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Article

To Re-Explore the Causality between Barriers to Renewable Energy Development: A Case Study of Wind Energy

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Abstract: The development of wind energy in developing countries has its limitations. This study adapted quantitative approaches to explore the causality relationships among these barriers. It was found that different areas of obstacles did affect one another; by barrier inference we learned that a lack of national policy caused other disorders, and that the occurrence of these disorders eventually resulted either directly or indirectly in high investment costs. Thus, the question of how to effectively reduce the investment cost of wind energy development is the most important issue to developing countries. Furthermore, the results of this study clarified that wind intermittency would not be the main reason hindering short and mid-term wind power development. However, from a long-term perspective, the impact of intermittency still cannot be treated lightly, as it was found that for each standard deviation unit improvement of the intermittency, the investment cost-effectiveness improvement increased by 0.185 σ, which was 1.78 times higher than the impact from national policies. Therefore, aside from strengthening the national policies in establishing a suitable institutional framework, we recommend that policy-makers should also emphasize the establishment of an economic assessment of available sites, a detailed wind resource assessment and improved forecasting of technical applications.

Keywords: wind energy; causality; national policies; investment costs; intermittency

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1. Introduction

Adaptation to climate change and reduction of the anthropogenic effects on greenhouse gas (GHG) emissions has become a key factor in developing energy policies in all nations. Coping strategies include: the improvement of energy efficiency [1], the development of green technologies for environmental sustainability [2], the recycle, capture, utilization, disposal/storage, as well as the increased use of renewable energy (RE) and the development of nuclear energy [3]. Among all these available options, development of RE is a widely accepted solution [4–10]. According to the Renewable 2012 Global Status Report by the Renewable Energy Policy Network for the 21st Century (REN21), despite the impact of the economic crisis, in 2011 the global investment in RE still reached around $25.7 billion, an increase of approximately $3.7 billion compared to 2010 and resulting in the total global RE capacity (excluding hydropower) reaching a level of approximately 390 GW [11]. Among all types of RE, wind power is not only a zero-pollution energy source [12–17], but also has a high degree of technical feasibility [18] and cost-effective features [19–31]. According to an authoritative report from the Intergovernmental Panel on Climate Change (IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation), wind energy has great potential for near-term (2020) and long-term (2050) GHG emission reductions [32].

On reviewing the literature relating to wind development we found that although wind energy has been widely utilized, there are still challenges that need to be resolved. For example, in developed countries, Loring explored the effects of four factors (public participation, network stability, level of public acceptance and the success of planning), on wind energy planning in England, Wales and Denmark. His [24] studies pointed out that the level of participation of the public, and responses to public opinion were key factors which affected the future development of wind energy. In a 2007 study Agterbosch *et al.* [33] pointed out that public opinion would still influence the outcome of wind energy development, even though the local government has the authority to make the final decision. That is, public awareness and participation in the development of RE can significantly impact a country's future development of its wind energy. This statement is also confirmed by Sovacool's studies. Research indicates that the public's misconception over the use of RE is often caused by a lack of understanding or knowledge of the subject [27,34], and such situations have a much higher impact on the RE and energy efficiency than technical and economic factors [35,36]. Furthermore, considering developing countries, Wang *et al.* have specifically analyzed the factors that affect the future of wind energy development in China. Their study [37,38] pointed out that inadequate transmission lines and the lack of flexibility of grid dispatching are the main reasons that limit the integration of wind energy with existing power systems. In addition, inappropriate power purchase prices and a lack of industrial innovation ability are also foreseeable challenges for the future development of wind energy [12,28,39–41]. Ling and Cai's study showed that even in a nation such as China that has an ample wind energy resources, the success of wind energy development, still relies to a considerable degree on the support of both central and the local governments to set up reasonable incentivizing programs towards the improvement of infrastructure, and the elevation of the R&D ability of the industry, with particular consideration of the characteristics of wind energy development [14,17,42]. Namely, aside from the decision maker's determination for RE development, the enhancement of the integration of the electricity grid, expansion of infrastructure, and increased industrial innovative

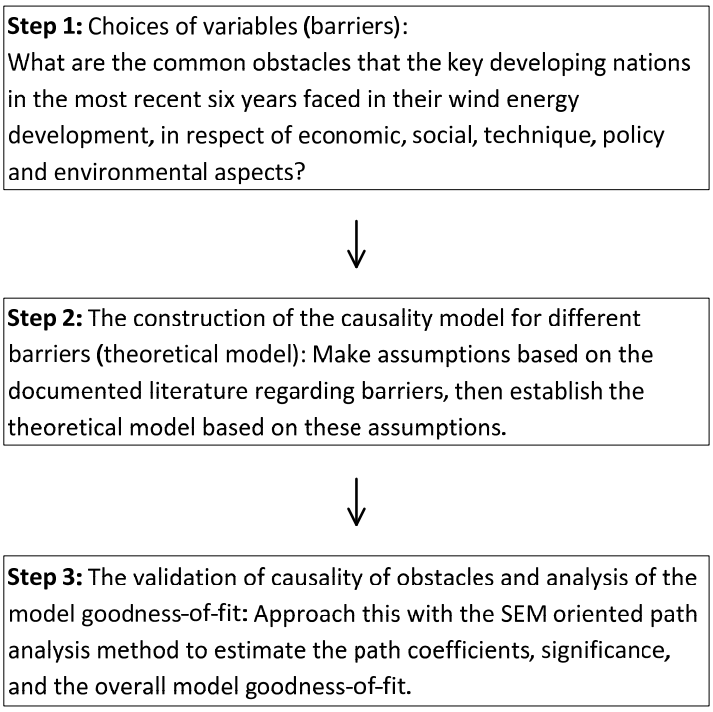
ability seem to be the priorities for China's future development of wind energy. Other related researches include the development of wind energy in the past, present and future [22,43], the potential of wind energy and strategies to promote RE market penetration [1,26,44],the restrictions of RE technology applications and coping measures [8,45], the potential of RE development, its current status and future prospects [46–49], the analysis of RE technology feasibility and the importance of public awareness [9], RE technology applied in rural areas [50], and clean energy and responses to energy-efficient technological improvement and obstacles [51]. In summary, if policy makers are determined to promote the penetration of RE, in addition to the necessary innovative policy framework, future areas that decision-makers should endeavor to address included the related technologies (*i.e.*, the information of wind energy development and technology), the environment (*i.e.*, the usability of the site), and social factors (*i.e.*, public education and improvement of public awareness).

From the discussion above, we find that wind energy development in developing countries will face more obstacles in different aspects, such as the economic, social, technical, policy and environmental dimensions, when compared to developed nations. Hence, the following question arises: how will these different types of barriers affect each other? This is an interesting issue, and one that deserves to be explored. To investigate the correlation between the barriers, particularly in developing countries, would be the most effective way to assist the energy and cultural reform [31,52]. In order to answer the question, this study first focused on important developing countries over the most recent six year period, including China, India, Vietnam, Pakistan and others (hereafter referred to as developing countries). The study took wind energy related issues as the core focus to explore the obstacles that were involved in the economic, social, technical, policy and environmental aspects; and secondly, to establish a causality model of barriers based on theory that resulted from the conclusions of the relationship between the obstacles that are documented in the literature. The purpose of this study was to understand the different barriers and how they influence each other, and then to validate this through the data collection and Structural Equation Modeling (SEM) orientation path analysis. With an understanding of the correlation between barriers, we expect to be able to clarify the cause(s) of the obstacles and possible short, medium and long-term development strategies.

2. Methodology

To take a rigorous and reasonable approach to explore the different areas of barriers and how they affect each other, this study analyzed the following three steps (see Figure 1): (1) The choice of variables (barriers); (2) the construction of the causality model for different barriers (theoretical model); and (3) the validation of causal relationship of obstacles and analysis of the model goodness-of-fit. Detailed descriptions of these steps are as follows:

Figure 1. Research Flow.



2.1. Research on Choices of Variables (Barriers)

Wind energy development among different developing nations faces a range of challenges. Thus, how to choose the appropriate variables (barriers) is a vital step prior to the establishment of the theoretical model. Initially, the Special Report on Renewable Energy Sources and Climate Change Mitigation produced by the IPCC pointed out four categories when identifying the effects of obstacles in RE development: market failures and economic barriers, information and awareness barriers, socio-cultural barriers, and institutional and policy barriers [32]. Research such as that of Valentine and Klessmann *et al.* [52,53] also mentioned that aside from the economic factors, others aspects such as social, political ones and techniques would also influence wind energy development. Therefore, when discussing obstacles to the development of wind energy it is necessary to include the possible impacts that come from the environment, economies, society, techniques, and policies. This point of view is also confirmed by Krupa, Praene *et al.* and Richards *et al.*'s research. Their studies [4,10,34,36] pointed out that the failure of RE development cannot be explained through a single technical, social, policy or economic factor, but rather a multi-dimensional inspection is required to clarify the cause of these obstacles. Secondly, as far as choosing the variables (barriers) is concerned, due to the difficulty of data collection, a complex model might not necessarily contribute to the development of wind energy in developing countries; on the contrary, a clear and simple result of the analysis provides better clearer insights. Therefore, this study selected important developing countries over the last six years and their wind energy development-related issues [1,8,9,12,14,17,22,26,28,37–51], in order to inspect common obstacles from the economic, social, technological, policy and environmental dimensions, which focused on 11 issues: the policy aspect—the lack of national policies and appropriate power purchase agreements (PPA); the economic aspect—the lack of fiscal incentives and high investment costs; the social aspect—the lack of social promotional measures with local

infrastructure deficiencies; the technical aspect—insufficient R&D capabilities, lack of projects and technology information, and necessary equipment for wind energy; and the environmental aspect—limitations over site availability, and the wind energy intermittency. Some other issues such as country-specific and region-specific barriers (for example: hurricanes, dust storms, *etc.*), or other emerging obstacles (for example: fund competitions due to other RE developments), will not be included in this study model.

2.2. The Establishment of the Causality Model of Barriers (Theoretical Model)

To build a causality model (or theoretical model), it is necessary to establish the model based on the theory. That is, the evolution of the research assumptions, or literature collation and derivation theory, becomes a hypothetical model to be verified [54,55]. This study is based on the existing literature on wind energy development barriers [1,8,9,12,14,17,22,26,28,37–51]. The causality model of barriers in the study is built by the assumptions of barriers that are documented in the literature. Descriptions addressed in the literature regarding to the possible relevance among obstacles and barriers are as follows:

1. Lack of national policies: a healthy policy environment is not only a prerequisite for a nation's sustainable development [14,17,22,28,44], but it also minimizes the conflict between RE and non-RE. If a nation does not have mandatory objectives in its development or a clear legal basis, it is easy to cause prejudice among various departments over the implementation of the subsidies. Thus, a higher financial risk in wind energy development resulting from inaccessibility to a reasonable purchase price of electricity restricts the participation of potential developers and penetration of the technology [42]. Furthermore, the lack of a central authority in charge of the wind energy development projects, one which can conduct a detailed assessment and assess the related information, results in a lack of public understanding regarding wind energy development and its economic, social and ecological benefits [26], while the lack of clear norms and an appropriate institutional framework also hinders participation of the private sector due to the deficiency of channels through which to exchange views between the decision makers and stakeholders [48,50]. From a technical aspect point of view, the lack of coordination among different sectors and setting of the research program is one of the main reasons leading to the redundancy of R&D activities, and will delay the commercialization and promotion of the technology [40,43,45]. Based on the above discussion, we assume that insufficient national policy may result in a lack of financial incentives and social measures, the occurrence of inappropriate PPA, and incapability in the RE industry's R&D;
2. Lack of appropriate PPA: a reasonable purchase price of electricity is an important condition to ensure the successful development of wind energy. Therefore, if the decision-makers did not consider the characteristics of wind energy development, for example, high investment costs and long-term investment returns, to set a reasonable price rate on electricity, this may provide inadequate compensation to the local population that results in issues of restriction on land availability [12,43,48]. In addition, an erratic pricing policy reduces the potential developers' willingness to invest, and limits R&D in turbine and other technologically related industries [40,44]. It is worth noting that a reasonable pricing policy not only elevates the economic potential brought by the wind energy [14,26,51,56–58], but also promotes integration

between wind energy and national grids [28,42]. From the discussion above, we assume that the absence of an appropriate PPA may limit the site availability and R&D capacity of the related industries;

3. Inadequate fiscal incentives: how to get enough profit during the generation of wind energy is the key issue for the future development of wind energy. Therefore, the absence of adequate financial incentives, such as subsidy imports or tariff exemptions, *etc.*, may result in high duties on imported components that hinder the industry's creation, operation and maintenance [45], and stagnates future development [1,12,39,47]. On the contrary, the implementation of appropriate fiscal incentives encourages potential developers to invest voluntarily in wind energy [50], while also stimulating the development of related industries and promoting technology [17,40,43,44]. Furthermore, the financial support to provide operating capital, such as special loans and preferential interest rates, will help construct the local infrastructure—the physical facilities such as roads and substations, transmission grids and distribution networks set up in the early stages. Such capital can also effectively drive consumers to participate in the development of the RE market to increase RE market demand [26,46]. From the discussion above, we assume that the lack of fiscal incentives may result in the deficiency of appropriate equipment and fundamental infrastructure to develop wind energy, as well as resulting in the incapability of industrial R&D;
4. Lack of social promotional measures: public awareness of RE development is an important condition for a successful outcome. Therefore, to improve public awareness and education on the subject [40], the establishment of a mechanism of information transmission between governments and stakeholders, including the collection and feedback of opinions, delivery of projects and technology information [49], has become the main purpose of implementing social promotional measures [26]. Therefore, it is understood that in the absence of information transmission to potential developers, insufficient knowledge regarding new technologies and their applicable information may result in reductions in the efficiency of the wind power generated [45,50]. Similarly, failure to improve public awareness and understanding on the subject, that may result in the choice of site may become an issue due to the "not in my back yard" (NIMBY) syndrome; often this results in the plant being located in remote areas, and these areas typically have insufficient infrastructure [44,48]. Thus, potential developers must invest additional funds in infrastructure such as building power grids and substations in the early stages of wind energy development [12,14,17,28,42,43,46,51]. Based on the above discussion, we assume that the lack of social promotion measures may result in insufficient knowledge regarding projects and technology information, with the limitations on site availability;
5. Lack of local infrastructure: the establishment of infrastructure through full grid transmission and network distribution for the future development of wind energy will help the integration between wind power and the nation grid [22,28,39,45]. This can also reduce the cost of construction and operation of wind energy developments [40,48]. On the contrary, the lack of appropriate physical infrastructure will force potential developers to invest additional funds in the power grid or other infrastructural improvement projects [8]. Studies have pointed out that turbines, related equipment imports and infrastructure construction account for a very high

proportion of the overall investment cost of wind energy [12]. Based on the above discussion, we assume that the lack of local infrastructure may lead to the occurrence of high investment costs;

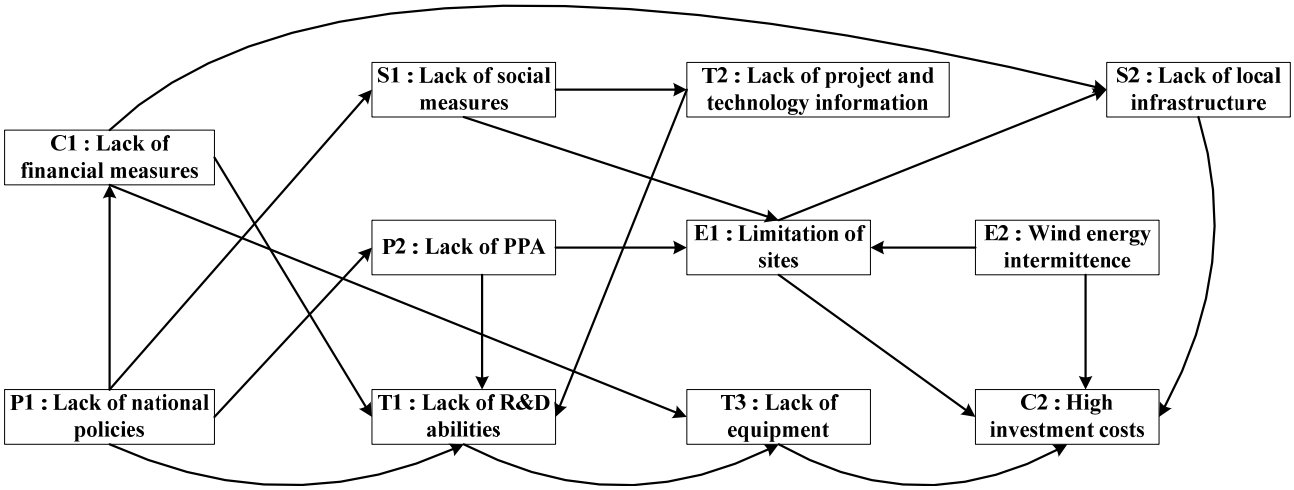
6. Lack of R&D capabilities: wind energy is a cross-cutting discipline [28]. For the future development of wind energy, R&D assistance provided by the government through power storage, technology research grants and related information transmission, and the elevation of the industry's innovative capability, will contribute to the penetration of wind energy technology [39,40,44,47]. Therefore, the lack of R&D capability in the domestic industry may require necessary equipment imports from overseas, such as turbines and other important components that support wind energy development and indirectly increase the overall costs [59]. Conversely, the cost of investment in wind energy development can be reduced when the use of local equipment and technology is enhanced [12,42,45]. It is understandable that the planning of innovation and development of technology must be according to demand and based on the resources of the country or region, rather than exclusively relying on the introduction of foreign technology [50]. Based on the above discussion, we assume that the lack of industrial R&D capacity may lead to the problem of storing equipment used for the development of wind energy;
7. Lack of projects and technology information: an information sharing system can greatly improve the economic potential of wind energy [42], as well as contributing to the long-term development of this renewable resource [28,48]. Therefore, if potential developers do not have appropriate information, such as the implementation and maintenance of wind energy, then the cost of development and derivative effect assessment to evaluate this may reduce the efficiency of the wind power generated, due to the use of inappropriate equipment in the development and application for a selected site, or that is incompatible with the existing system. In the turbine industry, the lack of projects and technology information, such as durability and reliability assessments to develop new technologies, will limit research in industrial technology and innovation, and hinder technological promotions [45,50,51]. Based on the above discussion, we assume that the lack of projects and technology information may result in an inadequate R&D capacity of the industry;
8. Lack of facilities required for wind energy development: research has confirmed that localized equipment manufacturing is one of the vital factors to reduce the investment cost and lead to the successful implementation of wind energy development [50]. Therefore, if the domestic industry does not have equipment manufacturing and maintenance capabilities then turbine components, such as rotors and gearboxes, must be imported from overseas. Since turbines and other import setting devices account for a considerable proportion of the total cost of wind energy production [42,45], the lack of equipment and components will require a substantial increase in the investment and production costs of wind energy development [8,12,22]. Based on the above discussion, we assume that the lack of equipment required for wind energy development may lead to high investment costs;
9. The intermittency of wind energy: the wind energy resource is an important criterion for its development [12,40]. However, by considering wind power variability and specific site selections in the large-scale development of wind energy, some managers believe that this will demand additional technology and applicable devices in power storage to ensure the stability of the grid integration. Thus, the initial investment costs of wind energy will be significantly

increased [1,14,28,45,46,51]. Considering site availability issues, a detailed assessment of wind energy resources, including the size of the available sites, economic assessment and map information is imperative. Without such a report, it is easily to overlook the possible issues of accessibility to a potential site with good wind, or the condition of the site development capacity, which then results in limited choices of sites [42]. Based on the above discussion, we assume that wind intermittency may lead to high investment costs and limitations on site availability;

10. The limitations on site availability: appropriate site selection will help the long-term development of wind energy and enhance its economic and technical performance. However, in the absence of social promotion measures, the choice of site may become an issue due to the NIMBY factor; often this results in plants being located in remote areas, and these areas typically have insufficient infrastructure [17,43,46], which results in low plant factors [42,51]. In addition, the limitations of the transmission pricing schemes, which are based on the transmission distance, will also increase the generation cost of wind energy. It is worth noting that site selection will be subjected to the limits of traditional land use rights; often requiring extensive consultations that result in paying huge subsidies or rent, thus, the cost of investment in wind energy increases [12,14,28,45,50]. Based on the above discussion, we assume that the limitations on site availability may result in insufficient infrastructure and high investment costs.

Figure 2 is based on the theoretical model created based on the correlated assumptions between the obstacles. The theoretical model is used to represent the interaction between the obstacles. In the theoretical model, the national policy (P1) and wind intermittency (E2) are the main independent variables, and the investment cost (C2) is the main dependent variable. It appears that the national policy and wind intermittency lead to other obstacles, and all obstacles lead to the end result of high investment cost. From the theoretical model, we found that national policies will have a direct effect on the R&D capacity, and it may also have indirect effect on the R&D capacity through the mediating effect of the PPA (P2) or the financial incentive measures (C1) (*i.e.*, P1 → P2 → T1 or P1 → C1 → T1). Thus the impact of national policies on the R&D capacity may be subject to change due to the PPA or fiscal incentives. In theory, we can take PPA with fiscal incentives as the mediator between P1 and T1 [5,60–66]. Similarly, the theoretical model includes three mediators: R&D capacity (*i.e.*, C1 → T1 → T3), site availability (*i.e.*, E2 → E1 → C2), and the fundamental infrastructure (*i.e.*, E1 → S2 → C2). However, it is necessary to apply an oriented path analysis method of SEM to verify the hypothesis of the correlation between the barriers and goodness-of-fit between the theoretical model and the observed data. We then know if the theoretical model can reasonably reflect wind energy development in developing countries.

Figure 2. Conceptual model of the causality between barriers.



2.3. The Validation of Causality between Obstacles and Model Goodness-of-Fit Analysis

SEM is a multivariate statistical analysis method, which applies two statistical techniques that integrate both traditional factor and path analysis. In theory, SEM models incorporate two sub-models—the measurement model and the structural model. The so-called measurement model is based on the concept of using factor analysis to describe the latent variables (*i.e.*, the phenomena that cannot be directly observed, such as pressure or IQ) and measured by the observed variables (*i.e.*, a phenomenon that can be directly observed); the structural model is based on the concept of path analysis to discusses the relationship between the different latent variables. In this study, all variables (barriers) were of the observed variable type, and the theoretical model was based on the structural path model analysis. In general, we could repeat multiple regression analysis using statistical software such as SPSS, to get all the path coefficients and make various combinations; this is known as regression orientation path analysis. However, the theoretical model of this study contains the presence of multiple mediators (Me), which change the original relationship between the independent variables (IV) and the dependent variables (DV) from direct effect (IV → DV) into an mediating effect (IV → Me → DV) [5,61,65,66]. In the consideration of the characteristics of the SEM method, we used the co-variance among variables, simultaneously to estimate the model parameters, and to test the goodness-of-fit between the theoretical models and the observed data [54,55,60,62–64]. Therefore, by considering all the reasons mentioned above, the SEM oriented path analysis was the more suitable choice of method for the study. Second, the sample data needed for the analysis came from the IPCC's Clean Development Mechanism. The screening of the sample data was based on whether the sample had barrier analysis in the project design document. As of 24 March 2013, a total of 143 samples were available for the model's use. It is worth noting that of the 143 sample data, more than half came from China (followed by 19% from India, 9% from Mexico, and with the remaining countries accounting for 22%). Yet based on the 4th step, the discussion of common practice analysis in the "Tool for the demonstration and assessment of additionality", 7th version, we could sample data as a separated and independent source of information [67]. Third, the data measurement was modified from the traditional 5-point Likert scales into a fuzzy linguistic scale for scoring. That is, the characteristics of the fuzzy number using fuzzy theory to describe different linguistic variables, for example: strongly agree ($\tilde{5}$),

agree ($\tilde{4}$), normal ($\tilde{3}$), disagree ($\tilde{2}$), strongly disagree ($\tilde{1}$). Later, we used the sum of linguistic variables, a total 100% as the condition, giving various linguistic variables appropriate percentage score bases on the comparison between the sample descriptions against the existing literature on the barriers and controls discussed in Section 2.2. Finally, the fuzzy membership weight was used to calculate the fuzzy value for the model analysis.

Table 1 describes the statistical analysis of the theoretical model, including mean, standard deviation, variance inflation factor (VIF), skewness and kurtosis. The purpose of the VIF analysis was to diagnose collinearity between the variables. In general, if the VIF is greater than 10 then this indicates serious collinearity between the variables; conversely, if the VIF is less than 10, then the issues of the collinearity between the variables can be ignored [62,63]. The analysis results showed that the VIF of each variable lies between 1.000 and 8.540, which is significantly smaller than 10; hence, the collinearity effect on the analysis of the model can be ignored. Table 2 shows the correlation analysis between the variables. The analysis shows that the degree of correlation ranges between −0.006 and −0.660, which has a low-to-medium degree of correlation.

The Mplus version 6.1.1 software [68] was used in this study for carrying out the analysis of the theoretical model. Considering there were several mediators in the theoretical model that required estimation, the ordinary least square (OLS) could not be applied in the selection of the path coefficient method [60]; rather the maximum likelihood (ML) fulfilled the role of path coefficient estimates and significance tests. In this study, the skewness and kurtosis of each variable range (Table 1) was between 0.155–1.680 and −1.402–1.652, which is in line with the basic hypothesis of the ML that are subject to normal distribution [62,63].

Table 1. Summary of descriptive statistics for study variables.

Variables	Means	SD	VIF	Skewness	Kurtosis
National policies (P1)	1.1437	1.0604	1.000	0.400	−1.081
PPA (P2)	1.1066	1.0410	2.967	0.352	−1.086
Financial measures (C1)	1.2836	1.1784	5.950	0.231	−1.402
Investment costs (C2)	1.2122	0.8902	6.540	0.155	−0.636
Social measures (S1)	0.7066	0.9062	3.159	0.909	−0.471
Local infrastructure (S2)	0.7088	0.7610	5.059	0.671	−0.200
R&D capabilities (T1)	0.5528	0.9906	3.630	1.680	1.652
Projects and technology information (T2)	0.9280	1.1558	7.416	0.958	−0.338
Equipment (T3)	1.0636	0.9414	8.540	0.496	−0.492
Sites (E1)	0.6818	0.9073	3.830	1.054	0.233
Wind intermittence (E2)	1.8161	1.0112	4.749	0.210	−0.765

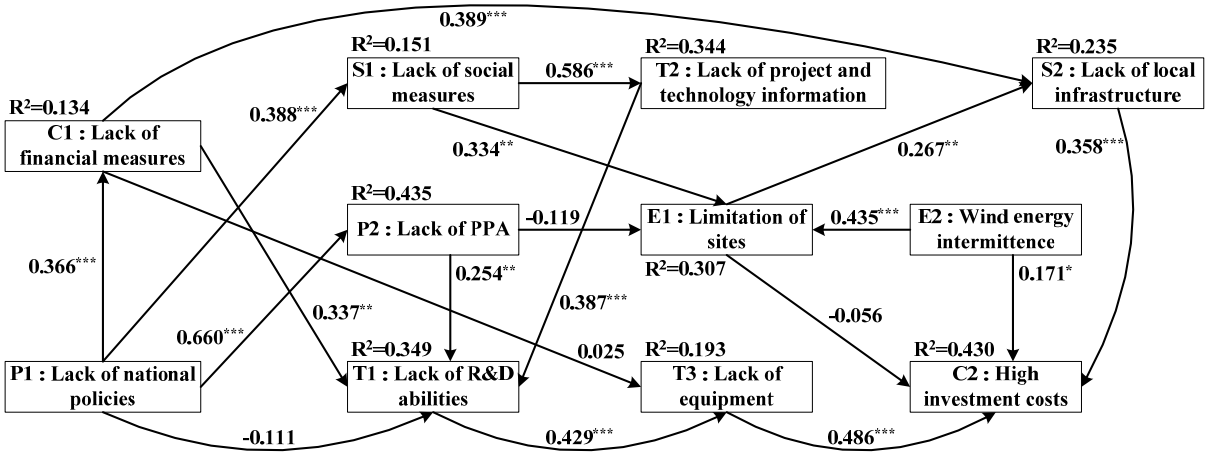
Table 2. Correlations for study variables.

Variables	1	2	3	4	5	6	7	8	9	10	11
National policies (P1)	1.000										
PPA (P2)	0.660 **	1.000									
Social measures (S1)	0.388 **	0.260 **	1.000								
R&D capabilities (T1)	0.251 **	0.279 **	0.586 **	1.000							
Sites (E1)	0.222 **	0.049	0.401 **	0.121	1.000						
Wind intermittence (E2)	0.273 **	0.187 *	0.243 **	0.197 *	0.485 **	1.000					
Local infrastructure (S2)	0.093	0.099	0.277 **	0.203 *	0.285 **	0.178 *	1.000				
Financial measures (C1)	0.366 **	0.378 **	0.273 **	0.232 **	0.031	0.093	0.398 **	1.000			
Investment costs (C2)	0.052	−0.006	0.278 **	0.315 **	0.206 *	0.279 **	0.402 **	0.279 **	1.000		
Projects and technology information (T2)	0.266 **	0.399 **	0.330 **	0.488 **	0.085	0.160	0.192 *	0.462 **	0.337 **	1.000	
Equipment (T3)	0.129	0.131	0.257 **	0.246 **	0.163	0.152	0.066	0.230 **	0.528 **	0.454 **	1.000

Notes: * $p < 0.05$; ** $p < 0.01$.

Figure 3 presents the results of the Mplus preliminary analysis of the theoretical model. The analysis showed that, aside from the four paths that do not reach the 0.05 significance level, the remaining paths all meet the 0.05 significance level requirements. The four paths that did not reach statistical significance were the national policy (P1) → R&D capacity (T1), financial incentive measurement (C1) → equipment (T3), PPA (P2) → site availability (E1), and site availability (E1) → investment cost (C2). In addition, some literature suggests that the goodness-of-fit between the overall model and the observed data can be judged using the following indices: Chi-Square (X^2), comparative fit index (CFI) [69], root mean square error of approximation (RMSEA) [62,65], standardized root mean square residual (SRMR) [60,70,71], and the Tucker-Lewis index (TLI) [63]. The analysis showed that all the indices reached the generally recommended standard requirements, X^2 (35, N = 143) = 49.546, $p > 0.05$, CFI = 0.969 > 0.95, TLI = 0.952 > 0.95, RMSEA = 0.054 < 0.06; 90% of the confidence interval (CI) = 0.000–0.086, SRMR = 0.068 < 0.08. The explanatory power of the model variables were: PPA (R^2 = 0.435), fiscal incentives (R^2 = 0.134), investment costs (R^2 = 0.430), social promotional measures (R^2 =0. 151), infrastructure (R^2 = 0.235), site availability (R^2 = 0.307), R&D capacity (R^2 = 0.349), projects and technology information (R^2 = 0.344), and equipment (R^2 = 0.193).

Figure 3. Model I-Preliminary analysis. Mplus output for conceptual model of the causality between barriers. Coefficients are standardized path coefficients. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. ($N = 143$; $R^2 = 0.430$).



To carry out a more detailed discussion on the model analysis, the four paths with less than the significance level were deleted in this study. It can also be confirmed that the four paths would not significantly affect the overall model interpretation on the investment cost (C2). Figure 4 is a theoretical model that demonstrates the result of final analysis with four paths that were less than the significance level removed. The analysis showed that In addition to the previously deleted four paths, all paths reached the 0.05 significance level, the same result as the previous analysis. Furthermore, the result of the analysis shows that aside from the CFI declining slightly (down 0.002), the TLI (0.954), RMSEA (0.052, 90% CI 0.000–0.083) and SRMR (0.069) all improved (Table 3), which described an excellent goodness-of-fit between the final model with the observed data. Finally, the explanatory power of the overall model on the investment cost (C2) had only a slight decrease of 0.004. Therefore, it was confirmed that the deletion of the four non-significant paths would not affect the explanatory power of the overall model on the investment cost.

Figure 4. Model II-Final model. Mplus output for conceptual model of the causality between barriers. Coefficients are standardized path coefficients. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; broken lines show non-significant paths at the $p = 0.05$ level ($N = 143$; $R^2 = 0.426$).

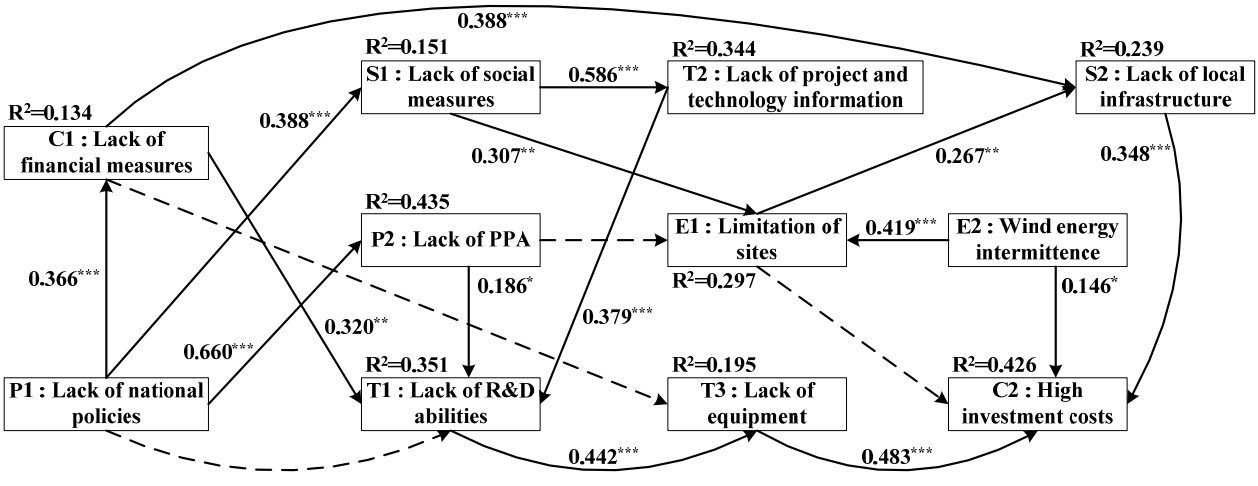


Table 3. Goodness-of-fit indices of models.

Models	X^2	df	*p*-Value	CFI	TLI	RMSEA	SRMR
Model I-Preliminary analysis	49.546	35	0.0526	0.969	0.952	0.054	0.068
Model II-Final model	54.332	39	0.0523	0.967	0.954	0.052	0.069

The analysis results above express an excellent goodness-of-fit between the final model and the observed data. However, close attention should be paid to the possible impact on the model analysis by the sample size. Some researchers have suggested that the ratio between the sample size and the parameters should be 10:1, although a 5:1 standard is still acceptable [60,62,63]. However, in the theoretical model of this study, 37 parameters were included to be estimated, as well as 33 parameters to be estimated in the final model against the sample size of 143; hence, the ratio of the sample size and the parameters was 4:1, slightly lower than the minimum requirements of the standard (5:1). Therefore, in order to double confirm the goodness-of-fit between the final model and the observed data, this study applied the method of partial least squares (PLS) to conduct the path coefficient estimates and significance tests. Chin's research pointed out that the model analysis of small samples (for example: <100) PLS is a far better method than the covariance-based methods (for example: ML, OLS) [72–74]. Figure 5 shows the results of the SmartPLS version 2.0.M3 (Ringle *et al*., Hamburg, Germany) [75] analysis on the final model, while Table 4 shows the comparison result of the standardized direct and indirect effect between the Mplus and SmartPLS. There were no significant differences found between the two from the result of the path coefficients that came from the comparison of different assessment methods and significant estimates (Table 4), and the explanatory power of the overall model on the variables (Figures 4 and 5). Therefore, an excellent goodness-of-fit was confirmed between the final model and the observed data, with the model reasonably reflecting the causality between barriers to the development of wind energy in developing countries.

Figure 5. Model II-Final model. SmartPLS output for conceptual model of the causality between barriers. Coefficients are standardized path coefficients. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; broken lines show non-significant paths at the $p = 0.05$ level ($N = 143$; $R^2 = 0.434$).

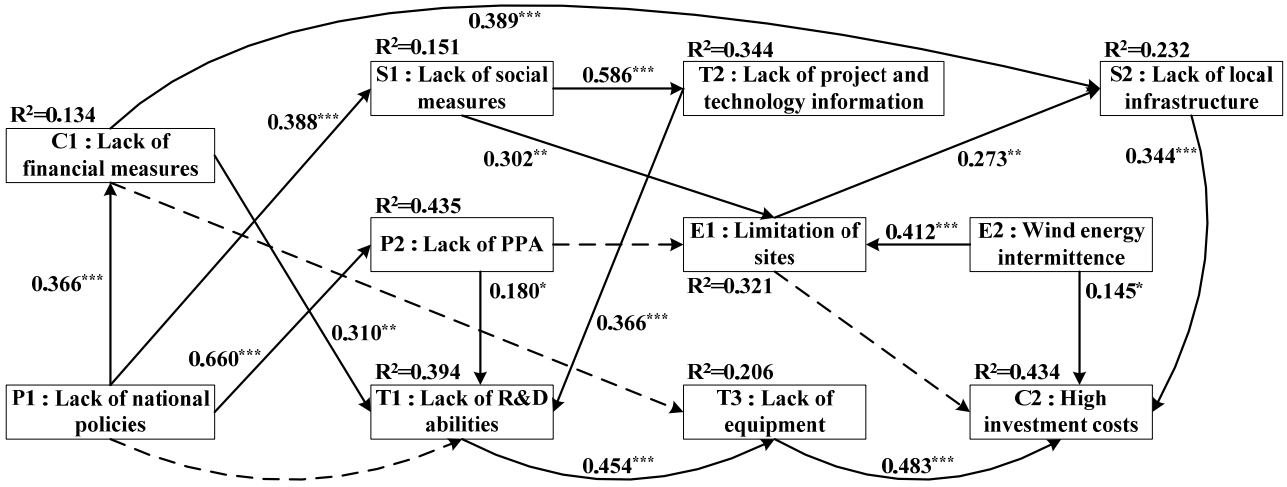


Table 4. Model II-Final model. Mplus and SmartPLS output for standardized direct, indirect and total effects.

Effects from A to B	Mplus			SmartPLS		
	Effects			Effects		
	Direct	Sum of indirect	Total	Direct	Sum of indirect	Total
P1 → C1	0.366***	N.A.	0.366***	0.366***	N.A.	0.366***
P1 → P2	0.660***	N.A.	0.660***	0.660***	N.A.	0.660***
P1 → S1	0.388***	N.A.	0.388***	0.388***	N.A.	0.388***
P1 → C2	N.A.	0.104***	0.104***	N.A.	0.129***	0.129***
P2 → T1	0.186*	N.A.	0.186*	0.180*	N.A.	0.180*
P2 → C2	N.A.	0.040*	0.040*	N.A.	0.040*	0.040*
C1 → T1	0.320**	N.A.	0.320**	0.310**	N.A.	0.310**
C1 → S2	0.388***	N.A.	0.388***	0.389***	N.A.	0.389***
C1 → C2	N.A.	0.203***	0.203***	N.A.	0.202***	0.202***
S1 → T2	0.586***	N.A.	0.586***	0.586***	N.A.	0.586***
S1 → E1	0.307**	N.A.	0.307**	0.302**	N.A.	0.302**
S1 → C2	N.A.	0.076***	0.076***	N.A.	0.075**	0.075**
S2 → C2	0.348***	N.A.	0.348***	0.344***	N.A.	0.344***
T1 → T3	0.442***	N.A.	0.442***	0.454***	N.A.	0.454***
T1 → C2	N.A.	0.214***	0.214***	N.A.	0.220***	0.220***
T2 → T1	0.379***	N.A.	0.379***	0.366***	N.A.	0.366***
T2 → C2	N.A.	0.081***	0.081***	N.A.	0.080**	0.080**
T3 → C2	0.483***	N.A.	0.483***	0.483***	N.A.	0.483***
E1 → S2	0.267**	N.A.	0.267**	0.273**	N.A.	0.273**
E1 → C2	─	0.093**	0.093**	─	0.094**	0.094**
E2 → E1	0.419***	N.A.	0.419***	0.412***	N.A.	0.412***
E2 → C2	0.146*	0.039**	0.185*	0.145*	0.038**	0.183*

Notes: P1: National policies, P2: PPA; C1: Financial measures, C2: Investment costs; S1: Social measures, S2: Local infrastructure; T1: R&D capabilities, T2: Projects and technology information, T3: Equipment; E1: Sites, E2: Wind intermittence; ─ indicates the paths that were insignificant and therefore not included for estimation; N.A. indicates paths that were not existed; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

3. Results and Discussion

What the study aimed to explore was whether the common barriers to wind energy development in developing countries affected each other. The study found that different obstacles indeed affected each other, while some phenomena were worthy of further exploration.

3.1. The Causality between Barriers

First, Wang *et al.*'s study [40] pointed out that if the responsible authority component is lacking for planning, goal setting and coordination among departments, that may lead to industrial R&D incapability. However, based on the result of the analysis, there was no significant relationship between national policy (P1) and R&D capacity (T1); that is, the national policy did not have a direct effect on the industrial R&D capability, rather the effect was indirect through financial incentive measures (C1), the PPA (P2) and the social promotional measures (S1); the main indirect effect path

being P1 → P2 → T1 (β = 0.1228). In addition, since there was no significant relationship between P1 and T1, both fiscal incentive measures (C1) and PPA (P2) would not have been the mediating effect to P1 and T1. Second, regarding the fiscal incentives (C1) and equipment (T3) aspect, Kumar *et al.*'s study [1,39,47] pointed out that the lack of tangible incentives, such as import subsidies or exemption of import tariffs, *etc.*, may lead to a shortage of equipment or replacement of spare parts in wind energy development. The analysis showed that there was no direct relationship between fiscal incentives and equipment; however, through the R&D capacity (T1) had an indirect impact on the equipment (β = 0.1414). That is, the direct cause of the shortage of equipment was due to the industry's R&D incapability rather than the high import costs or the lack of incentive measures; also there was no significant relationship between C1 and T3; therefore, the R&D capacity (T1) would not have been the mediating effect to C1 and T3. Third, considering PPA's (P2) impact over site availability (E1) and based on the previous theoretical assumptions, wind energy development will require a long and wide ranging occupation of land and time. Thus, if the decision-makers do not have a flexible power purchase plan that can provide adequate compensation to the local population, this will eventually derivate the limitation of the land use [26,43,48]. However, the analysis showed that there was no direct or indirect relationship between the PPA and the availability of the site. Thus, regardless of whether the decision-makers adopt a reasonable power purchase price, this does not appear to have any impact on the availability of the sites. Intermittency issues (E2, γ = 0.4190) were the main cause of the site limitations and this has a greater impact than the NIMBY effect (S1, β = 0.3070). Finally, regarding the results on the relationship between the availability of the site (E1) and investment cost (C2), Mirza *et al.*s' study [12,14,28,45,50] pointed out that the lease of land, subsidies, and high power transmission price to the remote sites would increase the investment costs of wind energy. However, the analysis showed that factors such as renting land or electricity transmission price would not have a direct effect on the investment cost, but rather an indirect effect through the infrastructure (S2, β = 0.0929). That is, because remote sites often have inadequate infrastructure, and this indirectly affects the investment cost of wind energy. In addition, since there was no significant relationship between E1 and C2, the infrastructure (S2) would not have been the mediating effect to E1 and C2; similarly, the site availability (E1) would not have been the mediating effect to E2 and C2.

Next, by considering the statistical significance of the paths, which represent the causality between barriers to the development of wind energy in developing countries, there are some phenomena that deserve special attention. First, from the observation of the path diagram (Figure 4), national policy (P1) was the main direct cause of the following three areas of obstacles: financial incentives (C1), social promotional measures (S1) and the PPA (P2), and the indirect cause of other obstacles. Through further comparison of the three paths of the coefficient and significance level, we could see that despite the significance of the three paths being the same, the influence of national policies on the PPA (γ = 0.660, $p > 0.001$) was far higher than the fiscal incentives (γ = 0.366, $p > 0.001$) and social promotion measures (γ = 0.388, $p > 0.001$). That is, every standard deviation unit of improvement on the national policy will directly improve by 0.660 σ units the PPA. Second, from the results of the analysis of the R&D capacity (T1), the analysis displayed that the three direct causes of industrial R&D incapacity include financial incentive measures (C1), PPA (P2) and projects and technology information (T2). However, from the comparison of the path coefficients and significance level, we could see that the projects and technology information had the highest degree of influence on the R&D

capacity (β = 0.379, $p > 0.001$). This seems to imply that the lack of establishment of projects and technology information delivery or sharing platform leads to the misunderstanding of the related industrial information, such as the durability and reliability assessment information on new technology development, which reduces the industry's R&D capacity. This was more evidently shown when we compared to the two phenomena C1 to T1 (β = 0.320, $p > 0.01$) and P2 to T1 (β = 0.186, $p > 0.05$) in the wind energy development of developing countries. The insights of this study suggest that if we want to help to improve the industrial R&D capacity in developing countries, strengthening of the transmission and exchange of information would be the priority; it is also worth noting that the R&D capacity (T1) is the only factor that causes obstacles in equipment (T3); therefore, every σ unit of improvement on the projects and technology information will indirectly improve by 0.168 σ units the equipment. Third, analysis of site availability (E1) showed that both intermittency issues (E2) and social promotional measures (S1) had a direct effect on the site availability issues. However, the significance and influences of intermittency issues on the site availability (γ = 0.419, $p > 0.001$) were higher than the impact from the social promotional measures (β = 0.307, $p > 0.01$); that is, intermittency issues are likely to be the main reason that limit the site selection, and this phenomenon compared to the NIMBY effect will be more evident in developing countries. The results of such an analysis were outside of our expectations because the majority of the literature suggests that public misperceptions of RE development is the main restriction to the site availability [44,48], in contradiction to the result of our analysis. The insight unveiled by the results of this study is that, because there is insufficient information for the decision-makers to have a thorough wind resource assessment on aspects such as the economies of scale of the available sites and maps, this limits site selection. Such effects have a much higher impact than the NIMBY effect. Therefore, the assessment of wind energy resources and the establishment of available site map information would be the priority measure to improve site availability issues in the developing countries. Fourth, it is interesting that the same results were found from the analysis of the infrastructure (S2). The majority of the literature indicates that the remote location of a site is a direct cause for the lack of infrastructure in wind energy development [12,17,42,43]. However, the results from the analysis showed that the significance and degree of impact from financial incentives (C1) (β = 0.388, $p > 0.001$) was much higher than the remoteness of the site location (β = 0.267, $p > 0.01$). That is, the lack of fiscal incentives was the main direct cause for the lack of infrastructure, and this phenomenon compared to the remoteness of the site will be more evident in developing countries. The insight unveiled by the results of this study is that, in the case of insufficient financial support provided by the authorities, local governments did not have adequate funding for the construction or improvement of the infrastructure, which led to the issues of inadequate infrastructure for the development of wind energy. Such an effect has a greater impact than the geographical factors. Therefore, the implementation of financial support measures of special loans and prime rate could be used as a priority to improve the local infrastructure, including grid transmission and the distribution network settings in the developing countries. Based on the theory, when financial incentives improve by one σ unit, the infrastructure improves by 0.388 σ units. Finally, the result of this analysis on the relationship between the intermittency issues (E2) and investment cost (C2) partly confirmed the discussions in the majority of the literature; *i.e.*, the additional measures such as electricity storage technology or equipment, taken in response to the stability of the power generation system affected by the intermittency issues will indeed elevate the investment cost of wind

energy ($\gamma = 0.146$, $p > 0.05$) [1,14,28,45,46,51], but this is not the main reason. Considering the coefficients and significance level of the path, equipment ($\beta = 0.483$, $p > 0.001$) and infrastructure ($\beta = 0.348$, $p > 0.001$) had a much greater impact than the intermittency issues. Therefore, strengthening the localization of equipment and components, and improving the domestic infrastructure would effectively and efficiently lower the investment cost of wind energy over a short period of time—the effective improvement of 0.831 σ units. The role played by intermittency issues in wind energy development among developing countries is mainly about inducing limitations over site availability (E1). Therefore, by exploring the mutual influence between the obstacles, it was clarified that wind intermittency issues would not be the main reason hindering wind energy development in developing countries.

3.2. The Inferential Effect of Obstacles

In addition to the path coefficients and significance between obstacles, we must also focus on the understanding of the influencing approach of barriers, or the mutual influence in the transmission process of barriers; this will help decision-makers in planning future short, medium and long-term development programs. First, the path diagram (Figure 4) shows the occurrence of all obstacles that will eventually either directly or indirectly impact on the investment costs (C2). Thus, how to effectively reduce the investment cost of wind energy development will be the most important issue for developing countries. Therefore, as the main objective to reduce the investment cost of wind energy, we found the equipment (T3) to be the main direct cause for high investment costs. Accordingly, decision-makers could focus on the localization and manufacture of the equipment and components as their short-term objectives. In theory, each additional unit of standard deviation improved by the localization of equipment reduces the investment cost by 0.483 σ units. Second, we found that the reason for the shortage of equipment was due to the lack of industrial R&D capability. Therefore, in general, we can take R&D capacity (T1) as the mid-term goal for wind energy development. It is worth noting that the improvement of local infrastructure (S2) warrants policy-makers' attention. When infrastructure improves by one standard deviation unit, this effectively improves investment costs by 0.348 σ units, which is even higher than the amount of improvement resulting from the R&D ability ($\beta = 0.213$). Therefore, for the medium-term development of wind energy, policy makers should focus on projects that elevate the industrial R&D capacity and improve the local infrastructure. Finally, a generally accepted view for the long-term goal in both developing and developed countries must focus on formulating relevant national policies, including the establishment of one single competent authority which has the power and responsibility of departmental coordination, goal planning and the setting of clear legal norms. [14,17,28,29,44,48,52,76]. Such a discussion is also confirmed by the analysis results of this study. That is, the lack of national policy (P1) indeed leads to the occurrence of other obstacles. Through the calculation of the manner in which barriers affect, we found that when national policies improve per standard deviation unit, the investment costs improve by 0.104 σ units (transmission process including: P1 → C1 → S2 → C2 = 0.049, P1 → C1 → T1 → T3 → C2 = 0.025, P1 → S1 → T2 → T1 → T3 → C2 = 0.018, P1 → S1 → E1 → S2 → C2 = 0.011). Interestingly, as previously pointed out, the role played by intermittency issues (E2) in wind energy development in developing countries is by inducing limitations in site availability (E1) and high investment costs (C2);

it was also confirmed by the comparison of the path coefficient and significance that intermittency issues would not be the main reason that hinders wind energy development. From the long-term perspective, the improvement of intermittency issues per standard deviation unit leads the investment costs to improve by 0.185 σ units (transmission process, including: E2 → C2 = 0.146, E2 → E1 →S2 → C2 = 0.039), which is even higher than the amount of improvement resulting from national policy. Therefore, for the long-term development of wind energy, aside from strengthening the development of the national policy and establishing an appropriate institutional framework, this study suggests that policy-makers should also focus on the related measures that can be used to improve intermittency issues that causes the limitation of site availability and high investment costs, including the establishment of an economic assessment of the site availability, the map information, detailed wind resource assessments, and better forecasting techniques and applications.

4. Conclusions and Limitations

The focus of this study was to understand the limitations for developing countries in respect of their development of wind energy, and to illustrate the causality between barriers through quantitative approaches, which we believed was worthy of discussion. Our study found that obstacles from different areas indeed affect each other. First, from the results of the analysis of the intermittency issues, while additional measures taken in response to the stability of the power generation system affected by the intermittency issues will indeed elevate the investment cost of wind energy, but this is not the main reason. From the perspective of the path coefficients and significance between obstacles, the equipment (T3) and the lack of local infrastructure (S2) are the two main reasons that cause the high investment costs. The role played by intermittency issues in wind energy development in developing countries is mainly about inducing limitations over site availability. For example, the lack of establishment of the economic evaluation of the site availability and the map information result in the limitations of the site's availability; and this has a greater impact than the NIMBY effect. Second, the lack of financial incentives, special loans and prime rate, are the main reasons that cause the infrastructure inadequacy, and the phenomenon compared to the remoteness of the site will be more evident in the wind energy development in developing countries.

In addition, by the inferences effect of barriers, we learnt that all barriers will eventually cause a direct or indirect impact on investment cost. Thus, how to effectively reduce the investment cost of wind energy development will be the most important issue for developing countries. Considering the main objective of reducing the cost of wind energy investment, strengthening the application of the localization of equipment and components would be the most effective and efficient approach for the short-term goal. In theory, each standard deviation unit improved on localization device maximizes the performance improvement of the investment cost. For the medium-term development of wind energy, it is worth drawing to policy-makers' attention the importance of strengthening local infrastructure (for example: roads, substations, transmission grids and distribution network settings, *etc.*). When infrastructure improves per standard deviation unit, this effectively improves investment costs by 0.348 σ units, which is even higher than the amount of improvement resulting from the R&D ability (β = 0.213). Therefore, for the medium-term goal, policy makers should focus on projects that elevate the industrial R&D capacity and improve the local infrastructure. Finally, this study confirmed that

both developed and developing countries should focus on the development of national policies in the long-term of wind energy development. From the perspective of the inference path between obstacles, the lack of national policy indeed leads to other disorders. It is worth noting that despite the fact that the study clarifies that intermittency issues will not be the main reason that hinders wind energy development in the developing countries, from a long-term point of view, when intermittency issues improve per standard deviation unit, the investment cost improves by 0.185 σ units, which is even higher than the amount of improvement resulting from the national policies. Therefore, for long-term development of wind energy in developing countries, policy-makers should certainly strengthen the development of national policy and ensure the establishment of an appropriate institutional framework; policy-makers should also focus on the related measures that can be used to improve intermittency issues that cause the limitation of site availability and high investment cost, such as the establishment of an economic assessment of the site availability, the map information, detailed wind resource assessment and better forecasting techniques and applications.

It is noteworthy that the proposed development strategies described above were based on a wide-angle point of view. However, if we need to explore the differences between the strategies for specific developing countries in the future, it is necessary to modify the model based on more detailed information to appropriately reflect the situations of the specific countries, including the collection of literature reviews, interviews, the understanding of current statuses and other systematic methods. For example: (1) in China, the wind energy industry has become a "market-oriented operation and management" concept with the establishment of a market economy system and energy market. Thus, to strengthen the application of the localization of equipment would not be the core focus for wind energy development in China. On the contrary, to reinforce the construction of the transmission lines, distribution network settings and the capability of the grid infrastructure, and improve the independent innovation in technology would be the most important measures for the short-term goal. For the medium and long-term development strategies, decision-makers could focus on formulating relevant policies and measures, including the energy and cultural reform, the diversity for regulations of grid stabilization and power supply structure. According to the above-mentioned, we have found that there are some differences between China's strategies and the one proposed in this study. A similar phenomenon has also been found in India and Mexico. (2) In India and Mexico, their development of wind energy are still at the early stage compared to China. Thus, short-term priorities for decision-makers would be to strengthen the application of the localization of equipment and components based on the resource accessibility. Next, for the medium-term development of wind energy, aside from expansion of infrastructure, decision-makers could also focus on the related promotional measures that can be used to improve the industrial innovative ability and public awareness of RE development. From a long-term point of view, the decision-maker's determination for RE and adequate financial incentives will be the key for the future development of wind energy, such as coordination and cooperation between various ministries, agencies, institutes and other stakeholders, appropriate PPA, the fund requirements in response to the stability of the power generation system and a well-defined policies for private participation.

Finally, this study primarily explores the common obstacles of wind energy development in developing countries. Other country-specific or region-specific barriers are recommended to be included for future discussion. In addition, in different periods of national development goals and

policies, countries may face emerging challenges, such as the competition for funds due to other RE developments. This study proposes a model architecture that is suitable as a preliminary insight into wind energy development in developing countries. In the future, researchers could make moderate modifications to the model based on different conditions to more appropriately reflect the situation of the countries in which wind energy development is being considered.

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Conflicts of Interest

The authors declare no conflict of interest.

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