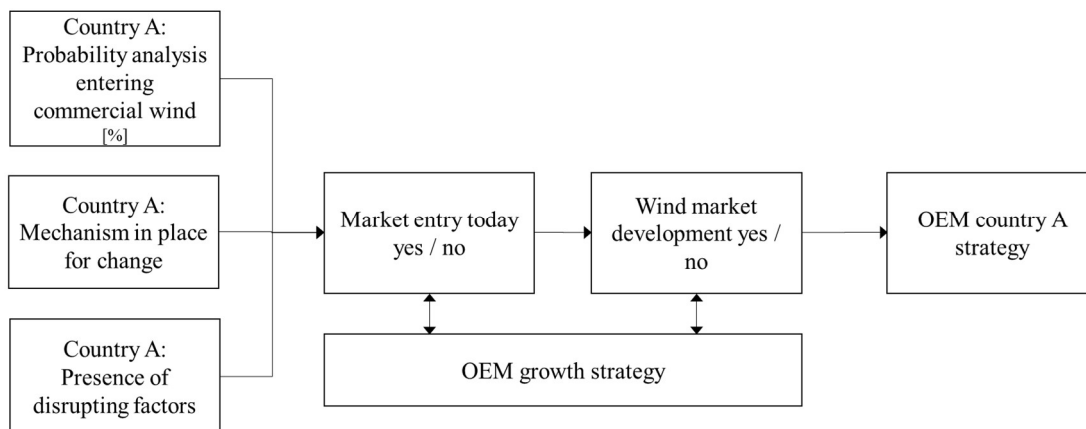


Figure 3 Combining the country analysis with the OEM strategy to make the specific market entry and development decisions.

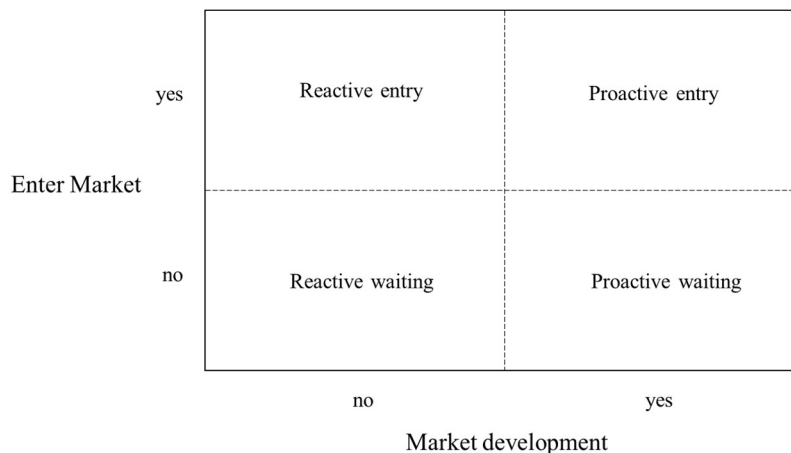


Figure 4 The OEM country strategy for new markets, split into 4 approaches.

Four different approaches to new wind markets are proposed:

- Reactive entry: enter the market and continue to respond to opportunities. The market develops by itself or the market does not develop by itself but either way the OEM should wait for tenders and respond to them competitively. By having a presence in the market, the speed of responding to tenders is high.
- Proactive entry: enter the market and improve the adoption probability by influencing the values of the explanatory variables, such as the business case potential or globalization. Potential supporting strategies to maximize impact could be joint ventures, licensing, acquisitions, developing wind projects, and (co) finance wind projects (Lacal-Arántegui, 2019).
- Reactive waiting: monitor the conditions of a country, reassess periodically the market entry decision.
- Proactive waiting: improve the adoption rate by influencing the values of the explanatory variables and reassess periodically the market entry decision. Potential supporting strategies to maximize early impact could be collaborate with industry organizations and trade networks.

Depending on the company growth strategy and the competitive environment, per country the OEM can select the fitting approach. Taking the earlier example of Iran: the probability analysis shows a tipping probability regarding the commercialization of wind energy (Table 6). Even though a feed-in-tariff is in place (Hosseinioun and Bashiri, 2020), the last large wind farm exceeding 50 MW was installed in 2016 (International Renewable Energy Agency, 2020b). Hence the current mechanism of change is not very effective. The present US sanctions (Wadhams and Wainer, 2021) form a disrupting factor, highly limiting international investments in or export to Iran. Assuming an aggressive but frugal growth strategy of a wind power OEM, reactive entry would introduce costs without soon to be expected revenues. A pro-active entry would introduce even higher costs to lobby regarding e.g. clean air initiatives. And with the current US sanctions in place, it is not likely that a significant wind energy

growth, for which export to Iran is necessary, can take place. This leaves two options: pro-active waiting and re-active waiting. Given the large amount of high probability countries and the OEMs desire for frugal market entry, focussing on the existing high probability countries would make the best use of corporate resources. This results in a re-active waiting market strategy for Iran. A new assessment for the market entry and market development strategy is to be made if alterations to the current US sanctions occur.

4.5 Policy implications

The implications for policy follow the three input elements presented in Figure 3. Firstly, the presence of disrupting factors should be minimized. Sudden significant effects such as war or disasters form blocking factors for wind energy growth (Zwarteveen *et al.*, 2021). Efforts need to be put in place to ensure political stability (Friebe, Von Flotow and Täube, 2014). Secondly, an effective mechanism of change is needed. Multiple effective mechanisms to stimulate wind power growth can be selected (Friebe, Von Flotow and Täube, 2014; Polzin *et al.*, 2015; Keeley and Matsumoto, 2018). However, constancy is needed to secure long-term market entry investments, hence uncertainty in policies, resulting in boom-bust cycles, should be avoided (Barradale, 2010). Lastly, policy makers should simulate the probability for their country to enter the commercial wind stage. This is novel. It would enable the country to forecast and adjust the attractiveness for OEMs (and other players in the wind industry) to enter their market. Table 1 shows the 9 factors influencing the probability to enter the commercial wind stage. These factors highlight the importance of integrating the wind energy policy with economic policy (electricity pricing), the foreign trade policy (neighbour influence and globalization efforts) and the generic energy policy (diversification of energy generation portfolio). The first step would be to calculate the current probability for commercial wind adoption, by using equation 1. If this results in low or tipping probability, scenarios are to be created for future values of the influencing factors. Iterations should be executed until the probability is high. The last step is to work backwards from the values of the

influencing factors of the high probability scenario to policies to achieve those. Creating long term integrated policies enable the simulation of future adoption probability for commercial wind and allow for long term holistic socio-economic and environmental scenarios.

4.6 Limitations

This study only considered the 67 highest wind potential countries. Further research is needed to determine if the model could also be applied to other countries with moderate wind resources. The model fit might be less accurate (currently it is 0.7), however by combining it with the mechanism of change and disturbances, the approach is likely to be of significant value to OEMs.

The categorization of the countries was based on the latest available data from the dataset of Zwarteveen et al (2021). However, the data for some variables dates to 2016. This dataset was chosen since it provided the latest, consistent data for all countries. For analysis of specific country, contemporary data could be used.

It should also be noted that onshore and offshore were both considered in the models. With the current growth of offshore extending into emerging markets (such as Vietnam (Afanasiev, 2021)), further research could focus on a specific offshore model.

Furthermore, the focus of this paper was on OEMs, however the findings might also be useful for international developers and international independent power producers who need to choose between different markets to place their investment.

5. Conclusions

The aim of this paper was to estimate the probability that late adopters of wind energy would begin significant wind utilization. Using a binary logistic probability model, 39 high wind potential countries with currently less than 500 MW installed were categorized into 3 groups: high probability, tipping probability, and low probability to enter commercial wind exploitation. Simulation showed that countries with tipping probability can either move quickly to the low or high probability group.

By combining the outcome of the prediction model with information on the mechanism of change and potential disturbing factors, the wind power OEM can make informed decisions on market entry and market development for new wind markets.

The broader implication for addressing the private investment gap to achieve the SDGs is that a thorough understanding of the local market conditions is needed to calculate the likelihood of long-term success. Simulating the probability of entering the commercialization stage based on path creation theory is a helpful method to de-risk investments related to market entries of sustainable technology. The triple bottom line should be considered simultaneously both from a private company and the local countries point of view. Regarding the economic value, only a reliable profitable business case both for the company (favourable risk-return balance) as well as for the country (local value creation resulting in employment) is needed to close today's significant SDG financing gap.

Appendices

Appendix A Variable values

Table A-1 Explanatory variables and their values per country (dataset (Zwarteveen, Zawwar and Angus, 2021)). Greenland removed due to missing data.

Country	v4	v5	v9	v10	v11	v12	v14	v15	v17
Afghanistan	-16.9421	0.11118	0.245101	56.9108	0.6	38.1618	0	0.107	0.829
Algeria	-25.9565	0.11704	3.69916	38.884	0.555556	56.778	74.894	0	0.638
Angola	-43.9855	0.06886	1.20286	32.3885	0.545455	41.4786	0	0	7.653
Belarus	1.08692	0.04595	6.13371	18.7656	1	68.619	33.507	0	0.405
Bolivia	37.1449	0.03498	1.95851	21.569	0.857143	59.156	7.189	0	2.234
Chad	172.362	0.01891	0.069756	66.0292	0.555556	41.0539	0	0	0
Colombia	64.1883	0.09707	2.03038	16.5272	0.857143	65.0934	10.822	3.153	56.648
Congo DR	-7.92757	0.04236	0.025645	44.9093	0.545455	45.2509	0.002	0	9.482
Czech Republic	127.29	0.01933	9.6739	16.0712	1	85.6801	3.747	41.206	3.04
Eritrea	145.319	0.05144	0.210687	48.0302	0.666667	30.3343	0	0	0
Ethiopia	-43.9855	0.02081	0.143525	38.9787	0.454545	44.6341	0	0	12.957
Iceland	46.1593	0.02842	6.15468	6.48115	1	72.2403	0	0	14.059
Indonesia	28.1304	0.04687	2.15376	16.5027	1	63.3752	50.511	187.645	18.6324
Iran	-49.3942	0.11382	8.3167	38.9788	0.4	55.2214	257.955	0	15.051
Iraq	-34.971	0.12822	5.1914	61.6362	0.6	44.1386	27.761	0	2.176
Kazakhstan	-25.9565	0.0459	13.8927	13.8243	0.4	64.6785	18.466	71.851	11.21
Kenya	100.246	0.02642	0.365117	28.5784	0.454545	55.9294	0	0	2.7768
Libya	-43.9855	0.18563	7.78851	54.2547	0.666667	55.445	22.834	0	0
Madagascar	37.1449	0.01758	0.156877	22.5423	0.545455	50.0556	0	0.116389	0.7885
Mali	127.29	0.07224	0.176967	38.5266	0.666667	48.7162	0	0	1.105
Mauritania	226.449	0.09548	0.657914	47.423	0.555556	52.2851	0	0	0
Mongolia	-16.9421	0.06011	8.30017	40.1129	0.4	66.5354	0	5.69417	0
Mozambique	37.1449	0.03241	0.285402	21.2987	0.545455	54.7181	2.93	0	14.06
Namibia	46.1593	0.20273	1.79304	25.3588	0.454545	59.1722	0	0.066	1.593
Niger	46.1593	0.00475	0.097016	94.0538	0.666667	47.6051	0	0.23034	0
Nigeria	1.08692	0.08096	0.647285	71.7982	0.454545	56.1364	26.67	0	5.527
Oman	-34.971	0.02671	14.1671	41.1152	0.6	62.9017	35.088	0	0
Paraguay	-7.92757	0.04809	1.09287	11.9091	1	63.1461	0	0	59.5634
Russia	-7.92757	0.04585	11.9994	16.1602	0.4	72.5747	518.659	168.046	187.131
Saudi Arabia	-16.9421	0.05927	17.3676	87.9454	0.4	66.1004	209.69	0	0
Somalia	848.449	0.11351	0.045496	32.0346	0.454545	31.2857	0	0	0
Syria	-43.9855	0.0837	1.65177	43.7573	0.6	51.459	10.559	0	0.754
Tanzania	19.1159	0.0198	0.225685	29.0766	0.545455	51.2824	4.227	0	2.35
Tunisia	1.08692	0.16022	2.6484	37.656	0.555556	68.0515	19.715	0	0.017
Turkmenistan	-43.9855	0.03913	12.4736	21.7677	0.6	41.1237	22.534	0	0

Uzbekistan	-34.971	0.05917	2.88279	28.4559	0.6	47.266	49.2737	3.249	8.42737
Venezuela	-34.971	0.08801	5.50071	17.0086	0.857143	53.6092	36.507	0	64.847
Zambia	-25.9565	0.11425	0.314183	27.438	0.545455	57.0869	0	1.335	12.198
							2017-	2017-	2017-
Year of data	2019	2019	2016	2017	2019	2017	2018	2018	2018

Appendix B Predicted probability

Table B-1 Predicted probability of exceeding 500 MW of wind power per country.

County number	Country	Predicted probability of exceeding 500 MW
1	Turkmenistan	0.000000%
2	Angola	0.000000%
3	Ethiopia	0.000000%
4	Kazakhstan	0.000000%
5	Uzbekistan	0.000000%
6	Oman	0.000000%
7	Syria	0.000000%
8	Venezuela	0.000000%
9	Congo DR	0.000000%
10	Madagascar	0.000000%
11	Afghanistan	0.000000%
12	Zambia	0.000000%
13	Tanzania	0.000000%
14	Iraq	0.000000%
15	Mongolia	0.000000%
16	Mozambique	0.000000%
17	Algeria	0.000020%
18	Libya	0.000109%
19	Paraguay	0.000804%
20	Iran	0.001072%
21	Bolivia	0.508415%
22	Belarus	3.690523%
23	Namibia	96.029546%
24	Iceland	99.363971%
25	Kenya	99.830275%
26	Tunisia	99.995971%
27	Indonesia	99.999319%
28	Eritrea	99.999486%
29	Nigeria	99.999792%
30	Colombia	100.000000%
31	Mali	100.000000%
32	Saudi Arabia	100.000000%
33	Niger	100.000000%
34	Chad	100.000000%
35	Somalia	100.000000%
36	Mauritania	100.000000%
37	Russia	100.000000%
38	Czech Republic	100.000000%

References

- Afanasiev, V. (2021) *Russian oil and gas player gets ready for Vietnam offshore wind splash*, *Upstream Energy Explored*. Available at: <https://www.upstreamonline.com/energy-transition/russian-oil-and-gas-player-gets-ready-for-vietnam-offshore-wind-splash/2-1-1032449> (Accessed: 6 July 2021).
- Agarwal, R. and Gort, M. (2001) 'First-Mover Advantage and the Speed of Competitive Entry, 1887–1986', *The Journal of Law and Economics*, 44(1), pp. 161–177. doi: 10.1086/320279.
- Aguinaldo, J. (2020) *Saudi Arabia plans separate wind power tender*, *Middle East Business Intelligence*. Available at: <https://www.meed.com/saudi-arabia-plans-separate-wind-power-tender> (Accessed: 6 July 2021).
- Arnold, M. G. (2018) 'Sustainability value creation in frugal contexts to foster Sustainable Development Goals', *Business Strategy & Development*, 1(4), pp. 265–275. doi: 10.1002/bsd2.36.
- Azzopardi, T. (2021) *Colombia prepares for wind power boom*, *Wind Power Monthly*. Available at: <https://www.windpowermonthly.com/article/1720453/colombia-prepares-wind-power-boom> (Accessed: 6 July 2021).
- Bacon, R. and Kojima, M. (2011) *Issues in estimating the employment generated by energy sector activities*. Available at: <https://documents1.worldbank.org/curated/en/627831468159915345/pdf/827320WP0empl000Box379875B00PUBLIC0.pdf>.
- Barradale, M. J. (2010) 'Impact of public policy uncertainty on renewable energy investment: wind power and the production tax credit', *Energy Policy*. Elsevier, 38(12), pp. 7698–7709. doi: 10.1016/j.enpol.2010.08.021.
- Barua, S. (2020) 'Financing sustainable development goals: A review of challenges and mitigation strategies', *Business Strategy & Development*, 3(3), pp. 277–293. doi: 10.1002/bsd2.94.
- Barua, S. and Chiesa, M. (2019) 'Sustainable financing practices through green bonds: What affects the funding size?', *Business Strategy and the Environment*, 28(6), pp. 1131–1147. doi: 10.1002/bse.2307.

Binnie, I., Steitz, C. and Hübner, A. (2021) *Looming loss piles pressure on turbine maker Siemens Gamesa, Reuters*. Available at: <https://www.reuters.com/business/energy/siemens-gamesa-trying-pass-rising-steel-costs-turbine-customers-ceo-2021-07-15/> (Accessed: 13 August 2021).

Buckley, P. J. and Casson, M. C. (1998) 'Analyzing Foreign Market Entry Strategies: Extending the Internalization Approach', *Journal of International Business Studies*, 29(3), pp. 539–561. doi: 10.1057/palgrave.jibs.8490006.

Cárdenas Rodríguez, M., Haščič, I., Johnstone, N., Silva, J. and Ferey, A. (2015) 'Renewable energy policies and private sector investment: evidence from financial microdata', *Environmental and Resource Economics*, 62(1), pp. 163–188. doi: 10.1007/s10640-014-9820-x.

Chertow, M. R. (2000) 'The IPAT Equation and Its Variants', *Journal of Industrial Ecology*, 4(4), pp. 13–29. doi: 10.1162/10881980052541927.

Chin, W. W. (1998) 'The partial least squares approach for structural equation modeling.', in *Modern methods for business research*. Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers (Methodology for business and management.), pp. 295–336.

Euromonitor International (2020) *Passport, economies and consumers annual data*. Available at: <https://www.portal.euromonitor.com/portal/statisticsevolution/index%0A> (Accessed: 5 February 2021).

Friebe, C. A., Von Flotow, P. and Täube, F. A. (2014) 'Exploring technology diffusion in emerging markets - the role of public policy for wind energy', *Energy Policy*. Elsevier, 70, pp. 217–226. doi: 10.1016/j.enpol.2014.03.016.

Gan, G., Ma, C. and Wu, J. (2007) *Data Clustering: Theory, Algorithms, and Applications*. Society for Industrial and Applied Mathematics. doi: 10.1137/1.9780898718348.

Geels, F. W. (2002) 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study', *Research Policy*, 31(8), pp. 1257–1274. doi: [https://doi.org/10.1016/S0048-7333\(02\)00062-8](https://doi.org/10.1016/S0048-7333(02)00062-8).

Global Petrol Prices (2020) *Electricity prices*. Available at: https://www.globalpetrolprices.com/electricity_prices/ (Accessed: 12 December 2020).

Gygli, S., Haelg, F., Potrafke, N. and Sturm, J.-E. (2019) 'The KOF Globalisation Index – revisited', *The Review of International Organizations*, 14(3), pp. 543–574. doi: 10.1007/s11558-019-09344-2.

Heinze, G. and Dunkler, D. (2017) 'Five myths about variable selection', *Transplant International*, 30(1), pp. 6–10. doi: 10.1111/tri.12895.

Hosseinioun, S. and Bashiri, M. R. (2020) 'Evaluation of Feed-in Tariff in Iran, An Experience from the Middle East', in *First National Conference of Optimizing in Renewable Energies*. Dezful, pp. 1–10. Available at: https://www.researchgate.net/profile/Seyed-Saeed-Hosseinioun/publication/344243589_Evaluation_of_Feed-in_Tariff_in_Iran_An_Experience_from_the_Middle_East/links/5f5ff74092851c078967773f/Evaluation-of-Feed-in-Tariff-in-Iran-An-Experience-from-the-Middle-Ea.

International Energy Agency (2021) *Net Zero by 2050*. Paris. Available at: <https://www.iea.org/reports/net-zero-by-2050>.

International Monetary Fund (2018) *World Economic Outlook - Database - WEO Groups and Aggregates Information*. Available at: <https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/groups.htm> (Accessed: 5 November 2018).

International Renewable Energy Agency (2019) *Renewable Power Generation Costs in 2018*, *International Renewable Energy Agency*. Abu Dhabi. doi: 10.1007/SpringerReference_7300.

International Renewable Energy Agency (2020a) *Renewable capacity statistics 2020*. Abu Dhabi. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_RE_Capacity_Statistics_2020.pdf.

International Renewable Energy Agency (2020b) *Renewable electricity capacity and generation statistics, July 2020*. Available at: <https://www.irena.org/Statistics/Download-Data> (Accessed: 7 August 2020).

International Renewable Energy Agency (2020c) *Renewable Power Generation Costs in 2019*, *Irena*. Abu Dhabi. Available at: <https://www.irena.org/->

/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_2017_Power_Costs_2018.pdf.

Jamasb, T. (2006) 'Between the state and market: Electricity sector reform in developing countries', *Utilities Policy*, 14(1), pp. 14–30. doi: 10.1016/j.jup.2004.11.001.

Keeley, A. R. and Matsumoto, K. (2018) 'Relative significance of determinants of foreign direct investment in wind and solar energy in developing countries – AHP analysis', *Energy Policy*, 123, pp. 337–348. doi: 10.1016/j.enpol.2018.08.055.

Kuik, O., Branger, F. and Quirion, P. (2019) 'Competitive advantage in the renewable energy industry: Evidence from a gravity model', *Renewable Energy*, 131, pp. 472–481. doi: 10.1016/j.renene.2018.07.046.

Lacal-Arántegui, R. (2019) 'Globalization in the wind energy industry: contribution and economic impact of European companies', *Renewable Energy*, 134, pp. 612–628. doi: 10.1016/j.renene.2018.10.087.

Lee, A. (2021) *Vestas strikes oil: wind group links with Russian fossil giant Rosneft*, *Recharge News*. Available at: <https://www.rechargenews.com/energy-transition/vestas-strikes-oil-wind-group-links-with-russian-fossil-giant-rosneft/2-1-1021212> (Accessed: 6 July 2021).

Lu, X., McElroy, M. B. and Kiviluoma, J. (2009) 'Global potential for wind-generated electricity', *Proceedings of the National Academy of Sciences*. doi: 10.1073/pnas.0904101106.

Luan, C., Tien, C. and Wu, P. (2013) 'Strategizing Environmental Policy and Compliance for Firm Economic Sustainability: Evidence from Taiwanese Electronics Firms', *Business Strategy and the Environment*, 22(8), pp. 517–546. doi: 10.1002/bse.1760.

McFadden, D. (1974) 'Conditional logit analysis of qualitative choice behavior', in *Zarembka, Frontiers in econometrics*. New York: Academic Press, pp. 104–142.

Newbery, D. (2004) *Issues and Options for Restructuring Electricity Supply Industries*.

Ortega-Izquierdo, M. and Río, P. del (2020) 'An analysis of the socioeconomic and environmental benefits of wind energy deployment in Europe', *Renewable Energy*, 160, pp. 1067–1080. doi: 10.1016/j.renene.2020.06.133.

Polzin, F., Migendt, M., Täube, F. A. and von Flotow, P. (2015) 'Public policy influence on renewable energy investments-A panel data study across OECD countries', *Energy Policy*, 80(June), pp. 98–111. doi: 10.1016/j.enpol.2015.01.026.

Popp, D., Hascic, I. and Medhi, N. (2011) 'Technology and the diffusion of renewable energy', *Energy Economics*. Elsevier B.V., 33(4), pp. 648–662. doi: 10.1016/j.eneco.2010.08.007.

Ranjbari, M., Shams Esfandabadi, Z., Zanetti, M. C., Scagnelli, S. D., Siebers, P.-O., Aghbashlo, M., Peng, W., Quatraro, F. and Tabatabaei, M. (2021) 'Three pillars of sustainability in the wake of COVID-19: A systematic review and future research agenda for sustainable development', *Journal of Cleaner Production*, 297, p. 126660. doi: 10.1016/j.jclepro.2021.126660.

Sivakumaran, T., Kohne, F. and Toth, M. (2015) 'Identification of critical success factors for emerging market entry planning processes in the automotive industry', in *2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*. IEEE, pp. 1694–1698. doi: 10.1109/IEEM.2015.7385936.

Steffen, B., Matsuo, T., Steinemann, D. and Schmidt, T. S. (2018) 'Opening new markets for clean energy: the role of project developers in the global diffusion of renewable energy technologies', *Business and Politics*, pp. 1–35. doi: 10.1017/bap.2018.17.

Surana, K. and Anadon, L. D. (2015) 'Public policy and financial resource mobilization for wind energy in developing countries: a comparison of approaches and outcomes in China and India', *Global Environmental Change*. Elsevier Ltd, 35, pp. 340–359. doi: 10.1016/j.gloenvcha.2015.10.001.

Tabachnick, B. G. and Fidell, L. S. (2013) *Using multivariate statistics*. 6th edn. Harlow: Pearson Education Ltd.

The World Bank (2019a) *PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)*. Available at: <https://data.worldbank.org/indicator/EN.ATM.PM25.MC.M3> (Accessed: 1 October 2020).

The World Bank (2019b) *Unemployment, total (% of total labor force)*. Available at: <https://data.worldbank.org/indicator/SL.UEM.TOTL.ZS> (Accessed: 20 March 2020).

The World Bank (2020) *CO2 emissions (metric tons per capita)*. Available at:

<https://data.worldbank.org/indicator/EN.ATM.CO2E.PC> (Accessed: 17 July 2020).

Thomas, N. and Sanderson, H. (2021) *Vestas cuts outlook as commodity prices squeeze margins*, *Financial Times*. Available at: <https://www.ft.com/content/20e7a28f-3d20-4021-94de-d30022283ef6> (Accessed: 13 August 2021).

UCLA (2021) *How do I interpret odds ratios in logistic regression?*, *Statistical Consulting Group*. Available at: <https://stats.idre.ucla.edu/other/mult-pkg/faq/general/faq-how-do-i-interpret-odds-ratios-in-logistic-regression/> (Accessed: 12 May 2021).

UNCTAD (2014) *World Investment Report*. Geneva: United Nations Publication. Available at: https://unctad.org/system/files/official-document/wir2014_en.pdf.

UNDP (2000) 'World Energy Assessment. Energy and the challenge of Sustainability', *UNDP*.

United Nations (2018) *Sustainable Development Goal 7*. Available at: <https://sustainabledevelopment.un.org/sdg7> (Accessed: 26 October 2018).

United Nations (2020a) *Country Savings Assessments, United for Efficiency*. Available at: <https://united4efficiency.org/countries/country-assessments/> (Accessed: 12 December 2020).

United Nations (2020b) *Hydro, UNdata*. Available at: <http://data.un.org/Data.aspx?q=hydro&d=EDATA&f=cmID:EH%0A> (Accessed: 17 July 2020).

United Nations (2020c) *Thermal Electricity*. Available at: <http://data.un.org/Data.aspx?q=Electricity&d=EDATA&f=cmID%3AET> (Accessed: 20 March 2020).

Wadhams, N. and Wainer, D. (2021) *Biden's Iran Nuclear Deal Ambitions Shrink as Tensions Flare*, *Bloomberg*. Available at: <https://www.bloomberg.com/news/articles/2021-08-09/biden-s-iran-nuclear-deal-ambitions-shrink-as-tensions-flare> (Accessed: 11 August 2021).

Yoo, S.-H. and Lee, J.-S. (2010) 'Electricity consumption and economic growth: A cross-country analysis', *Energy Policy*, 38(1), pp. 622–625. doi: 10.1016/j.enpol.2009.05.076.

Yusta, J. M. and Lacal-Arántegui, R. (2020) 'Measuring the internationalization of the wind energy industry', *Renewable Energy*, 157, pp. 593–604. doi: 10.1016/j.renene.2020.05.053.

Zwarteveen, J. W., Figueira, C., Zawwar, I. and Angus, A. (2021) 'Barriers and drivers of the global imbalance of wind energy diffusion: A meta-analysis from a wind power Original Equipment Manufacturer perspective', *Journal of Cleaner Production*, 290, p. 125636. doi: 10.1016/j.jclepro.2020.125636.

Zwarteveen, J. W., Zawwar, I. and Angus, A. (2021) 'Market entry for wind energy: Strategic approaches for the original equipment manufacturer', *Business Strategy & Development*. doi: 10.1002/bsd2.188.

7 IMPACT ASSESSMENT

“When pride comes, then comes disgrace, but with humility comes wisdom”

--- Solomon (in: Proverbs, New International Version)

Abstract

This specific paper evaluates the impact of the DBA study at different levels. Multiple stakeholders were engaged over the course of the research: academic stakeholders, the wind industry, society and the author himself. The engagement took place in two directions: the stakeholders shaped the research direction and the output of the research provided knowledge for the stakeholders. Key impacts were the publication of 3 international journal papers, 2 energy related industry publications, multiple speaker opportunities and 30 LinkedIn articles attracting close to 70000 views.

Keywords: Wind Energy, Diffusion, Developing and Emerging Economies, Impact, Engagement

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1 Introduction

Developing and emerging markets (definition by IMF (2018)) have significant unused wind resources (Zwarteveen *et al.*, 2021). This study aims to increase understanding of global wind power diffusion to create business opportunities for wind power Original Equipment Manufacturers (OEMs) and at the same time contribute to achieving the Sustainable Development Goals, in particularly goal number seven (United Nations, 2018). This specific paper evaluates the impact of this DBA study at different levels.

Besides providing education and research, universities play an important role in applied problem solving (Deiaco, Hughes and McKelvey, 2012). This frequently involves engagement with the stakeholders, which is defined as “knowledge-related interactions of academic scientists with external organisations” (Perkmann *et al.*, 2021).

It is important to note that engagement is a two-way process. Academic research is refined and enhanced by targeted engagement with stakeholders. Academic research can then deliver benefits to stakeholders. Therefore, engagement can be used as an input to research to focus on stakeholder’s interests (Perkmann *et al.*, 2021). The output of the study can be considered as a source of open innovation (Mina, Bascavusoglu-Moreau and Hughes, 2014), available for all stakeholders to be exploited for their benefit.

Therefore, in this paper the impact of the DBA study is considered in two directions: impact from the stakeholders on the research and impact of the research on the stakeholders (stakeholders are summarized in Table 1). Section two focusses on the academic stakeholder, followed by the wind industry and society in section three and four. The author offers his reflections in section five. A comparison between the impact plan and the actual impact is listed in section six, which is followed by the conclusion.

Table 1 Stakeholders of the research.

Stakeholder	Description	Interest
Academic	Academic community in the field of energy strategy research, both within Cranfield University and outside. DBA program faculty.	Contribution to academic discussion, creation of new knowledge
Wind industry	Includes the actors in the wind industry (such as developers, policy makers, power producers), with a special focus on the wind power OEM.	Improve knowledge to make wind power diffusion more efficient and effective
Society	Public actors interested in energy transition and diversification	Increase knowledge on the energy transition or diversification
The author	The author of the DBA thesis and of the papers submitted to academic journals. The author is simultaneously employed as a director in one of the leading wind power OEMs.	Increase academic and industry relevant knowledge on cost-efficient market entries for wind energy, especially in developing and emerging markets.

2 Engagement with academia

This section describes how the academic stakeholders were engaged to enhance the outputs of the research. The academic stakeholders of the research consist of the academic community in the field of energy strategy research, both within Cranfield University (including DBA faculty and 2018 DBA cohort) and outside.

2.1 Impact on the research

The systematic review was published in the Journal of Cleaner Production, which is listed on the Cranfield University Leading Academic Journal List and rated as a 2* journal on the Chartered Association of Business Schools (CABS) journal list. This publication considers more than 2,000 papers (Zwarteveen *et al.*, 2021) and provides a comprehensive review of prior art. The paper also identifies several dimensions within the field of wind power diffusion.

Categorizing the existing literature into these dimensions has identified understudied areas, which resulted in the focus of the empirical paper. More details can be found in the published literature review (Zwarteveen *et al.*, 2021). One of the academic impacts of the publication is the introduction of a feedback-loop system to explain technology diffusion. This concept can be applied to other technology adoption contexts as well.

The paper received insightful feedback from the two peer reviewers. The most important feedback was regarding how to better position the paper in an existing academic discussion. Based on the feedback, the research was positioned in the discussion of multi-perspective renewable energy diffusion (Negro, Alkemade and Hekkert, 2012; Abdmouleh, Alammari and Gastli, 2015; Strantzali and Aravossis, 2016; Keeley and Matsumoto, 2018; Polzin *et al.*, 2019). The novel part to the discussion was to introduce the wind power OEM's point of view, impacting multi-perspective research by making it more complete.

The empirical paper, titled "Market entry for wind energy: Strategic approaches for the original equipment manufacturer", was published in the Business Strategy and Development journal (Zwarteveen, Zawwar and Angus, 2021), the sister

journal to Business Strategy and the Environment (a 3* journal on the CABS journal list). The reviewing phase steered the focus of the paper in the direction of business impact and development context. Keeping the wind power OEM's point of view but making the conclusions specific for business managers and addressing the corporate responsibility to contribute to inclusive development within developing and emerging markets. Introducing a novel quantitative method to describe path creation impacted further research, that could replicate the approach to quantify influencing factors of technology adoption.

The simulation paper was accepted for publication by Cleaner Production Letters in April 2022 (Zwarteveen and Angus, 2022). The reviewer's comments resulted in changes that clarified the difference between wind energy *technical potential* capacity and wind energy *installed* capacity. Also, the lack of quantitative research to date to aid the wind power OEM in their internationalization efforts was introduced as the research gap addressed by the simulation paper.

Lastly, the DBA faculty and the DBA cohort 2018 had a steering and motivating impact over the course of the study. The supervisor supported with his positivist philosophical lens, his excellent writing and correction feedback and his experience to interpret the feedback from the journal reviewers. Finally, having peers in the cohort to compare progress, share barriers and success stories resulted in increased motivation.

2.2 Impact of the research

The major impact of the research to date is by means of the publications. Firstly, the literature review was published in the Journal of Cleaner Production (Zwarteveen *et al.*, 2021), which is the highest ranked journal in the category 'Sustainable Development', measured by the h-index (Google Scholar, 2021). Secondly, invited by ERP Environment and Wiley, the empirical paper was published in the Business Strategy and Development (Zwarteveen, Zawwar and Angus, 2021), the new and, therefore, unranked sister journal of the CABS 3 * Business Strategy and the Environment. Lastly, the simulation paper was accepted in April 2022 for publication by Cleaner Production Letters (Zwarteveen

and Angus, 2022), the open access sister journal of the Journal of Cleaner Production.

Impact of publications is generally measured in number of citations, but accumulating citations can take years (Thelwall and Kousha, 2015). Therefore, altmetrics are developed as early indicators (Priem *et al.*, 2010). ResearchGate and Academia.edu are both academic social platforms providing research statistics, both citation statistics as well as altmetrics. For this paper, the statistics of ResearchGate are used, since this platform has a highest ranking in global internet engagement of the two (Alexa, 2021a, 2021b). ResearchGate provides following altmetrics: the RG Score and the H index. However, both are measured on author level. As part of his previous Master of Science education, the author has published work not relevant to the DBA. Therefore, the impact per publication is more appropriate to consider. ResearchGate provides the Research Interest, the number of citations, recommendations and reads. The current values of the impact metrics of the DBA research are shown in Table 2. The numbers show a moderate interest regarding number of reads; however, the published work is already receiving in multiple citations. This illustrates that the produced academic papers are providing valuable input to further research.

Table 2 Impact metrics for the DBA research measured by ResearchGate, status 08-04-2022.

Impact metrics	Barriers and drivers of the global imbalance of wind energy diffusion: A meta-analysis from a wind power Original Equipment Manufacturer perspective (Zwarteveen <i>et al.</i> , 2021)	Market entry for wind energy: Strategic approaches for the original equipment manufacturer (Zwarteveen, Zawwar and Angus, 2021)	Forecasting the probability of commercial wind development in lagging countries (Zwarteveen and Angus, 2022)
Research Interest	1.7	0.4	0
Citations	4	1	0
Recommendation	0	0	0
Reads	15	13	3

2.3 Further dissemination and exploitation

The simulation study is accepted for publication and is awaiting the print publication. Secondly, parts of the papers are targeted to be used for academic teaching purpose by Dr. Andrew Angus. Lastly, based on the published SLR, an

invitation has been received to guest edit a new article collection for the peer-reviewed journal *Frontiers in Sustainability*, details can be found in Appendix A.

Table 3 Key academic contribution of the research.

Publication	Key contributions
Literature review (Zwarteveen <i>et al.</i> , 2021)	Meta-analysis of wind energy diffusion, diffusion mechanism
Empirical project (Zwarteveen, Zawwar and Angus, 2021)	Quantitative regression applied to path creation, introduction of OEM perspective in wind diffusion research
Forecasting study (Zwarteveen and Angus, 2022)	Quantitative simulation applied to path creation, risk reduction method for closing finance gap to achieve SDGs

3 Engagement with the wind industry

The wind industry stakeholders relevant to this study include the wind power OEM, energy developers, energy policy makers, power producers, industry societies, energy financiers and energy media outlets.

3.1 Impact on the research

During the research, partial results and insights were shared by the author in several customer conversations and in energy fora (details in Appendix B). It confirmed the research focus on economic benefits of wind diffusion. It also indicated that the energy developments we are seeing resembles more a diversification (increase the energy sources) than a transition (move from one source to another). This insight was used in the empirical paper (Zwarteveen, Zawwar and Angus, 2021).

During the Siemens Gamesa Renewable Energy service business unit strategy summit in 2021, one of the senior managers commented that the company had to get better at market entries: which market to enter, which one not to enter. Many wind power OEMs are under financial pressure (Keown, 2021), hence a costly decision of market entries should be taken comparing today's costs with the future return. This statement was the basis for the simulation paper (Zwarteveen and Angus, 2022). The simulation paper indicates which of the last wind adopters are promising markets and which are less promising.

As a positivist, quantitative and measurable data are the basis of new knowledge. Hence the qualitative inputs received in discussions were not considered to be data, merely as inputs for the research direction.

3.2 Impact of the research

Firstly, the academic journals for publishing were chosen based on their targeted impact in the industry, such as having industry actors amongst their target audience (Table 4). For the most practical paper, the simulation study, an open access journal was selected to maximize the impact. During the course of the

research, knowledge generated was disseminated through multiple channels (full details in Appendix B), such as:

- Conversations between the author and customers regarding business development (4 conversations).
- Speaker and participant in industry group discussions and fora (5 events).
- Energy industry related news publications (2 publications).
- Representation of SGRE in corporate news publications (1 press release).
- Contribution to the International Renewable Energy Agency Call for Action regarding scaling up Renewable Energy Investment in the Philippines (1 letter).

Table 4 Audience of targeted journals.

Journal	Paper	Description and targeted audience
Journal of Cleaner Production	Literature Review	"The Journal of Cleaner Production serves as a platform for addressing and discussing theoretical and practical cleaner production, encompassing environmental, and sustainability issues in corporations, governments, education institutions, regions, and societies." (Elsevier, 2021b)
Business Strategy and Development	Empirical paper	<p>"The journal will provide original contributions that add to the understanding of business responses to improving development and contributing to national and international development goals. It will examine links between competitive strategy and development with an emphasis on the private sector's role in alleviating poverty and improving the livelihoods of low income populations"</p> <p>"Contributions are encouraged which examine the ways in which the private sector can contribute to development through its goods and services, management of value chains and through partnerships with other stakeholders to create positive development outcomes." (John Wiley and Sons, 2021)</p>
Cleaner Production Letters	Simulation paper	"Cleaner Production Letters (CLPL) is an international, inter-, multi- and transdisciplinary journal focusing on Cleaner Production, Environmental, and Sustainability research and practice. CLPL is committed to publish top-tier original research from the cleaner production community and to serve as a platform for communications in addressing and discussing emerging topics with potential of high societal impact and great significance." (Elsevier, 2021a)

3.3 Further dissemination and exploitation

Following the publication of the empirical the forecasting study, the author plans to create a graphical summary for the strategy department within SGRE, potentially to be also shared with customers, industry organizations and industry news outlets. The key findings of the research are to be included within the graphical summary (Table 5).

Table 5 Key findings of the research relevant to the wind industry.

Publication	Key findings
Literature review (Zwarteveen <i>et al.</i> , 2021)	Diffusion system: mechanism of change, desire for change, disturbing factors.
Empirical project (Zwarteveen, Zawwar and Angus, 2021)	Factors influencing early stages of wind power path creation
Simulation study (Zwarteveen and Angus, 2022)	Categorization of last adopters to wind energy in high and low probability adopters Simulation formula Method for creating market entry and development strategies

4 Engagement with society

This section addresses the engagement with actors in the public that are interested in energy transition and diversification.

4.1 Impact on the research

The Sustainable Development Goals (in particularly goal number 7 (United Nations, 2018)) influenced the research direction. Not only do wind power OEMs benefit from an increase in wind energy in new markets, also these markets benefit from social and economic improvements, as measured by the Sustainable Development Goals.

News about energy transition and diversification in emerging markets was used as input for the author to write LinkedIn articles (details in Appendix C). The responses addressed broader topics, such as the role of the government, zero carbon strategies and green house gas (GHG) impacts. The input did not change the research focus, but it confirmed that the research is embedded in the larger phenomena of energy transition and energy diversification and there are many actors in society with an active interest in this topic.

4.2 Impact of the research

As stated in section 4.1, the author used the knowledge developed in the research to comment on energy transition and diversification related news items addressing emerging markets. Between July 2019 and February 2022, a total of 30 articles published on LinkedIn, resulting in an accumulated 68630 views (details in Appendix C). The following key influencers within the field of energy engaged in discussions with the Author following the publication of the articles (details in Appendix C, Table C-2):

- **Monalisa Dimalanta.** Chairwomen of the National Renewable Energy Board (Philippines), Professor of Energy Law at the Ateneo de Manila University Law School, Asia-Pacific IFLR1000 Women Leaders for 2021, 100 Most Influential Filipino Women on LinkedIn. 2020 Women in Renewables Asia awardee.

- **Christoph Zipf.** Press and Communications Manager WindEurope.
- **Nuki Agya Utama.** Executive Director at ASEAN Center for Energy.

4.3 Further dissemination and exploitation

The author continues to respond to energy transition and diversification news on LinkedIn, particularly focussing on emerging markets. Secondly, he is planning to apply to participate in the “ARNECC Paper Talks” of the ASEAN Energy organization (ASEAN Climate Change and Energy Project, 2021).

5 Engagement with the author

The author of the DBA thesis is simultaneously employed as a director in one of the leading wind power OEMs.

5.1 Impact on the research

Before embarking on the DBA journey, the author accumulated years of experience in operations and maintenance of wind energy projects in emerging markets. He observed promising markets that did not develop as quickly as hoped at the time of market entry. Simultaneously, he observed many countries with high wind capacity, but without significant installed wind energy. Industry reports provided unsatisfactory explanations beyond the obvious lack of governmental support. These observations resulted in the formulation of the research proposal. The synergies between the research and the job at hand also resulted in a close engagement between industry and academia. This engagement improved the authors research productivity, as also confirmed by Perkmann et al (2021).

5.2 Impact of the research

Firstly, the DBA deepened the author's knowledge regarding energy transition, technology diffusion and global wind power path creation. This knowledge was used directly in discussions with customers and other stakeholders (see section 2, 3 and 4). The author changed roles during the DBA from Service Area Manager Middle East and Central Asia, to Service Area Manager East Asia which included the role of Managing Director for the Philippines. In the latter role, the engagement with energy stakeholders increased and more of the knowledge obtained could be used. The knowledge acquired also allowed for critical reflection. Is the energy transition driven by risk mitigation to prevent climate change or by responding to climate change, a form of climate adaptation (Mauree *et al.*, 2019)? Can the current development within energy sources be described as energy transition (move from one source to another) or does it resemble diversification (additional sources to spread risk)? Regarding the interest in renewable energy, do people mean what they say (Bertrand and Mullainathan,

2001) or is the warm glow effect (Hartmann and Apaolaza-Ibáñez, 2012; Hartmann *et al.*, 2017) limiting them from telling their real motivations? To what extent is further wind energy exploitation desirable, when will the environmental and socio-economic disadvantages outweigh the advantages (Tabassum-Abbasi *et al.*, 2014)? Is climate change influenced by more than only human caused GHG emissions (Cohen and Stanhill, 2021; Dorman, 2021; Haywood, 2021; Lourens, 2021; Stenchikov, 2021)? Even if countries become carbon neutral the climate will continue to change. Having this in mind, is the current focus on carbon neutrality to avoid climate change justified? Should development solutions, such as electricity provision, be organized in a more decentralized manner (Ahlborg and Hammar, 2014) to avoid central accumulation of power (with the risk of large scale abuse)? Who will benefit the most from the economic development of emerging and developing economies? What is the role of the SDGs: monitoring global human wellbeing or trying to centrally control global growth? To what extent is the development of the world evolutionary, to what extent is it intentional (Zartha Sossa, López Montoya and Acosta Prado, 2021)? The author recognized the meaning of Aristotle's words "*the more you know, the more you know you don't know*". The hunger for knowledge resulted in a desire to change the approach: rather asking questions than making statements. This process will continue long after the DBA process is completed.

Secondly, new research methods were discovered. The most important part was becoming aware of the philosophical lens, which is positivism (Blaikie, 2007). Knowledge is developed through positive measurements, repeatable experiments. The evidence-informed management approach (Tranfield, Denyer and Smart, 2003) was applied to business situations, particularly focussing on measurable evidence.

5.3 Further dissemination and exploitation

The DBA helped the author to develop a new habit of continuous learning (leisure is for learning (Jedličková, 2017)). The knowledge gained through the DBA will be used in further personal corporate development. However, the broader process of energy transition sparked the authors interest and he is keen to

explore the other energy technologies that are important to the development of emerging markets. Also, the academic environment was inspiring. The author would appreciate if this could continue, for example by providing guest lectures related to energy management and energy transition (in emerging markets). Lastly, he would be delighted to be able to share his knowledge through non-executive board member roles for energy related businesses or start-ups.

6 Reflections

The impact plan, written at the beginning of the DBA, highlighted the difficulty to achieve an impact where stakeholders start *doing*. Impacting *thinking* and *feeling* would be steps before *actions*, which was targeted through publishing online articles and posts that enable engagement with stakeholders. Looking back at the impact achieved, this assessment was rather accurate. The main focus was on knowledge transfer, but it is a little early to point at real actions that were taken because of the research.

The detailed engagement of the impact plan is shown in the Table below.

Table 6 Stakeholders of the study and the impact strategy at the start of the DBA study in 2019.

Stakeholder type	Stakeholder name	Channel	Strategy
Primary stakeholder	Siemens Gamesa Renewable Energy (SGRE)	Internal communication, authors interactions with customers	<ul style="list-style-type: none"> • Get involved in business development • Use knowledge in customer discussions to support in growth • Publish articles on Yammer
Secondary stakeholder	Wind sector (private & public)	Energy / Renewable Energy / Wind Energy Organizations / Practitioners Journals	<ul style="list-style-type: none"> • Publish intermediate results through articles on organizations websites / during conferences • Use responses to shape research
Secondary stakeholder	Academic community in the field of energy management	Published papers	Aim to publish <ul style="list-style-type: none"> • Literature study (under review) • Results
Broader stakeholder	Electricity consumers / environmental stakeholders	Social media	Use social media (LinkedIn) <ul style="list-style-type: none"> • Build relevant network • Post content-based articles, linking news to knowledge developed in study • Focus on feeling, thinking and doing • Use relevant hashtags • Use SGRE to publish my results • Engagement through responses

The main stakeholders were regrouped over the course of the research, SGRE and the wind sector merged into one. Also, the author was added as a new category. Regarding the strategy, limited communication within SGRE has taken place, this is planned after completion of the DBA. Intermediate results were published and the responses were used to shape the direction. The SLR was published and social media was used to disseminate knowledge into the larger public.

Reflecting personally, the research has brought the author knowledge about concepts where he was not familiar with when writing the research proposal (for

example technology diffusion and positivism). It was never boring, despite having a busy job. Support of Cranfield was good, especially from the supervisor. The author is looking forward applying the knowledge to contribute to the energy sector to support sustainable development in emerging markets.

7 Conclusion

This research addressed multiple stakeholders at different levels. The aim of the engagement with the stakeholders was both to influence the research direction as well as to inform the stakeholders with new knowledge. The overview of the engagement is shown in the Table 7.

Table 7 Key impacts of stakeholders on the research and vice versa.

Stakeholder	Impact on the research	Impact of the research	Further dissemination / exploitation
Academic	Literature review brought focus: wind energy growth vs path creation	Published literature review (Zwarteveen <i>et al.</i> , 2021)	Published literature review to be read and cited
	Due to the feedback of the reviewers of the Journal of Cleaner Production, the research was positioned in the academic discussion of multi-perspective renewable energy diffusion.	Published empirical study (Zwarteveen, Zawwar and Angus, 2021)	Published empirical project to be read and cited
		Simulation study (Zwarteveen and Angus, 2022)	Published simulation study to be read and cited
Wind industry	Strategy summit of service SGRE: We have to get better at market entries: which market to enter, which one not to enter.	Academic journals for publishing were chosen based on having readers in the energy industry	Forward graphical summary to customers, industry groups, SGRE strategy department and industry news and ask for testimonial.
	Philippine Energy Transition forum: Coal energy growth even in clean energy scenario. Is the clean energy scenario showing a transition or a diversification?	Knowledge generated by research used in customer conversations	
		Knowledge disseminated as a speaker for industry groups and through industry publications	
Society	Sustainable Development Goals (in particular number seven) (United Nations, 2018)	Knowledge used in how the author officially represents SGRE externally through company news publications.	Continue to respond to energy transition and emerging market news
	News about energy transition and diversification, used for writing LinkedIn articles		
The author	Initial interest in market entry in emerging markets was leading to the formulation of the research proposal	Becoming aware of my philosophical lens: positivism	Use gained knowledge in further development: explore roles related to other technologies in the energy transition (hydrogen, energy fusion etc).
		Learning a new management skill: evidence-based management.	
		Development of interest in larger mechanism of energy transition	
			Involvement in academia, e.g. by providing guest lectures related to energy management and energy transition.
			Explore advisory board member roles for energy related start-ups

Appendices

Appendix A Academic impact journal

Table A-1 Academic impact journal, status 16-02-2022.

Date	Impact	Input received
03-2021	<p>Publication of literature study</p> <p>"Barriers and drivers of the global imbalance of wind energy diffusion: A meta-analysis from a wind power Original Equipment Manufacturer perspective"</p> <p>Journal of Cleaner Production</p> <p>(Zwarteveen <i>et al.</i>, 2021)</p>	<p>Journal reviewers: Place the research in an existing academic discussion.</p> <p>Adjustments made: Research was placed in the academic discussion about multi-perspective renewable energy diffusion (Montalvo and Kemp, 2008; Mignon and Bergek, 2016; Keeley and Matsumoto, 2018; She <i>et al.</i>, 2019)</p> <p>The novel part was to introduce the wind power Original Equipment Manufacturer point of view.</p>
06-2021	<p>Request for guest editing a new article collection based on the publication of the literature review (email)</p> <p>Dear Dr. Angus,</p> <p>At Frontiers in Sustainability we regularly scan for interesting, relevant research. Your article, Barriers and drivers of the global imbalance of wind energy diffusion: A meta-analysis from a wind power Original Equipment Manufacturer perspective, recently came to our attention.</p> <p>Based on your expertise in your field we'd like to offer you the opportunity to guest edit a new article collection with us.</p> <p>This is a great chance to shine a light on your area of research. Articles published in Frontiers' collections - or Research Topics - are highly discoverable and attract millions of views and downloads.</p> <p>If you're interested in this opportunity and would like to discuss it further with a member of the Frontiers in Sustainability team, please do get in touch.</p> <p>Best regards, Molly Hawes, Journal Manager</p>	
11-2021	<p>Publication of empirical paper</p> <p>"Market entry for wind energy: strategic approaches for the Original Equipment Manufacturer"</p> <p>Journal of Business Strategy and Development</p> <p>(Zwarteveen, Zawwar and Angus, 2021)</p>	<p>Journal reviewers: Specify the development context and strategic decisions that managers can make.</p> <p>Changes made: The significant role multinational companies have regarding the SGDs (Arnold, 2018) The definition of inclusive development to consider the empowerment of the marginalized (Gupta, Pouw and Ros-Tonen, 2015) The importance of local value creation through localization (Arnold, 2018) How wind power OEMs have failed to create inclusive market entries so far (Lacal-Arántegui, 2019) That business efforts need to be increased to achieve sustainability (Redman, 2018)</p>

		An additional paragraph has been added addressing the "implications for business strategy", and specific recommendations for practitioners was included.
04-2022	Simulation study accepted for publication	Journal reviewers:
	"Forecasting the probability of commercial wind power development in lagging countries"	Clarify clearly the differences between potential capacity and installed capacity.
	Cleaner Production Letters	Put into perspective: current installation vs potential capacity.
	(Zwarteveen and Angus, 2022)	Clarify the research gap this paper is addressing.
		Changes made:
		Included the explanation of high wind potential countries: it is the technical potential that is the measurement unit.
		Included the minimum potential (MW) for the high wind potential countries. Also, the lack of quantitative research to date to aid the wind power OEM in their internationalization efforts was introduced as the research gap addressed by the simulation paper.

Appendix B Industry impact journal

Table B-1 Industry impact journal, status 16-02-2022.

Date	Impact	Reference used	Input received
07-2019	Leading the discussion about renewable desalination with a large customer in the Middle East. Update 12-2021: They announced plans for renewable desalination and hydrogen production, unfortunately without SGRE.	The role of desalination in 100% renewable scenario (Barasa <i>et al.</i> , 2018)	Customer showed high interest in combining renewable energy and desalination. However, combined tenders needed to make it feasible.
10-2019 - ongoing	Renewable desalination: start of SGRE internal working group in corporate technology to explore potential of renewable desalination and SGREs role. This project merged with offshore hydrogen generation from wind power, which requires first to do the desalination.	The role of desalination in 100% renewable scenario (Barasa <i>et al.</i> , 2018)	
11-2019	Included different motives (energy security, job creation, environmental benefits) in presentation to Kuwait oil companies to understand what drives them to potentially invest in wind energy.	What drives investment in wind energy (Ydersbond and Korsnes, 2016)	Audience was interested in the levelized costs of energy for wind energy. Levelized costs of pilot wind energy in Kuwait was lower than for pilot solar PV project.
12-2019	Discussion with head of large wind energy operator in Russia on future of Russian market and their drivers.	Literature study: what motivates governments to adopt wind energy (Ydersbond and Korsnes, 2016)	Based on this discussion, customer requested to lobby together for more wind growth in Russia. Joined partnerships needed to open new markets.
02-2020	Discussion with sales director APAC to understand drivers of wind energy in different Asian countries.	Literature study (work in progress) (Zwarteveen <i>et al.</i> , 2021)	
05-2020	Discussion with CEO Siemens Philippines about stimulating the post-covid recovery	Literature study (work in progress): the importance of economic drivers for wind energy uptake (Zwarteveen <i>et al.</i> , 2021)	
05-2020	Yammer Q&A with CEO SGRE Markus Tacke on the importance of job creation vs climate change in the post covid recovery period.	Economic benefits of wind energy, based on literature study (work in progress) (Zwarteveen <i>et al.</i> , 2021)	The answer of Markus Tacke: Climate change mitigation and economic benefits key elements of Green Recovery.
08-2020	Interviewed on the 14th of Aug by energy journalist Myrna Velasco about the potential of wind energy in the Philippines. Aim is to use the information in a report for energy planning for the Philippines. Published 09-2020 (Velasco, 2020)	Economic benefits of wind energy, based on literature study (work in progress) (Zwarteveen <i>et al.</i> , 2021)	Concerns about the intermittency of wind power
09-2020	Participation in Energy Round Table of the Philippines, focussing on 2018-2040 energy plan	Asked question related to if there is a real desire for renewable energy given the recent significant increase in coal energy.	Even though renewable energy is interesting, no real transition is taking place. It resembles a diversification.
10-2020	Meeting with the Chair of the Philippine National Renewable Energy Board (advisory & monitoring board of government), Monalisa Dimalanta	Tried to link renewable energy deployment with economic recovery, especially after Covid.	Confirmation of the importance of job creation of renewable energy

10-2020	Speaker on the Wind Energy Developers Association Philippines meeting for 45 minutes.	Discussing how to stimulate wind energy deployment in the Philippines (energy security, cost reduction and job creation). Content based on literature study (work in progress) (Zwarteveen <i>et al.</i> , 2021)	Renewable Portfolio Standards: uncertain how effective this policy will be. Technology specific policy needed
11-2020	Speaker on the Nordic Innovation Forum. The Nordics Inspire the Philippines to Act Smart and Sustainable.	Split between desire for renewable energy and mechanism of change. Content based on literature study (Zwarteveen <i>et al.</i> , 2021)	The Philippines signed a moratorium of new coal investment.
01-2021	Participant in the Philippine Energy Transition group discussion (Philippine Energy Independence Council & European Chamber of Commerce Philippines)	Address the economic drivers of the transition: jobs & cost savings. Presented the visual summary of the literature study (Zwarteveen <i>et al.</i> , 2021)	In the clean energy scenario, coal consumption will grow with 100%. In the standard scenario coal consumption will grow with 300%. Integration of intermittent renewable energy is considered to be a problem.
02-2021	Author of an article in the newsletter of ASEAN center for Energy (supported by GIZ) - 4,247 subscribers Published online 03-21, (Zwarteveen, 2021) Published in ASEAN email newsletter in 05-21.	The literature study (Zwarteveen <i>et al.</i> , 2021)	Wind energy currently competes with most traditional energy sources in ASEAN countries. (ASEAN center for energy and GIZ, 2019) As stated in the 6th ASEAN Energy Outlook (ASEAN center for energy, 2020), the increased installation of wind power in the APAEC Target Scenario would add about 61,000 jobs in 2025 and about 83,000 jobs in 2040 to the region
04-2021	Speaker on GIZ / ASEAN center for Energy (ACE) - Virtual Talkshow: Facts and Myths about Energy Transition - 240 registered participants (Youths 18-30)	The literature study (Zwarteveen <i>et al.</i> , 2021)	Coal exporting countries might soon become energy importing countries due to the increase in domestic consumption (e.g. Indonesia) Questions from the audience: What is the energy transition and why is it happening? Is renewable energy expensive?
04-2021	Discussion on the reasons for countries to join the paris climate agreement with one of the negotiators representing the European Union for the Paris agreement.	Warm glow effect explained (Hartmann and Apaolaza-Ibáñez, 2012; Hartmann <i>et al.</i> , 2017)	The 1:1 discussions with countries were touching the economic benefits and energy security (e.g. independence of Russian gas), but the plenary sessions mainly focussed on the environmental side.
05-2021	Meeting with director of GIZ in the Philippines and climate programme director of GIZ	Warm glow (Hartmann and Apaolaza-Ibáñez, 2012; Hartmann <i>et al.</i> , 2017) and energie wende	Opinion of Philippine Energy Secretary Cusi changed since 5 years ago. It was only cheap and reliable (which was coal). 70% was coal, 30% could

			be played with. Now not anymore.
05-2021	Participation in 2021 SGRE service strategy summit		Key question for SGRE is: which market to enter, which one not to enter
05-2021	Discussion about a new project in Davao with a potential new customer	Importance of economic benefits of wind energy, based on the literature study (Zwarteveen <i>et al.</i> , 2021)	Motivation for wind energy also included: community care. All benefits normally go to the main Island Luzon, Mindanao falls behind. Fluctuating uncontrollable oil price was mentioned as a reason to explore wind.
05-2021	Interviewed following the announcement of winning a new wind project in the Philippines. (Chen, 2021; Mavrokefalidis, 2021; RENews, 2021; Reve, 2021)	Share my view on low cost and job creation benefits of wind, based on findings in the literature study (Zwarteveen <i>et al.</i> , 2021)	
06-2021	Invited by the president of the Wind Energy Developers Association Philippines to discuss how to promote offshore wind energy in the Philippines	Empirical study: job, security, energy diversification. Working together with existing power producers to de-risk their energy portfolio. Combination of wind and hydro. Based on the empirical study (to be published)	Replacing import of LNG with wind. Intermittency simply to be solved with batteries. Caliraya lake as energy storage
01-2022	Contributed to the Call for Action of the Global Wind Energy Council (GWEC) to accelerate offshore wind energy in the Philippines	Literature study and empirical study	

Table B-2 Visual journal status, 16-02-2022.

Date	Material and source	
27-05-2020	Source: Internal SGRE social platform	
	 Zwarteveen, Jan Willem (SGRE SE R APAC ON O)	Seen by 1,191
	May 13, 2020	
	Hello Markus,	
	Thank you for the opportunity to ask questions.	
	For the post-covid economic recovery, job creation seems to be crucial. Climate change is still a topic countries are looking at, however as the economic problems are more certain and more urgent, the economic recovery seems to be prioritized.	
	Three questions:	
	<ul style="list-style-type: none">• Does wind energy create more jobs compared to other renewables and conventional energy generation?• And are you planning to rebrand our "green energy" to "job creating energy", potentially even putting some productivity programs on hold and hiring additional personnel (and ask governments for subsidies)?• Due to limited recovery budget in developing countries, what is your outlook for market growth in these parts of the world?	



Tacke, Markus Michael (EXT) (SGRE) May 27, 2020
Hi Jan, extensive questions, so let's take it one by one:



Q1: According to IRENA, the Renewable Energy sector employed worldwide 11 million people at the end of 2018. Over 3 million jobs are in solar PV, more than 1.2 million in wind – these are worldwide figures, it looks different in the regions. Many governments have prioritized renewable energy development to reduce emissions and meet international climate goals, also in pursuit of broader socio-economic benefits. Wind projects and manufacturing are often in what were declining industrial areas and small towns in rural areas. Old shipyard areas profit from becoming offshore wind hubs, so this is very relevant for regional development.

Q2: Since the outbreak of the pandemic and the consequences of the COVID-19 crisis on the economy have become apparent, we have been very active supporting initiatives for a 'green recovery' (with messages, with our logo). Core message is that tackling climate change remains a central task. Investment in clean technologies such as wind power will be a solution in the green recovery, it is future oriented and will bring economic benefits. You can view this also on our social media channels where we have been very active.

Q3: Our efforts in putting Wind power at the heart of the post pandemic situation are global, thanks to our global leadership and positioning. I'm personally involved in a number of discussions with government representatives. Wind is the most competitive energy source in many places, we successfully develop local value chains wherever we operate and there is a clear bet throughout the whole value chain (investors, Utilities, IPPs, OEMs, suppliers...) to unlock the full potential of our sector. Developing markets (LATAM, Africa and APAC- excl China) will indeed play a key role, on top of new emerging OF markets, where ON is already well established. When raising our voice towards putting renewable energy at the center of the post pandemic scenario, we at SGRE are engaged with key stakeholders in emerging markets. For example, we are funding members of the renewAfrica initiative, a European multi-stakeholder backed initiative to accelerate Africa's sustainable energy transition. It seeks to catalyze renewable energy investments that will foster the continent's future sustainable development.

23-09-2020

Source: (Velasco, 2020)

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BUSINESS / TRADE & ENERGY / RE-volution: Trinity of energy, climate change and job creation solutions

Business, Trade & Energy

RE-volution: Trinity of energy, climate change and job creation solutions

Published September 23, 2020, 5:00 AM
by Myrna M. Velasco

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Jan Willem Zwarteveen, managing director of Siemens Gamesa Philippines, opined that if the Philippines could take advantage of the reinvigorated interest of investors in the RE sector, "this will serve as a fantastic opportunity to solve the predicament of the millions of job losses caused by Covid-19."

04-11-2020

Source: LinkedIn, Nordic Chamber of Commerce



Nordic Innovation Forum
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Smart Energy Reactor



Jan Willem Zwartveen
Managing Director, Philippines,
Siemens Gamesa Renewable
Energy

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The award winning alumni of both Stanford University and Delft University of Technology, Jan Willem Zwartveen has a passion for renewable energy and developing countries. This passion brought him as multi's teacher to a lecturing in South Africa and as a process engineer to a bio diesel factory in Kenya. About 10 year ago, he joined Siemens Gamesa, where he held several management positions including service area manager for Middle East, Central Asia and Africa. Currently he is the CEO of Siemens Gamesa Renewable Energy in the Philippines as well as the service area manager for Japan, Korea, Indonesia, Thailand and the Philippines. He has around 1.5 GW distributed over 30 wind farms under his operational responsibility.

In developing countries, he experienced the big impact economic growth has on the population and the important role of technology. In words of Mahatma Gandhi: "While technology is important, it's what we do with it that truly matters". Jan is an advocate of making profit and improving livelihoods through it.

Along his journey, he obtained a master's degree in Mechanical Engineering. To understand the role of technology in developing countries, he is currently writing his doctoral dissertation at Cranfield School of Management in the field of wind energy growth in developing countries.

In his spare time, he gets his hands dirty by working on vintage cars. His latest project is a Fiat conversion from diesel to vegetable oil of a vintage White Jeep, a car that continuously breaks down.

Just like his dog, Jan becomes restless and annoyed without his daily work out. Together with his wife and friends, he likes to run long distances in nature. He has participated in 115 ultra trail marathons up to 100km, from which he was unable to finish.

He dreams of reducing poverty, contributing to a cleaner world and maybe finishing a 100 mile triathlon.

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03-2021

Source: (Zwartveen, 2021)



The Economic Importance of Energy Diversification for Emerging Markets



Photo Credit: Siemens Gamesa

by: Jan Willem Zwartveen, Managing Director Siemens Gamesa Renewable Energy Philippines

A recently published meta-analysis identified 259 factors influencing wind energy diffusion (<https://doi.org/10.1016/j.jclepro.2020.125636>).

26-05-2021 Source: (Chen, 2021)

Siemens Gamesa to supply largest wind farm in the Philippines as wind momentum builds in the country

"As the leading wind and hybrid solution provider in the Philippines, we have expanded our local presence and accumulated prov experience to exceed customer expectations. We are well positioned to support our customers and partners to accelerate the per wind energy, bringing low-cost electricity to many households and creating job opportunities in communities as well as improv energy security during the post-Covid green recovery," added Jan Zwartveen, Managing Director of Siemens Gamesa in the Phi

28-04-2021

Source: LinkedIn, ASEAN Foundation



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<p>Moderator</p> <div> <p>Mahmudi Yusbi Head of Programme, ASEAN Foundation</p> </div>	<p>Moderator</p> <div> <p>Ricky Fauzianto Team Leader Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)</p> </div>

Appendix C Social media impact journal

Table C-1 Social media impact journal LinkedIn, status 16-02-2022.

Date	Topic	Impact	Reference used	Input received
07-2019	Creating clean water with green energy	3493 views, 45 responses, 2 comments	Scoping study: role of desalination in 100% renewable scenario (Barasa <i>et al.</i> , 2018)	What would be the best solution: large scale or decentralized small scale?
09-2019	Fossil free living: is there a name for this lifestyle?	1210 views, 16 responses, 0 comments	Vattenfall's commercial on fossil free within one generation	
03-2020	Will the #Coronavirus increase the desire for local #windenergy? Scramble for goods to supply basic needs - electricity import dependency	1478 views, 16 responses, 1 comment	Analysis on desire and electricity security (Zwarteveen <i>et al.</i> , 2021) and recent Covid developments	Pause could lead to reckoning
03-2020	Covid19 and the desire for wind energy. Short term drop of electricity demand and drop in electricity price	1406 views, 19 responses, 1 comment	Analysis on desire and economic value, price of wind, environment (Zwarteveen <i>et al.</i> , 2021) and recent Covid developments	Change is never ending
04-2020	Is there a shift in power taking place away from the #oilindustry (and what would that mean)?	1848 views, 20 responses, 1 comments, 1 re-share	Analysis on desire based on vested interests (Zwarteveen <i>et al.</i> , 2021) and recent Covid developments	Important influences: the economics and the world leaders' response to climate change and pollution
04-2020	When the recovery begins, Canada can build a stronger and more resilient economy by investing in a cleaner and healthier future for everyone	1068 views, 13 responses, 0 comments	Analysis of desire based on spill-over effects (Zwarteveen <i>et al.</i> , 2021) and recent Covid developments	
04-2020	We are in a crisis when the data tells us	1361 views, 19 responses, 2 comments	Education & change in behavior (needs and desires)	Selection of data sources is the choice of the individual.
05-2020	The world need a green recovery for economic reasons, not for environmental reasons	2379 views, 35 responses, 3 comments	Environmental and economic aspects of renewable energy transition compared (Zwarteveen <i>et al.</i> , 2021)	Would the time when the impact is expected to take place also influence decision making regarding the energy transition?
05-2020	Jobs created per energy source	7260 views, 63 responses, 10 comments	Job creation as one of the drivers for renewable energy (Zwarteveen <i>et al.</i> , 2021), additional source on number of jobs for energy sources per 1 Mio USD spending	What will be the impact of digitalization? What types of jobs will be created?
05-2020	End of dominant investment in oil and gas in emerging markets?	836 views, 5 responses	Recovery budgets of development banks & new vested interest rise (Zwarteveen <i>et al.</i> , 2021)	
05-2020	Job loss during Covid, with a focus on low and middle income countries	888 views, 3 responses	Job creation as one of the drivers for renewable energy (Zwarteveen <i>et al.</i> , 2021), additional source on actual job loss globally	
05-2020	Renewables are the smallest losers during the covid crisis, but	2704 views, 24 responses, 2 comments	Energy transition driven by multiple reasons, not only green.	Governments play an important role regarding the

	who will be the biggest winners during the recovery?			investments in renewables
06-2020	The post-covid "Energie-Wende" has started in Asia	1601 views, 17 responses, 0 comments	Energy transition Korea vs Germany. And rest of Asia	
06-2020	With the cost reductions we're seeing, we're outcompeting with all kinds of fuels. You can't build gas-fired plants and coal plants and nuclear plants that can match wind	2106 views, 32 responses, 0 comments	Wind pioneer highlighting economic value of wind energy	
06-2020	World CO2 emissions dropped during the financial crisis of 2008-2009 and showed a record increase during the recovery	1034 views, 17 responses, 0 comm	Warm glow effect in practice	
06-2020	Extending the lifetime of existing nuclear reactors is one of the recommendations by the IEA	1047 views, 6 responses, 0 comm	Use of local resources as benefit	
07-2020	Energy security in the Philippines	801 views, 6 responses, 0 comm	Energy security as driver for renewable energy	
07-2020	Job losses and wind energy in the Philippines	1290 views, 7 responses, 1 comm	Job loss as driver for renewable energy	What is the total amount of jobs wind can bring to the Philippines?
07-2020	Siemens Energy CEO vision of hydrogen development in emerging markets	2311 views, 43 responses, 0 comm	Hydrogen to make wind energy an export product	
08-2020	Share prices of oil companies that participate in energy transition go up, others down	2196 views, 19 responses, 4 comm	Perceived value of renewable energy	Fossil fuel is not future-proof. Policy interventions make investments in fossil fuels less predictable. In EU the direction is towards net-zero carbon world by 2050
09-2020	Vietnam, isomorphism and the energy plan	2418 views, 33 responses	Isomorphism and renewable energy increase. Vietnam as an example for other Asian countries.	
11-2020	Philippines and no new coal power plants	2680 views, 62 responses, 6 comm	Energy transition drivers of energy security, cost savings, job creation and environment	How to ensure grid stability with renewables?
02-2021	Role of women in the energy transition (Internationalwomensday)	2082 views, 38 responses, 1 comment	Role of women in energy transition (Loarne-Lemaire <i>et al.</i> , 2021), Asia pacific energy week with only 6% female panel participation	More women and better education might lead to unlocking more solution pathways
03-2021	Reference to article with GIZ on economic importance of energy diversification	1666 views, 26 responses, 1 comment	Reference to own literature study. Economic importance.	
05-2021	Green job potential in Philippines	2138 views, 38 responses, 2 comments	Importance of jobs in energy transition	Is replacement of coal possible with renewable energy in the Philippines?

06-2021	Reference to SGRE winning largest wind farm order in PH	6382 views, 150 responses, 14 comments	Reference to energy security, job creation and clean air	Is there battery storage capacity needed?
07-2021	Increase in coal price, impact on energy diversification of coal-dependent countries	4071 views, 26 responses, 2 comments	Business case potential as key driver for energy transition	Interesting to see if the shift in non-China countries will be enough to offset the higher GHG emissions expected from higher coal use of China.
07-2021	Announcement of Philippine Energy Secretary Cusi in favour of wind energy.	4150 views, 85 responses	Energy security, job creation	
08-2021	ADB to ramp down existing coal power plants before end of life	1231 views, 24 responses, 1 comment	The impact of globalization	
01-2022	Offshore energy attracting attention in the Philippines	3495 views, 57 responses, 2 comments	Spill-over effects as driver for wind energy	

Table C-2 Visual overview of interactions with key experts on LinkedIn, status 16-02-2022.

Date	Material
	<div><div></div><div><div>Nuki Agya Utama, PhD · 1st</div><div>Executive Director at ASEAN Centre for Energy</div><div>Talks about #asean, #energy, #energypolicy, #energysecurity, and #renewableenergy</div><div>Indonesia · Contact info</div><div>2,684 followers · 500+ connections</div></div><div> ASEAN Centre for Energy</div></div>
04-2021	<div><div></div><div><div>Nuki Agya Utama, PhD · 1st</div><div>Executive Director at ASEAN Centre for Energy</div><div>3mo · </div></div></div> <p>"The survey found the executives saw a number of hurdles in the way of progress, including the need for greater levels of finance, particularly in emerging economies, and better measurement and reporting standards."</p> <p>The role of private sectors mostly aiming short and medium term perspective, while the role of policy makers plays on the longer term perspective.</p> <p>Overseeing the energy transition we need to see the broaden and longterm energy view, through energy planning. By developing more realistic scenarios as well as by including all possible primary energy supply both renewable and non renewable is a wise choices. The cost optimization is a must approach in order to make sure that the countries will not sink into a deeper debt or choosing a wrong technology and fuel.</p> <p>https://lnkd.in/gx7_eCh</p> <p>#energy #energypolicy #asean</p> <p>Most relevant ▾</p> <div><div></div><div><div>Jan Willem Zwartveen · You</div><div>Driving the energy diversification: ensuring stable renewable power gen...</div><div>3w ...</div></div><div><p>The "warm-glow effect" explains that people have a preference to formulate pro-social statements, such as a net zero strategy. In practice however, it is likely that decisions are driven by other factors. I believe that an energy transition, especially in emerging markets, is truly driven by energy security and economic (cost and job creation) reasons. If the technology improves on those levels, a quick diversification will be seen.</p></div><div><div>Like ·  2</div><div>Reply · 1 Reply</div></div></div> <div><div></div><div><div>Nuki Agya Utama, PhD Author</div><div>Executive Director at ASEAN Centre for Energy</div><div>3w ...</div></div><div><p>Indeed, couldn't agree more. Energy security and affordability should hand in hand with the decarbonization policies</p></div><div><div>Like ·  1</div><div>Reply</div></div></div>



Monalisa Dimalanta · 1st

Asia-Pacific IFLR1000 Women Leaders for 2021, 100 Most Influential Filipino Women on LinkedIn. 2020 Women in Renewables Asia awardee

Philippines · [Contact info](#)

500+ connections



PJS Law

Lee Kuan Yew School of Public Policy



04-2021



Monalisa Dimalanta · 1st

Asia-Pacific IFLR1000 Women Leaders for 2021, 100 Most Influential Filipino Women on LinkedIn. 2020 Women in Renewables Asia awardee

3mo · 

Worth developing a similar model or tool for an archipelago like the Philippines...

"This modeling disproves the old paradigms that claim DERs are too expensive. Continuing to invest in centralized solutions, without considering the contributions from new distributed technologies, will result in a costly energy system, with stranded and underutilized investments. And, as we all know, stranded utility costs are traditionally paid for by customers. It's clear the needs of the electric grid are evolving to a more distributed energy future."

[#re4phrecovery](#) [#distributedenergyresources](#)

<https://lnkd.in/gErUK2P>





Jan Willem Zwarteveen · You

Driving the energy diversification: ensuring stable renewable power gen...

3mo · 

Thank you for sharing [Monalisa Dimalanta](#). Additionally, decentralized systems are likely to be more resilient to climate change related disasters.

Like ·  1 | Reply · 1 Reply



Monalisa Dimalanta **Author**

Asia-Pacific IFLR1000 Women Leaders for 2021, 100 Most Influential Filipino Women on LinkedIn. 2020 Women in Renewables Asia awardee

3mo · 

Indeed, [Jan Willem](#)!

Like ·  1 | Reply

274

07-2021



Jan Willem Zwarteveen

Driving the energy diversification: ensuring stable renewable power generati...
4d •

The business case potential of [#renewableenergy](#), measured as the electricity price minus the LCoE of renewables, is likely to be a key contributor to the [#energydiversification](#) and [#energytransition](#).

The coal price recently hit record high (since 2011), caused by a strong demand in [#China](#). High coal prices might make renewable alternatives more interesting for many other coal-dependent countries.

Will we soon witness that China's hunger for coal is causing an increase in energy diversification in the rest of the world?



Indonesia sets coal benchmark price at highest in a decade on Chinese demand

reuters.com • 1 min read



Monalisa Dimalanta • 1st

Asia-Pacific IFLR1000 Women Leaders for 2021, 100 Most Influential Fili...

3d •••

Interesting to see if the shift in non-China countries will be enough to offset the higher GHG emissions expected from higher coal use of China.



Christoph Zipf • 2nd

Press & Communications Manager bei WindEurope

Brussels, Brussels Region, Belgium • [Contact info](#)

500+ connections

 WindEurope



Jan Willem Zwarteveen

Driving the energy diversification: ensuring stable renewable power generati...

11mo • Edited •



08-2020

The targeted return on [#oilinvestment](#) is around 15%. For [#renewableenergy](#) it is between 7%-10%.

https://lnkd.in/eB5ny_y

Interestingly, the share prices of energy companies that are transferring to renewable energy have increased, whereas traditional oil companies saw a sharp decrease.

This indicates two things:

- Investors value a lower return with renewables more than a higher (but volatile) return with oil.
- Oil companies need to transition to renewables in order to keep the share price up.

The [#energytransition](#) to renewable energy seems to be driven by the risk appetite of investors. The open question is: will the picture change once the economic recovery starts?



Christoph Zipf • Following

Press & Communications Manager bei WindEurope

10mo • • •

We (at least in the EU) are moving towards a net-zero carbon world by 2050. If you don't want to gamble for short term profits but build up a solid long-term portfolio, you need to invest in companies that are future-proof. Policy interventions such as carbon pricing, emission targets, etc. make investments in fossil fuels less predictable. Investors seem to have understood this fact.

Like • 4 • Reply • 1 Reply

References

- Abdmouleh, Z., Alammari, R. A. M. and Gastli, A. (2015) 'Review of policies encouraging renewable energy integration & best practices', *Renewable and Sustainable Energy Reviews*. doi: 10.1016/j.rser.2015.01.035.
- Ahlborg, H. and Hammar, L. (2014) 'Drivers and barriers to rural electrification in tanzania and mozambique - grid-extension, off-grid, and renewable energy technologies', *Renewable Energy*, 61, pp. 117–124. doi: 10.1016/j.renene.2012.09.057.
- Alexa (2021a) *academia.edu Competitive Analysis, Marketing Mix and Traffic*. Available at: <https://www.alexacom/siteinfo/academia.edu> (Accessed: 23 July 2021).
- Alexa (2021b) *researchgate.net Competitive Analysis, Marketing Mix and Traffic*. Available at: <https://www.alexacom/siteinfo/researchgate.net> (Accessed: 23 July 2021).
- Arnold, M. G. (2018) 'Sustainability value creation in frugal contexts to foster Sustainable Development Goals', *Business Strategy & Development*, 1(4), pp. 265–275. doi: 10.1002/bsd2.36.
- ASEAN center for energy (2020) *The 6th ASEAN energy outlook (AEO6)*. Jakarta. Available at: <https://aseanenergy.org/the-6th-asean-energy-outlook/>.
- ASEAN center for energy and GIZ (2019) *Levelised costs of electricity (LCOE) for selected renewable energy technologies in ASEAN member states II*. Jakarta. Available at: <https://aseanenergy.org/levelised-costs-of-electricity-for-renewable-energy-technologies-in-asean-member-states-ii/>.
- ASEAN Climate Change and Energy Project (2021) *ARNECC Paper Talks*. Available at: <https://accept.aseanenergy.org/event/arnecc-paper-talks-1-event/> (Accessed: 3 December 2021).
- Barasa, M., Bogdanov, D., Oyewo, A. S. and Breyer, C. (2018) 'A cost optimal resolution for Sub-Saharan Africa powered by 100% renewables in 2030',

Renewable and Sustainable Energy Reviews, 92, pp. 440–457. doi: 10.1016/j.rser.2018.04.110.

Bertrand, M. and Mullainathan, S. (2001) 'Do people mean what they say? Implications for subjective survey data', *American Economic Review*, 91(2), pp. 67–72. doi: 10.1257/aer.91.2.67.

Blaikie, N. (2007) 'Approaches to social enquiry: Advancing knowledge (2nd edition)', *Contemporary Sociology*. doi: 10.2307/2076918.

Chen, D. (2021) *Siemens Gamesa to supply largest wind farm in the Philippines as wind momentum builds in the country*, Siemens Gamesa. Available at: <https://www.siemensgamesa.com/en-int/newsroom/2021/05/212605-siemens-gamesa-press-release-largest-wind-farm-philippines> (Accessed: 23 July 2021).

Cohen, S. and Stanhill, G. (2021) 'Changes in the Sun's radiation', in *Climate Change*. Elsevier, pp. 687–709. doi: 10.1016/B978-0-12-821575-3.00032-3.

Deiaco, E., Hughes, A. and McKelvey, M. (2012) 'Universities as strategic actors in the knowledge economy', *Cambridge Journal of Economics*, 36(3), pp. 525–541. doi: 10.1093/cje/bes024.

Dorman, L. I. (2021) 'Space weather and cosmic ray effects', in *Climate Change*. Elsevier, pp. 711–768. doi: 10.1016/B978-0-12-821575-3.00033-5.

Elsevier (2021a) *Cleaner Production Letters*. Available at: <https://www.elsevier.com/journals/cleaner-production-letters/2666-7916/guide-for-authors>.

Elsevier (2021b) *Journal of Cleaner Production*. Available at: <https://www.journals.elsevier.com/journal-of-cleaner-production> (Accessed: 23 July 2021).

Google Scholar (2021) *Categories: Life Sciences and Earth Sciences, Sustainable Development, Top Publications*. Available at: https://scholar.google.com/citations?view_op=top_venues&hl=en&vq=bio_sustainabledevelopment (Accessed: 8 September 2021).

Gupta, J., Pouw, N. R. M. and Ros-Tonen, M. A. F. (2015) 'Towards an Elaborated Theory of Inclusive Development', *The European Journal of Development Research*, 27(4), pp. 541–559. doi: 10.1057/ejdr.2015.30.

Hartmann, P. and Apaolaza-Ibáñez, V. (2012) 'Consumer attitude and purchase intention toward green energy brands: The roles of psychological benefits and environmental concern', *Journal of Business Research*. Elsevier Inc., 65(9), pp. 1254–1263. doi: 10.1016/j.jbusres.2011.11.001.

Hartmann, P., Eisend, M., Apaolaza, V. and D'Souza, C. (2017) 'Warm glow vs. altruistic values: How important is intrinsic emotional reward in proenvironmental behavior?', *Journal of Environmental Psychology*. Elsevier Ltd, 52, pp. 43–55. doi: 10.1016/j.jenvp.2017.05.006.

Haywood, J. (2021) 'Atmospheric aerosols and their role in climate change', in *Climate Change*. Elsevier, pp. 645–659. doi: 10.1016/B978-0-12-821575-3.00030-X.

International Monetary Fund (2018) *World Economic Outlook - Database - WEO Groups and Aggregates Information*. Available at: <https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/groups.htm> (Accessed: 5 November 2018).

Jedličková, I. (2017) 'Leisure-Time Activities and Lifelong Learning', in *Leisure, Health and Well-Being*. Cham: Springer International Publishing, pp. 179–186. doi: 10.1007/978-3-319-33257-4_16.

John Wiley and Sons (2021) *Business Strategy and Development*. Available at: <https://onlinelibrary.wiley.com/page/journal/25723170/homepage/forauthors.htm> (Accessed: 23 July 2021).

Keeley, A. R. and Matsumoto, K. (2018) 'Investors' perspective on determinants of foreign direct investment in wind and solar energy in developing economies – Review and expert opinions', *Journal of Cleaner Production*, 179, pp. 132–142. doi: 10.1016/j.jclepro.2017.12.154.

Keown, C. (2021) *European wind turbine makers blown off course. Here's why.*,

Market Watch. Available at: <https://www.marketwatch.com/story/european-wind-turbine-makers-blown-off-course-heres-why-11626366245> (Accessed: 23 July 2021).

Lacal-Arántegui, R. (2019) 'Globalization in the wind energy industry: contribution and economic impact of European companies', *Renewable Energy*, 134, pp. 612–628. doi: 10.1016/j.renene.2018.10.087.

Loarne-Lemaire, S. Le, Bertrand, G., Razgallah, M., Maalaoui, A. and Kallmuenzer, A. (2021) 'Women in innovation processes as a solution to climate change: A systematic literature review and an agenda for future research', *Technological Forecasting and Social Change*, 164, p. 120440. doi: 10.1016/j.techfore.2020.120440.

Lourens, L. J. (2021) 'The variation of the Earth's movements (orbital, tilt, and precession) and climate change', in *Climate Change*. Elsevier, pp. 583–606. doi: 10.1016/B978-0-12-821575-3.00028-1.

Mauree, D., Naboni, E., Coccolo, S., Perera, A. T. D., Nik, V. M. and Scartezzini, J.-L. (2019) 'A review of assessment methods for the urban environment and its energy sustainability to guarantee climate adaptation of future cities', *Renewable and Sustainable Energy Reviews*, 112, pp. 733–746. doi: 10.1016/j.rser.2019.06.005.

Mavrokefalidis, D. (2021) *Wind blows faster in Philippines*, *Energy Live News*. Available at: https://www.energylivenews.com/2021/05/26/wind-blows-faster-in-philippines/?__cf_chl_jschl_tk__=pmd_9efbcf4ac8c30bbf81c7c5baf8f395a896ddff32-1627026518-0-gqNtZGzNAk2jcnBsZQb6 (Accessed: 23 July 2021).

Mignon, I. and Bergek, A. (2016) 'System- and actor-level challenges for diffusion of renewable electricity technologies: an international comparison', *Journal of Cleaner Production*. Elsevier Ltd, 128, pp. 105–115. doi: 10.1016/j.jclepro.2015.09.048.

Mina, A., Bascavusoglu-Moreau, E. and Hughes, A. (2014) 'Open service innovation and the firm's search for external knowledge', *Research Policy*, 43(5),

pp. 853–866. doi: 10.1016/j.respol.2013.07.004.

Montalvo, C. and Kemp, R. (2008) 'Cleaner technology diffusion: case studies, modeling and policy', *Journal of Cleaner Production*. doi: 10.1016/j.jclepro.2006.06.005.

Negro, S. O., Alkemade, F. and Hekkert, M. P. (2012) 'Why does renewable energy diffuse so slowly? A review of innovation system problems', *Renewable and Sustainable Energy Reviews*. doi: 10.1016/j.rser.2012.03.043.

Perkmann, M., Salandra, R., Tartari, V., McKelvey, M. and Hughes, A. (2021) 'Academic engagement: A review of the literature 2011-2019', *Research Policy*, 50(1), p. 104114. doi: 10.1016/j.respol.2020.104114.

Polzin, F., Egli, F., Steffen, B. and Schmidt, T. S. (2019) 'How do policies mobilize private finance for renewable energy?—A systematic review with an investor perspective', *Applied Energy*, 236, pp. 1249–1268. doi: 10.1016/j.apenergy.2018.11.098.

Priem, J., Taraborelli, D., Groth, P. and Neylon, C. (2010) *Altmetrics: a manifesto*. Available at: <http://altmetrics.org/manifesto/>.

Redman, A. (2018) 'Harnessing the Sustainable Development Goals for businesses: A progressive framework for action', *Business Strategy & Development*, 1(4), pp. 230–243. doi: 10.1002/bsd2.33.

RENews (2021) *Siemens Gamesa picks up 160MW Philippines deal*, *RENews.biz*. Available at: <https://renews.biz/69836/siemens-gamesa-picks-up-160mw-philippines-deal/> (Accessed: 23 July 2021).

Reve (2021) *Siemens Gamesa to supply largest wind farm in the Philippines*, *Evwind*. Available at: <https://www.evwind.es/2021/05/26/siemens-gamesa-to-supply-largest-wind-farm-in-the-philippines/80959> (Accessed: 23 July 2021).

She, Z. Y., Cao, R., Xie, B. C., Ma, J. J. and Lan, S. (2019) 'An analysis of the wind power development factors by Generalized Bass Model: A case study of China's eight bases', *Journal of Cleaner Production*. Elsevier Ltd, 231, pp. 1503–

1514. doi: 10.1016/j.jclepro.2019.05.255.

Stenchikov, G. (2021) 'The role of volcanic activity in climate and global changes', in *Climate Change*. Elsevier, pp. 607–643. doi: 10.1016/B978-0-12-821575-3.00029-3.

Strantzali, E. and Aravossis, K. (2016) 'Decision making in renewable energy investments: A review', *Renewable and Sustainable Energy Reviews*. doi: 10.1016/j.rser.2015.11.021.

Tabassum-Abbasi, Premalatha, M., Abbasi, T. and Abbasi, S. A. (2014) 'Wind energy: Increasing deployment, rising environmental concerns', *Renewable and Sustainable Energy Reviews*, 31, pp. 270–288. doi: 10.1016/j.rser.2013.11.019.

Thelwall, M. and Kousha, K. (2015) 'ResearchGate: Disseminating, communicating, and measuring Scholarship?', *Journal of the Association for Information Science and Technology*, 66(5), pp. 876–889. doi: 10.1002/asi.23236.

Tranfield, D., Denyer, D. and Smart, P. (2003) 'Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review', *British Journal of Management*, 14(3), pp. 207–222. doi: 10.1111/1467-8551.00375.

United Nations (2018) *Sustainable Development Goal 7*. Available at: <https://sustainabledevelopment.un.org/sdg7> (Accessed: 26 October 2018).

Velasco, M. (2020) *RE-volution: Trinity of energy, climate change and job creation solutions*, *Manila Bulletin*. Available at: <https://mb.com.ph/2020/09/23/re-revolution-trinity-of-energy-climate-change-job-creation/> (Accessed: 23 July 2021).

Ydersbond, I. M. and Korsnes, M. S. (2016) 'What drives investment in wind energy? A comparative study of China and the European Union', *Energy Research and Social Science*. Elsevier Ltd, 12, pp. 50–61. doi: 10.1016/j.erss.2015.11.003.

Zartha Sossa, J. W., López Montoya, O. H. and Acosta Prado, J. C. (2021) 'Determinants of a sustainable innovation system', *Business Strategy and the Environment*, 30(2), pp. 1345–1356. doi: 10.1002/bse.2689.

Zwarteveen, J. W. (2021) *The Economic Importance of Energy Diversification for Emerging Markets*, ASEAN-German Energy Programme. Available at: <https://agep.aseanenergy.org/the-economic-importance-of-energy-diversification-for-emerging-markets/> (Accessed: 23 July 2021).

Zwarteveen, J. W. and Angus, A. (2022) 'Forecasting the probability of commercial wind power development in lagging countries', *Cleaner Production Letters*, p. 100006. doi: 10.1016/j.clpl.2022.100006.

Zwarteveen, J. W., Figueira, C., Zawwar, I. and Angus, A. (2021) 'Barriers and drivers of the global imbalance of wind energy diffusion: A meta-analysis from a wind power Original Equipment Manufacturer perspective', *Journal of Cleaner Production*, 290, p. 125636. doi: 10.1016/j.jclepro.2020.125636.

Zwarteveen, J. W., Zawwar, I. and Angus, A. (2021) 'Market entry for wind energy: Strategic approaches for the original equipment manufacturer', *Business Strategy & Development*. doi: 10.1002/bsd2.188.

8 DISCUSSION AND CONCLUSION

“How can aims of individual liberty and economic efficiency be reconciled with aims of social justice and environmental sustainability?”

--- Phil Rosenzweig (in: The Last Unknowns, 2019)

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1. Conclusions

The objective of this research is to understand wind energy diffusion with the aim to promote wind energy in underdeveloped areas for sustainable benefits of both country and wind industry. The thesis followed the paper format (Cranfield University, 2016), with distinct chapters, some submitted to journals, covering the different parts of the research. The structure consisted of an introduction describing the context, a positioning study to map the different relevant bodies of literature, a literature study to deepen the knowledge of the state of the art, an empirical piece in an understudied area, a simulation chapter to extend the empirical work and an impact study to highlight the relevance of the work produced. This chapter is to conclude and discuss the overall work produced in the combination of all chapters.

The positioning study highlighted 68 high wind potential countries. Especially the developing and emerging countries of these were not using the wind energy wealth available to them.

To first understand the academic landscape, the literature study and meta-analysis targeted to answer the following question:

According to literature, what are factors impacting global adoption of wind energy?

It was found that literature provided two ways to measure wind energy diffusion: wind energy growth (annual capacity addition) and wind energy path creation (transition from no wind power to different stages of wind power commercialization). Most of the research addressed wind energy growth, path creation received less attention, especially from a quantitative point of view. In the 74 articles selected through the systematic review, 259 dependent factors influencing wind diffusion were identified, sorted into 8 factors categories and 170 factor sub-categories. The 8 factor categories influencing wind energy diffusion were: economic, environmental, political, regulatory, social, technical potential, technological and a combination of the aforementioned. The research indicated

that economic factors are of key importance in emerging and developing countries, whereas environmental factors are not driving wind energy growth, contrary to expectations. A new wind diffusion concept was proposed, consisting of mechanism of change (how is wind power diffused), desire for change (why is wind power diffused) and disturbing factors (such as war). The identified factors influencing wind energy diffusion were grouped into these three categories, resulting in mechanism-related factors, desire-related factors and disturbing factors, combinedly holistically influencing wind power diffusion. Also, multiple perspectives were identified in literature, with the policy maker as the most prominent one and the wind power Original Equipment Manufacturer (OEM) as the missing one.

Following the identified under-studied area in literature, the objective of the empirical work was 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 corporate diffusion strategies. The empirical research specifically focussed on desire-related factors, not on mechanism-related factors. Wind power development in many emerging markets is in a particularly early stage, and quite often the mechanisms, such as feed-in-tariffs, are missing for the pioneering projects (Steffen *et al.*, 2018). As such, the purpose of the research is not to wholistically explain wind diffusion, it is to understand how important the desire-related factors are in early stages of wind power path creation. To dissect the study area, research was divided into three questions. The questions and the answers the study provided are shown below.

RQ1: How much of the wind energy path creation can be explained by looking at desire related factors only?

Binary logistic panel based regression formed the basis of the empirical study, considering 67 countries over 20 years. Of the 68 high wind potential countries Sudan country was excluded as it was split into two countries during the period considered. M1, M2 and M3 were the three developed binary regression models

based on only desire-related factors describing respectively the transitions from no wind to pre-commercialization, pre-commercialization to early commercialization and early commercialization to commercialization (details in Table 1). The average model fit (using the McFadden's pseudo R-squared - (McFadden, 1974)) of M1-3 was found to be 0.537. This means that 53.7% of the transitions between the stages of wind energy path creation can be explained with desire-related factors.

The combination of desire-related factors, mechanism-related factors and disturbing factors is describing the complete phenomena of wind diffusion (Zwarteveen *et al.*, 2021). As the models only took the desire-related wind diffusion factors into account, consequently the model fit of M1-3 was expected to be significantly below 1. A model fit of over 50% by only taking desire-related factors into account demonstrates how important it is to start with *why* a country would adopt wind, before discussing *how*, as is the main focus of policy-related research.

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”. Therefore it was expected that particularly M1 would have a high model fit. As a market commercializes, it could be argued that the importance of effective and efficient policies (which are mechanism-related) would pick up in importance, resulting in a decreasing model fit of M1-3. Contrary to these expectations, the model fit was the strongest for the model describing the transition to commercialization (0.684). It appeared that the mechanism of change will autonomously follow once the desire for change exists. A significant share of literature focusses on the design of effective and efficient policies. The findings of this study complete existing research, demonstrating that policy research only makes sense if a strong desire exists, as desire related factors explain close to 70% of the transition to wind commercialization. This research rejects the premise that focussing on effective and efficient policies by itself is sufficient to successfully promote wind diffusion.

Table 1 Overview of the regression models and their model fit.

Model	Description	McFadden's pseudo R-squared
M1	Transition from no wind (0-1 MW wind capacity installed) to pre-commercialization (>1-50 MW wind capacity installed)	0.478
M2	Transition from pre-commercialization (>1-50 MW wind capacity installed) to early commercialization (>50-500 MW wind capacity installed)	0.449
M3	Transition from early commercialization (>50-500 MW) to commercialization (>500MW)	0.684
Average		0.537

RQ2: What are the differences in desire related factors that influence path creation of wind energy between advanced economies and emerging and developing economies?

The International Monetary Fund (IMF) categorizes countries into advanced economies and emerging and developing economies to distinguish their stage in development (International Monetary Fund, 2018). The dummy variable “country IMF category” appeared to be non-significant in all regression models M1, M2 and M3. Two variables were significant for all stage transitions considered in the models: the business case potential, defined as the difference between the country specific electricity price and the levelized costs of energy of wind, and the installed hydropower capacity. For the business case variable, the values differed significantly for advanced economies and emerging and developing economies. The average value of the business case potential was positive for advanced economies and negative for emerging and developing economies. For the hydropower variable, the average value of installed hydropower was higher in advanced economies compared to emerging and developing economies. Concluding, a negative business case potential and less hydropower installed in emerging and developing economies are disadvantageous regarding wind power path creation compared to advanced economies.

RQ3: What are the differences in desire related factors that influence the different stages of new path creation of wind energy?

The empirical study revealed that the factors differed per stage in early path creation. Constant factors however were the business case potential and

installed hydro power. Regarding M1, the transition from no wind to pre-commercialization, additionally was driven by the education index, electricity import dependency, energy import dependency and globalization. Regarding M2, the transition from pre-commercialization, besides the business case potential and hydro power, only smog levels appeared to be significant. Not only had M3 the highest model fit, it also had the highest number of significant variables: 12 of the 15 considered variables appeared to be significant: the business case potential, unemployment rate, electricity import dependency, energy import dependency, greenhouse gas emission (barrier), smog, oil based electricity capacity, gas based electricity capacity, coal based electricity capacity and hydro capacity.

Concluding, a strong business case potential and installed hydropower are constant drivers for wind energy path creation. Education seems important in the initial step only, and a holistic collection of variables seems to impact the transition to commercial wind. Indications are that wind energy path creation commercialization is driven by climate adaptation, vested interests in fossil fuels and hydropower, and the business case potential. 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 for wind power OEMs.

Following the empirical study, the simulation study focussed on the lagging countries (countries that have not reached wind commercialization yet) in order to understand under which conditions they would adopt significant wind energy. The following question formed the basis for the simulation analysis:

What is the probability of the lagging high wind potential countries to enter the commercialization stage?

By using backwards elimination, model M3 was simplified and used for simulation, using the latest available data for the predicting variables. Based on the outcome of the simulation, the lagging countries were split into three groups: low probability of commercialization, high probability of commercialization and

tipping probability of commercialization (Table 2). Simulation of a tipping country showed that small changes in dependent variable values would result in a low or high probability of commercialization. Four novel market entry and market development approaches for wind power OEMS were proposed based on quantitative assessments of the market potential: reactive market entry, proactive market entry, reactive waiting and proactive waiting.

Table 2 Predicted probability to exceed 500 MW in wind power for all lagging countries.

Low	Tipping point	High
Turkmenistan	Namibia	Indonesia
Angola	Iceland	Eritrea
Ethiopia	Kenya	Nigeria
Kazakhstan	Tunisia	Colombia
Uzbekistan	Libya	Mali
Oman	Paraguay	Saudi Arabia
Syria	Iran	Niger
Venezuela	Bolivia	Chad
Congo DR	Belarus	Somalia
Madagascar		Mauritania
Afghanistan		Russia
Zambia		Czech Republic
Tanzania		
Iraq		
Mongolia		
Mozambique		
Algeria		

A summary of the research objective and the research questions with key findings is shown in Table 3.

Table 3 Key research findings.

Research objective			
To understand wind energy diffusion with the aim to promote wind energy in underdeveloped areas for sustainable benefits of both the country and the wind power Original Equipment Manufacturer			
Chapter	Title	Research question	Key findings
3	Literature study	According to literature, what are factors impacting global adoption of wind energy?	<p>In the 74 articles selected through the systematic review, 259 dependent factors influencing wind diffusion were identified, sorted into 8 factors categories and 170 factor sub-categories</p> <p>It was found that literature provided two ways to measure wind energy diffusion: wind energy growth (annual capacity addition) and wind energy path creation (transition from no wind power to different stages of wind power commercialization).</p> <p>A new wind diffusion method was proposed, consisting of "mechanism of change" (how is wind power diffused), "desire for change" (why is wind power diffused) and disturbing factors (such as war).</p>
5	Empirical study	RQ1: How much of the wind energy path creation can be explained by looking at desire related factors only?	<p>Model 1. Transition from no wind to pre-commercialization: R-squared 0.48</p> <p>Model 2. Transition from pre-commercialization to early commercialization: R-squared 0.45</p> <p>Model 3. Transition from early commercialization to commercialization: R-squared 0.68</p>
		RQ2: What are the differences in desire related factors that influence path creation of wind energy between advanced economies and emerging and developing economies?	<p>IMF country classification (advanced versus developing and emerging) not significant in any of the models</p> <p>A negative business case potential and less hydropower installed in emerging and developing economies are disadvantageous regarding wind power path creation compared to advanced economies</p>
		RQ3: What are the differences in desire related factors that influence the different stages of new path creation of wind energy?	<p>A strong business case potential and installed hydropower are constant drivers for wind energy path creation.</p> <p>Education seems important in the initial step only, and a holistic collection of variables seems to impact the transition to commercial wind.</p> <p>Indications are that wind energy path creation commercialization is driven by climate adaptation, vested interests in fossil fuels and hydropower, and the business case potential</p>
6	Simulation study	What is the probability of the lagging high wind potential countries to enter the commercialization stage?	<p>38 lagging wind power adopting countries with high wind potential were split into 3 groups:</p> <p>12 countries with a high probability of commercializing wind power, 17 with a low probability and 9 with a tipping probability.</p>
Implications for the wind power Original Equipment Manufacturer			
Recommendations to stimulate wind power path creation:			
<ul style="list-style-type: none"> • Improve price competitiveness of wind energy compared to local electricity price (country specific) • Collaborate with existing hydro and fossil OEMs (climate adaptation portfolio diversification) • Work with governments on globalization, employment, clean air, climate adaptation and diversification strategies 			
Recommendations for market entry decisions in lagging markets			
<ul style="list-style-type: none"> • Simulate the wind power commercialization probability of the country • Assess the mechanism for wind power uptake (e.g. transmission lines, policies) • Assess existing disturbing factors (e.g. war) • Based on assessment, choose a market strategy: reactive waiting, reactive entry, pro-active waiting, pro-active entry 			

2. Academic and industry contributions

The aim of the Doctorate of Business Administration (DBA) program is to target a dual impact: both academically and practically. The main academic contributions of the research are:

- Meta analysis of determinants of wind energy diffusion.
- Feedback model to explain wind energy diffusion, which could also be applied to explain general technology diffusion.
- Quantitative model to determine factors explaining wind power path creation.
- Simulation method to reduce risk for closing finance gap to achieve SGDs.

The practical impact focusses on the wind power OEM. The main contributions to the wind power OEM are:

- Understanding the difference between “mechanism of change” and “desire for change” and use this to the benefit of convincing new markets of wind energy.
- Factors influencing wind path creation per stage resulting in specific approaches for stimulating wind energy diffusion depending on market size.
- List of high, low, tipping probability countries for wind energy commercialization.
- Simulation based approaches to create market entry and market development strategies.

3. Discussion, limitations and areas for further research

The research was not without its limitations. Even with a panel data set of 67 countries and 20 years, the number of datapoints in the empirical study for certain countries was restricted. Because of the strict limit to only include high wind potential countries to control for wind potential, including more countries would not have been possible. Further research could however test the applicability of the developed model to countries with less wind potential available.

This study followed a deterministic positivist approach. According to evolutionary economists, “the paths and stages that Innovation Systems follow towards sustainability is an evolutionary process and not of an intentional nature” (Zartha Sossa, López Montoya and Acosta Prado, 2021). The question is if, at all, an OEM manager could influence wind power path creation. However, diversification and selection are likely to be, at least partially influenced by strategic innovation.

The selection of high wind potential countries was based on the onshore technical potential capacity (Lu, McElroy and Kiviluoma, 2009; Jung, Schindler and Laible, 2018). Lu et al (2009) presented separately the onshore and the offshore technical wind potential, whereas Jung et al (2018) only focussed on land-based technical wind potential. To define the high wind potential countries based on more than one study, the onshore technical capacity was chosen as the selection criteria for the high wind potential countries. This can also be justified considering early wind power path creation: due to higher costs for offshore wind energy, it is reasonable to expect onshore wind energy precedes offshore wind energy (Jung, Schindler and Laible, 2018). In the studied years (2000-2019) no new market started with offshore first (International Renewable Energy Agency, 2020). This means, it is the onshore wind capacity that today determines if a country starts to exploit wind energy. Offshore wind energy forms a small part of total wind energy installed (less than 5% of total capacity status 2019) and is concentrated only in limited markets (International Renewable Energy Agency, 2020). To capture the wholistic exploitation of wind energy, the total installed wind capacity was used

to determine the dependent variable for the regression models. The impact of including offshore in the models was negligible: of the 15 countries with offshore wind energy installed, 10 countries reached already the commercialization phase with onshore wind energy before exploiting the offshore potential and in none of the considered high wind potential countries did offshore wind energy influence the years of the stage transitions of path creation (International Renewable Energy Agency, 2020). However, with the expected strong growth of offshore (International Energy Agency, 2020) and with the extension into emerging markets (such as Vietnam (Afanasiev, 2021)), further research might want to explore a specific offshore diffusion model. Offshore specific diffusion research has started (e.g. (Umoh and Lemon, 2020)), further research could aim to bundle offshore research into a literature review.

The main focus of this paper was to support OEMs in understanding and promoting wind diffusion. The purpose was not to wholistically model wind diffusion, it was to understand how much early wind power path creation can be explained by only considering the defined set of variables (desire-related factors). In order to wholistically model path creation, further research could consider taking more sets of variables into account (mechanism-related and disturbing factors). Not central to this paper, but potentially interesting for future research would be the role of governments (ie, via industrial policy or relevant regulation(s), infrastructure, etc) in enabling (or not) wind power path creation. The initial choice for wind power might come from desire-related factors, but effective or ineffective policies (Ragwitz and Steinhilber, 2014) and interest politics (Moe, 2017) might explain swings in further wind power growth (Moe, 2017). Also, the impact of cross border military tensions (such as Russia's role in Ukraine) on wind power path creation to secure the local energy production and reduce international dependencies is recommended to further study quantitatively.

Despite the primary focus on wind power OEMs, the findings might however also be useful for international wind power developers and international independent wind power producers, as they also need to choose in which new markets they target to invest.

The developed diffusion method consisting of desire for change, mechanism of change and disturbing factors is de facto technology independent. Further research outside wind energy but related to technology diffusion can build on this mechanism. Also, as this study showed, using regression to model path creation resulted in new insights, allowing researchers to apply this to other technology-based path creation studies.

The literature review that formed the basis of the study, dated from 2020. Since then, research in the field has continued. The first group of novel studies continued to explore global wind power diffusion. Several studies addressed country or regional specific wind diffusion (e.g. Africa (Abbas *et al.*, 2020), Ghana (Sun *et al.*, 2020), Brazil (Farkat Diógenes *et al.*, 2020), Pakistan (Solangi, Longsheng and Shah, 2021), China (Ma and Xu, 2021)). Although very relevant to the geographical area studied, no significant new insight was produced relevant to the scope of this study, as the main factors influencing wind energy diffusion remained within the 8 defined factor categories (economic, environmental, political, regulatory, social, technical potential, technological and a combination of the aforementioned). Outside the scope of the literature research as it does not address wind energy specifically, however providing a new insight, is the article by Loarne-Lemaire *et al* (2021) regarding the particular role of women on climate change related technological innovation process. Their SLR highlight that “more women within the technological innovation process promise greater productivity and better results”. Further research could focus on the quantification of this factor specific to wind energy. The second group of novel studies focussed on several energy-nexus topics, such as desalination and wind energy (Greco, Heijman and Jarquin-Laguna, 2021; Rosales-Asensio, Rosales and Colmenar-Santos, 2021; Rostamzadeh *et al.*, 2021), internet of things and wind energy (Liu *et al.*, 2020), synthetic fuel production and renewable energy (Berger *et al.*, 2021), electric mobility and renewable energy (Senthilkumar *et al.*, 2021), hydrogen and wind energy (Berg, Apostolou and Enevoldsen, 2021; Xue, Wang and Zhang, 2021), battery storage and wind energy (Prasad Ganthia *et al.*, 2022). The main focus of current nexus research is on the technical and

economic feasibility. Any form of transportable storage (e.g. desalinated water, synthetic fuel, hydrogen) enable the export of wind energy beyond the local demand, potentially substantially stimulating local demand for economic reasons. As the nexus related technologies mature, it is expected that these will further drive the diffusion of wind energy. Once evidence matures, the quantification of the impact of the emerging technologies on wind energy diffusion shall be studied to further explore, understand and potentially stimulate the transition to sustainable societies to the benefits of the emerging world.

As with all technologies, wind energy also has a limited lifetime. New, replacement technologies could emerge and follow the same stages in path creation. The current global focus on electrification of transport and industrial heat significantly will increase the electricity demand. And the demand is further driven by the combination of global population growth and increase in living standards. It is clear that the world will need significant additional amounts of electricity. Even though it is technically possible to supply the additional electricity from renewable energy sources with wind playing a major role, the question is if it is socially acceptable (not in my backyard (NIMBY) effect (Simmie, Sternberg and Carpenter, 2014)). More research is needed, but potentially energy fusion (Carayannis, Draper and Bhaneja, 2021) will enable a sustainable, inclusive, self-sufficient and local development on a scale that the future demands.

References

Abbas, Q., Khan, A. R., Bashir, A., Alemzero, D. A., Sun, H., Iram, R. and Iqbal, N. (2020) 'Scaling up renewable energy in Africa: measuring wind energy through econometric approach', *Environmental Science and Pollution Research*, 27(29), pp. 36282–36294. doi: 10.1007/s11356-020-09596-1.

Afanasiev, V. (2021) *Russian oil and gas player gets ready for Vietnam offshore wind splash, Upstream Energy Explored*. Available at: <https://www.upstreamonline.com/energy-transition/russian-oil-and-gas-player-gets-ready-for-vietnam-offshore-wind-splash/2-1-1032449> (Accessed: 6 July 2021).

Berg, T. L., Apostolou, D. and Enevoldsen, P. (2021) 'Analysis of the wind energy market in Denmark and future interactions with an emerging hydrogen market', *International Journal of Hydrogen Energy*, 46(1), pp. 146–156. doi: 10.1016/j.ijhydene.2020.09.166.

Berger, M., Radu, D., Detienne, G., Deschuyteneer, T., Richel, A. and Ernst, D. (2021) 'Remote Renewable Hubs for Carbon-Neutral Synthetic Fuel Production', *Frontiers in Energy Research*, 9. doi: 10.3389/fenrg.2021.671279.

Carayannis, E. G., Draper, J. and Bhaneja, B. (2021) 'Towards Fusion Energy in the Industry 5.0 and Society 5.0 Context: Call for a Global Commission for Urgent Action on Fusion Energy', *Journal of the Knowledge Economy*, 12(4), pp. 1891–1904. doi: 10.1007/s13132-020-00695-5.

Cranfield Univerity (2016) *Senate Handbook: Managing Research Students*. Cranfield.

Farkat Diógenes, J. R., Coelho Rodrigues, J., Farkat Diógenes, M. C. and Claro, J. (2020) 'Overcoming barriers to onshore wind farm implementation in Brazil', *Energy Policy*, 138, p. 111165. doi: 10.1016/j.enpol.2019.111165.

Greco, F., Heijman, S. G. J. and Jarquin-Laguna, A. (2021) 'Integration of Wind Energy and Desalination Systems: A Review Study', *Processes*, 9(12), p. 2181.

doi: 10.3390/pr9122181.

International Energy Agency (2020) *Renewables 2020*. Paris. Available at: <https://www.iea.org/reports/renewables-2020>.

International Monetary Fund (2018) *World Economic Outlook - Database - WEO Groups and Aggregates Information*. Available at: <https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/groups.htm> (Accessed: 5 November 2018).

International Renewable Energy Agency (2020) *Renewable electricity capacity and generation statistics, July 2020*. Available at: <https://www.irena.org/Statistics/Download-Data> (Accessed: 7 August 2020).

Jung, C., Schindler, D. and Laible, J. (2018) 'National and global wind resource assessment under six wind turbine installation scenarios', *Energy Conversion and Management*. doi: 10.1016/j.enconman.2017.11.059.

Liu, J., Li, Y., Lu, Y., Fu, X. and Yan, S. (2020) 'Research on the influence factors of ubiquitous power Internet of things for promoting consumption of wind power based on fuzzy G1-ISM in China', *International Journal of Electrical Power & Energy Systems*, 121, p. 106124. doi: 10.1016/j.ijepes.2020.106124.

Loarne-Lemaire, S. Le, Bertrand, G., Razgallah, M., Maalaoui, A. and Kallmuenzer, A. (2021) 'Women in innovation processes as a solution to climate change: A systematic literature review and an agenda for future research', *Technological Forecasting and Social Change*, 164, p. 120440. doi: 10.1016/j.techfore.2020.120440.

Lu, X., McElroy, M. B. and Kiviluoma, J. (2009) 'Global potential for wind-generated electricity', *Proceedings of the National Academy of Sciences*. doi: 10.1073/pnas.0904101106.

Ma, L. and Xu, D. (2021) 'Toward Renewable Energy in China: Revisiting Driving Factors of Chinese Wind Power Generation Development and Spatial Distribution', *Sustainability*, 13(16), p. 9117. doi: 10.3390/su13169117.

- McFadden, D. (1974) 'Conditional logit analysis of qualitative choice behavior', in Zarembka, *Frontiers in econometrics*. New York: Academic Press, pp. 104–142.
- Moe, E. (2017) *Does politics matter? Explaining swings in wind power installations*, *AIMS Energy*. doi: 10.3934/energy.2017.3.341.
- Prasad Ganthia, B., Suriyakrishnaan, K., Prakash, N., Harinarayanan, J., Thangaraj, M. and Mishra, S. (2022) 'Comparative Analysis on Various Types of Energy Storage Devices for Wind Power Generation', *Journal of Physics: Conference Series*, 2161(1), p. 012066. doi: 10.1088/1742-6596/2161/1/012066.
- Ragwitz, M. and Steinhilber, S. (2014) 'Effectiveness and efficiency of support schemes for electricity from renewable energy sources', *Wiley Interdisciplinary Reviews: Energy and Environment*, 3(2), pp. 213–229. doi: 10.1002/wene.85.
- Rosales-Asensio, E., Rosales, A.-E. and Colmenar-Santos, A. (2021) 'Surrogate optimization of coupled energy sources in a desalination microgrid based on solar PV and wind energy', *Desalination*, 500, p. 114882. doi: 10.1016/j.desal.2020.114882.
- Rostamzadeh, H., Rostami, S., Amidpour, M., He, W. and Han, D. (2021) 'Seawater Desalination via Waste Heat Recovery from Generator of Wind Turbines: How Economical Is It to Use a Hybrid HDH-RO Unit?', *Sustainability*, 13(14), p. 7571. doi: 10.3390/su13147571.
- Senthilkumar, P., Samidurai, S., Nedunchezian, V., Krishnan, N., Sharma, G. and Senjyu, T. (2021) 'Profit maximization in hybrid microgrid system incorporating demand response and plug in EV', *International Transactions on Electrical Energy Systems*, 31(12). doi: 10.1002/2050-7038.13260.
- Simmie, J., Sternberg, R. and Carpenter, J. (2014) 'New technological path creation: evidence from the British and German wind energy industries', *Journal of Evolutionary Economics*, 24(4), pp. 875–904. doi: 10.1007/s00191-014-0354-8.
- Solangi, Y. A., Longsheng, C. and Shah, S. A. A. (2021) 'Assessing and

overcoming the renewable energy barriers for sustainable development in Pakistan: An integrated AHP and fuzzy TOPSIS approach', *Renewable Energy*, 173, pp. 209–222. doi: 10.1016/j.renene.2021.03.141.

Steffen, B., Matsuo, T., Steinemann, D. and Schmidt, T. S. (2018) 'Opening new markets for clean energy: the role of project developers in the global diffusion of renewable energy technologies', *Business and Politics*, pp. 1–35. doi: 10.1017/bap.2018.17.

Sun, H., Khan, A. R., Bashir, A., Alemzero, D. A., Abbas, Q. and Abudu, H. (2020) 'Energy insecurity, pollution mitigation, and renewable energy integration: prospective of wind energy in Ghana', *Environmental Science and Pollution Research*, 27(30), pp. 38259–38275. doi: 10.1007/s11356-020-09709-w.

Umoh, K. and Lemon, M. (2020) 'Drivers for and Barriers to the Take up of Floating Offshore Wind Technology: A Comparison of Scotland and South Africa', *Energies*, 13(21), p. 5618. doi: 10.3390/en13215618.

Xue, Q., Wang, Z. and Zhang, Y. (2021) 'Environmental Benefit and Investment Value of Hydrogen-Based Wind-Energy Storage System', *Frontiers in Energy Research*, 9. doi: 10.3389/fenrg.2021.629136.

Zartha Sossa, J. W., López Montoya, O. H. and Acosta Prado, J. C. (2021) 'Determinants of a sustainable innovation system', *Business Strategy and the Environment*, 30(2), pp. 1345–1356. doi: 10.1002/bse.2689.

Zwarteveen, J. W., Figueira, C., Zawwar, I. and Angus, A. (2021) 'Barriers and drivers of the global imbalance of wind energy diffusion: A meta-analysis from a wind power Original Equipment Manufacturer perspective', *Journal of Cleaner Production*, 290, p. 125636. doi: 10.1016/j.jclepro.2020.125636.