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Macroeconomic Cost-Benefit Analysis for Renewable Energy Integration

Ea Energy Analyses

DHI GRAS

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Abbreviations

AECID	Agencia Española de Cooperación Internacional para el Desarrollo; Spanish Agency for International Development Cooperation
AEP	Annual Energy Production
CapEx	Capital Expenditure
CL	Cluster
CO2	Carbon Dioxide
DEA	Danish Energy Agency
ESA CCI	European Space Agency Climate Change Initiative
EUR	Euro
FLH	Full Load Hour
FIT	Feed-In-Tariff
GADM	Global Administrative Areas
GDE	General Directorate of Energy
GDP	Gross Domestic Product
GHG	Green House Gas
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GHI	Global Horizontal Irradiation
IEA	International Energy Agency
LCOE	Levelized Costs of Electricity
MoIT	Ministry of Industry and Trade, Vietnam
NREL	American National Renewable Energy Laboratory
NTP	National Technical Potential
O&M	Operation and Maintenance (costs)
OpEx	Operational Expenditure
PCL	Provincial cluster
PCL_F	Provincial cluster Far (from infrastructure)
PV	Photovoltaics
RE	Renewable Energy
SRTM	Shuttle Radar Topographic Mission
WACC	Weighted Average Cost of Capital
WDPA	World Database on Protected Areas
WEO	World Energy Outlook (IEA publication)

Disclaimer

The results of the present study are intended for top-level power system development planning purposes on a regional/cluster level, and **are not to be used for individual RE project site selection.** Wind energy resource potential data used in the present study is based on meteorological modelling, and not on-site measurements. The analysis results are subject to the accuracy of input data sources and development projection assumptions used.

Foreword

This is the Final Report relating to the project 'Macroeconomic Cost-Benefit Analysis for Renewable Energy Integration'. The project is being carried out by Ea Energy Analyses in collaboration with DHI GRAS and the Institute of Energy (Viện Năng lượng) within the framework of the Danish-Vietnamese cooperation between the Danish Energy Agency and the Ministry of Industry and Trade of Vietnam. The funding of the project is provided by GIZ.

This project is a supporting activity for the currently on-going initiative of the Danish-Vietnamese cooperation programme, the Model-Based Power Sector Scenarios for Vietnam.

Executive Summary

The current report presents the details and results of the land-based wind resource mapping GIS analysis, as well as provides the Levelised Cost of Energy (LCOE) perspective on selected wind resource clusters characterized by above-average wind resource. A more detailed wind resource mapping analysis has been carried out for selected six provinces: Binh Thuan, Ninh Thuan, Khanh Hoa, Phu Yen, Binh Dinh and Quang Ngai.

The GIS analysis of land-based wind resources within the current study follows the resource potential estimation approach whereby the total (theoretical) resource potential is constrained (based on topography and land use limitations, population density and terrain slope etc.) to represent the technically feasible potential. The technically feasible potential has thereafter been evaluated using economic criteria, in this case additional costs associated with infrastructure proximity (distance to main roads and transmission grid) and projected annual wind power generation. Both 220 kV (national and regional) and 110 kV (regional) transmission network are used in the analysis subject to the identified cluster size.

The land-based wind resource GIS mapping analysis suggests that Vietnam is endowed with significant wind power potential. Based on the exclusion criteria applied in the GIS analysis, the national technical potential (NTP) has been estimated at 214 GW. The NTP area overlaid with average wind speeds is shown in Figure 1.

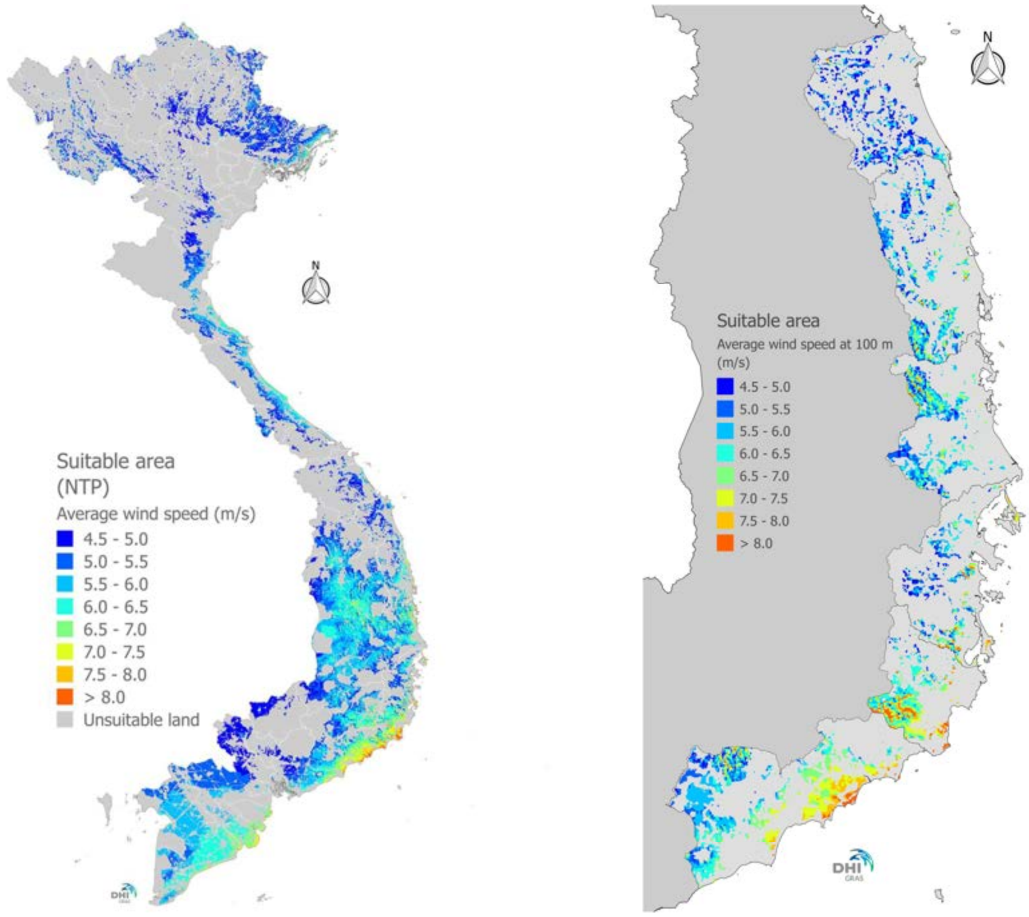


Figure 1. Suitable areas of National Technical Potential (NTP) overlaid with average wind speed (left) and provincial technical potential (right).

For this study wind speeds from 4.5 m/s have been considered based on the screening criterion used in (IRENA, 2016). The vast majority of the Vietnamese NTP is characterized by relatively low wind resource quality (mean annual wind speed of 4.5 – 6m/s at 100m height**). However, ca 25% of the national NTP (ca 52 GW) is located in areas with mean annual wind speed of 6m/s and higher**. Central region has the largest share of the higher quality wind resource locations, corresponding to 37 GW, followed by South at 14 GW. Only 1.2 GW of the higher quality wind resource is located in the North. Table 1 provides an overview of the NTP across regions and wind speed ranges.

Table 1: National Technical Potential (NTP) across regions and wind speed ranges (expressed in km² and MW)

	Technical potential land area (km²)				Technical potential wind capacity (MW)			
Wind speed range	***North***	***Central***	***South***	***TOTAL***	***North***	***Central***	***South***	***TOTAL***
National technical potential (NTP)								
4.5 - 5.0 m/s	5,167	4,720	3,945	**13,832**	15,501	14,160	11,835	**41,496**
5.0 - 5.5 m/s	3,086	10,150	5,400	**18,636**	9,258	30,450	16,200	**55,911**
5.5 - 6.0 m/s	954	14,600	6,127	**21,681**	2,862	43,800	18,381	**65,043**
6.0 - 6.5 m/s	281	7,866	3,345	**11,492**	843	23,598	10,035	**34,476**
6.5 - 7.0 m/s	104	2,487	949	**3,540**	312	7,461	2,847	**10,620**
7.0 - 7.5 m/s	11	1,323	217	**1,551**	33	3,969	651	**4,650**
7.5 - 8.0 m/s	2	543	19	**564**	6	1,629	57	**1,692**
Over 8.0 m/s	1	264	0	**265**	3	792	-	**795**
TOTAL	**9,606**	**41,953**	**20,002**	**71,561**	**28,818**	**125,859**	**60,006**	**214,683**
TOTAL (6+ m/s)	**399**	**12,483**	**4,530**	**17,411**	**1,197**	**37,449**	**13,590**	**52,233**

The GIS analysis steps highlight the relative share of importance of the different exclusion criteria towards the NTP. Almost a quarter of the total land area in Vietnam has been excluded based on mean annual wind speed threshold criterion, i.e. areas with mean annual wind speed at 100m height not reaching 4.5m/s. Further significant land exclusion criteria (i.e. resulting in large land exclusion areas) have been based on populated areas / population density, protected areas, forests, as well as areas characterized by high terrain steepness.

NTP scenarios

The alternative scenarios based on infrastructure proximity and availability of agricultural land provide further insights. It should though be noted that only existing infrastructure of transmission grid and roads has been included in the analysis (i.e. no envisioned development of the infrastructure network has been considered due to data availability). Hence, the infrastructure proximity of the wind resource areas could improve over time as infrastructure development continues.

- **Within 20km distance:** Over two thirds of the NTP (or 143 GW) are identified in the regions within 20 km distance, both from the closest 220kV transmission infrastructure point, and the closest major road
- **Within 10km distance**: Approximately one third (77GW) of the NTP is identified in the regions within 10 km distance, both from the closest 220kV transmission infrastructure point, and the closest major road. The analysis also suggests that clusters with high wind potential generally lie within relative proximity to infrastructure (i.e. within 0-10 and 10-20 km distance to closest transmission grid and / or road considered).
- **Within 20 km distance, no agricultural land**: An NTP of 54 GW is identified in the regions within 20 km distance, both from the closest 220kV transmission infrastructure point, and the closest major road, but excluding agricultural land.
- **Within 10 km distance, no agricultural land**: An NTP of 27 GW is identified in the regions within 10 km distance, both from the closest 220kV transmission infrastructure point, and the closest major road, but excluding agricultural land.

A significant share of the NTP lies on agricultural land (croplands), comprising 40 340 km² of the total NTP area. This corresponds to 126 GW of the NTP, and includes a vast majority of high wind resource potential of 6m/s and higher mean annual wind speed, especially in South (13.1 GW out of 13.6 GW in the

NTP) and Central (24 GW out of 37 GW in the NTP). More than 80% of all NTP in the South is located on agricultural land (and over 95% of all high wind resource areas). The Central region still exhibits the highest resource potential (both in terms of capacity level and wind resource quality), but North exceeds South in terms of total resource potential (as well as in potential for high wind resource) in the cropland exclusion scenario. The availability of agricultural land for wind power project development is therefore a critical factor for wind power deployment in Vietnam.

Siting wind power projects on agricultural lands is a common practice internationally. The wind turbines are reported to have minor impact on farming and ranching activities – the turbines have a small footprint and “crops can be grown and livestock can be grazed right up to the base of the turbine” (NREL, 2003). At the same time, income from wind power projects can provide significant additional revenue stream to farmers and rural landowners. In addition, diversification of revenue streams helps safeguard the farmers from highly volatile agricultural crop yields and commodity prices. This is accompanied by significant local tax revenue, e.g. property taxes that benefit the local communities (Bloomberg, 2016). Table 2 provides an overview of the national technical potential scenarios across regions.

Table 2: National technical potential scenarios across regions (expressed in km² and MW, wind speeds from 4,5m/s)

	Technical potential land area (km2)				Technical potential wind capacity (MW)			
Scenario	***North***	***Central***	***South***	***TOTAL***	***North***	***Central***	***South***	***TOTAL***
National technical potential (NTP)								
NTP total	9,606	41,953	20,002	**71,561**	28,818	125,859	60,006	**214,683**
NTP 20km	3,938	29,862	14,006	**47,806**	11,814	89,586	42,018	**143,418**
NTP 10km	2,304	16,141	7,408	**25,853**	6,912	48,423	22,224	**77,559**
NTP No croplands	6,214	19,920	3,469	**29,603**	18,642	59,760	10,407	**88,809**
NTP No croplands 20km	2,637	13,095	2,286	**18,018**	7,911	39,285	6,858	**54,054**
NTP No croplands 10km	1,504	6,416	1,127	**9,047**	4,512	19,248	3,381	**27,141**

Provincial wind resource mapping

The more detailed wind resource mapping analysis carried out for the selected six provinces (Binh Thuan, Ninh Thuan, Khanh Hoa, Phu Yen, Binh Dinh and Quang Ngai) suggests significant wind resource potential. The total technical potential across the six provinces exceeds 12 GW, with Binh Thuan, Phu Yen and Binh Dinh demonstrating the highest contributions (4.8 GW, 2 GW and 1.8 GW, respectively). Binh Thuan and Ninh Thuan stand out in particular in relation to prevalence of high wind resource quality potential – technical potential of areas with mean annual wind speeds of 6 m/s or higher exceed 2.8 GW and 1.3 GW, respectively. The technical potential suitable area (overlaid with average wind speeds for the six provinces) is shown in Figure 1 (right). Table 3 provides an overview of the provincial technical potential across wind speed ranges.

Table 3: Provincial technical potential wind power capacity across wind speed ranges expressed in MW

Annual average wind speed range	**Binh Dinh**	**Binh Thuan**	**Khanh Hoa**	**Ninh Thuan**	**Phu Yen**	**Quang Ngai**	**Total**
4.5-5 m/s	159	96	124	15	104	452	950
5-5.5 m/s	461	524	245	34	490	358	2,112
5.5-6 m/s	602	1,337	183	135	683	184	3,124
6-6.5 m/s	364	580	127	455	429	110	2,065

6.5-7 m/s	156	680	95	333	187	21	1,472
7-7.5 m/s	83	986	60	263	71	5	1,468
7.5-8 m/s	14	487	60	131	45	0	737
8+ m/s	8	140	29	160	10	1	348
Total	**1,847**	**4,830**	**923**	**1,526**	**2,019**	**1,131**	**12,276**
Total (6+ m/s)	**625**	**2,873**	**371**	**1,342**	**742**	**137**	**6,090**

The GIS analysis steps highlight the relative share of importance of the different exclusion criteria towards the provincial technical potential. Only ca 5% of the total land area in the selected provinces has been excluded based on mean annual wind speed threshold criterion, i.e. areas with mean annual wind speed at 100m height not reaching 4.5m/s (in the NTP the share reached 25%). Similar to the NTP, further significant land exclusion criteria (i.e. resulting in large land exclusion areas) have been based on populated areas / population density, protected areas, forests, as well as areas characterized by high terrain steepness. Another criterion (specific to the provincial analysis) resulting in major additional land exclusion area has been residential and public lands.

The analysis also suggests that, akin to the findings of the NTP analysis, clusters with high wind potential in the selected provinces generally lie within relative proximity to infrastructure (i.e. within 0-10 and 10-20 km distance to closest transmission grid and / or road considered). Overall, the infrastructure proximity for the selected clusters can be assessed as non-prohibitive. For context, the threshold for grid connection proximity used in IRENA analysis in relation to wind power projects in Latin America has been set at 75 km (IRENA, 2016).

LCOE analysis

The LCOE analysis explored 'clusters', i.e. areas characterised by significant proportion of adjacent above-average wind resource cells, both nationally, and within the six selected provinces. It should be noted, however, that the clusters identified have been based exclusively on accumulation of feasible resource potential adjacent to above-average wind resource quality cells, and have been used for illustrative purposes. The clusters hereby identified are not to be used as recommendations for wind power project site boundary selection. The clusters explored in the LCOE analysis are represented in Figure 2.

It should be noted that the LCOE values are highly dependent on the wind time series used. As discussed in Chapter 5, the wind series used in this study are subject to limitations connected to meteorological modelling as opposed to on-site measurements.

The results should also be seen in the context of the wind farm size assumed. Size-dependent infrastructure costs have been considered in the LCOE calculations, as documented in Appendix II. The wind farm size in the LCOE calculations has been based on the potential of the individual cluster. However smaller projects might have higher LCOEs, e.g. in the national cluster Bac Lieu, in the wind class 6-6.5 m/s, a 600 MW installation would have a Base Case LCOE of 10.65 $ct/kWh where a 30 MW farm would have LCOEs of 12.03 $ct/kWh (13% increase). The increase in LCOE when comparing a 30 MW farm to a 600 Mw farm is very dependent on the distance from roads and grid. On average, an increase of 20% can be expected in Base Case LCOEs when comparing wind farm size of 600 MW to 30 MW (22% in the Low Case). No size-dependence of the remaining capital costs has been included in the calculations, which might increase the LCOEs for small wind farms even further due to wind farm costs that do not scale linearly with size.

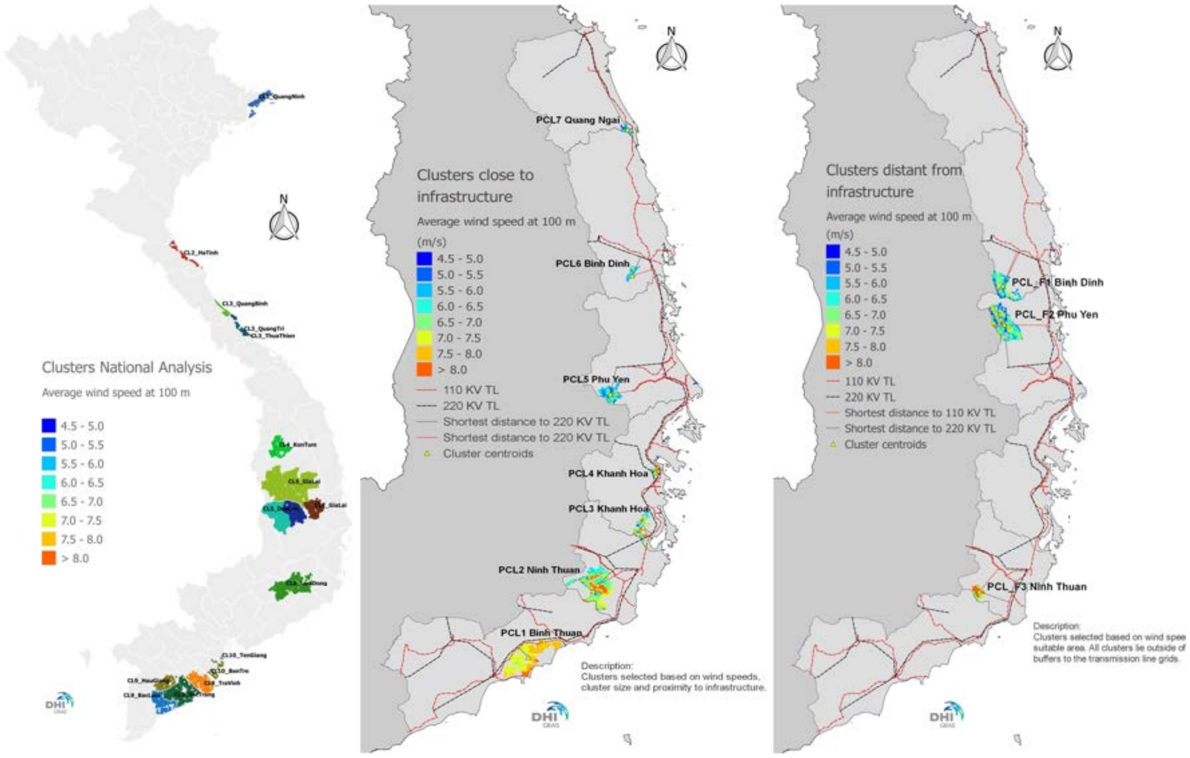


Figure 2: National (left) and provincial (center and right) clusters explored in the LCOE analysis

Two LCOE cases were developed: LCOE Base Case and LCOE Low. LCOE Base Case is based on assumptions deemed to be representative of the situation in Vietnam currently. LCOE Low, in turn, can be interpreted as the assumptions projected to be representative of the near- to mid-term future as the wind power industry in Vietnam would mature, economies of scale would develop, and the cost levels would increasingly converge with the international averages.

Of course, it should be noted that the LCOE Base Case analysis is only indicative of overall project costs, and does not reflect the specific conditions of the individual project (e.g. differences in administrative/permitting and financing conditions of larger versus smaller projects).
Similarly, LCOE Low case illustrates one potential technology and cost development projection, and is subject to high degree of uncertainty. The LCOE levels have been estimated assuming infrastructure cost sharing across the entire cluster, please see Allocation of infrastructure costs in the LCOE calculation section for a description of the approach used.

- **LCOE Base Case**: Overall, the LCOE of clusters range from just under 8 $ct/kWh to 14 $ct/kWh in the LCOE Base Case. However, most of the clusters are within the 9.5-12.5 $ct/kWh range.
    - **Good locations (6 - 7.5m/s):** The LCOE Base Case analysis suggests good locations could be developed in an LCOE range of ca 8 – 11 $ct/kWh
    - **Best locations (+ 7.5m/s):** In addition, limited 'best' locations could be developed down to under 7 $ct/kWh
    - **Worst locations (4.5 - 5m/s):** The LCOE increases progressively along with decreasing wind resource quality, the 4.5-5 m/s mean annual wind speed locations reaching ca. 20 $ct/kWh.
- **LCOE Low Case:** The LCOE Low case analysis suggests that more favourable project development and technology conditions could yield significant LCOE reductions (e.g. in the medium term), and the absolute reductions are most prominent for lower wind resource locations – both nationally, and within the selected provinces. Overall, the LCOE of clusters range from just 5 $ct/kWh to 9 $ct/kWh in the in the LCOE Low Case. However, most of the clusters are within the 6-8 $ct/kWh range.
    - **Good locations (6 - 7.5m/s):** The LCOE Low Case analysis suggests good locations could be developed in an LCOE range of 5.2 – 6.9 $ct/kWh.

- **Best locations (+ 7.5m/s):** Limited 'best' locations could be developed in the range of 4.2 – 4.7 $ct/kWh.
- **Worst locations (4.5 - 5m/s):** Locations with 4.5-5 m/s mean annual wind speed yield an average of ca. 13 $ct/kWh, which is a significant reduction from the 20 $ct/kWh in the LCOE Base Case.

Figure 3 provides a representative overview of the LCOE Base Case and LCOE Low across wind speed ranges for a selection of provincial clusters.

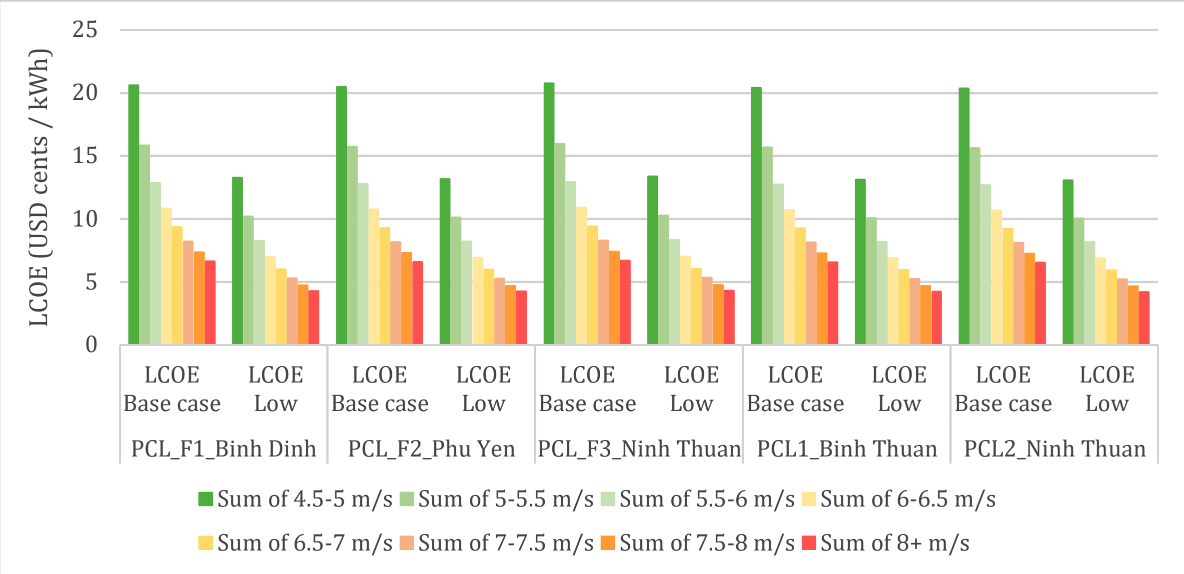


Figure 3: LCOE overview per provincial cluster (LCOE Base Case and LCOE Low) across average annual wind speed ranges. Selection of representative clusters (close and large distance to infrastructure)

The compound LCOE values per cluster (the capacity-weighted LCOE values per wind speed ranges of each cluster) indicate that the clusters' lowest overall LCOE are located in the provinces with the best wind resource (Central and South regions), whilst the cluster with the highest LCOE is located in the North (Quang Ninh) as presented in Figure 4. Larger clusters that feature a wide spectrum of different wind resource sites (including large shares of lower wind speed sites) also generally exhibit higher LCOE values. Interestingly, a cluster with good wind resource yet in relatively longer distance from infrastructure (PCL_F3 in Ninh Thuan province) ranks among the lowest cost clusters, supporting the finding of the possibility of infrastructure costs becoming a minor factor in wind power project competitiveness.

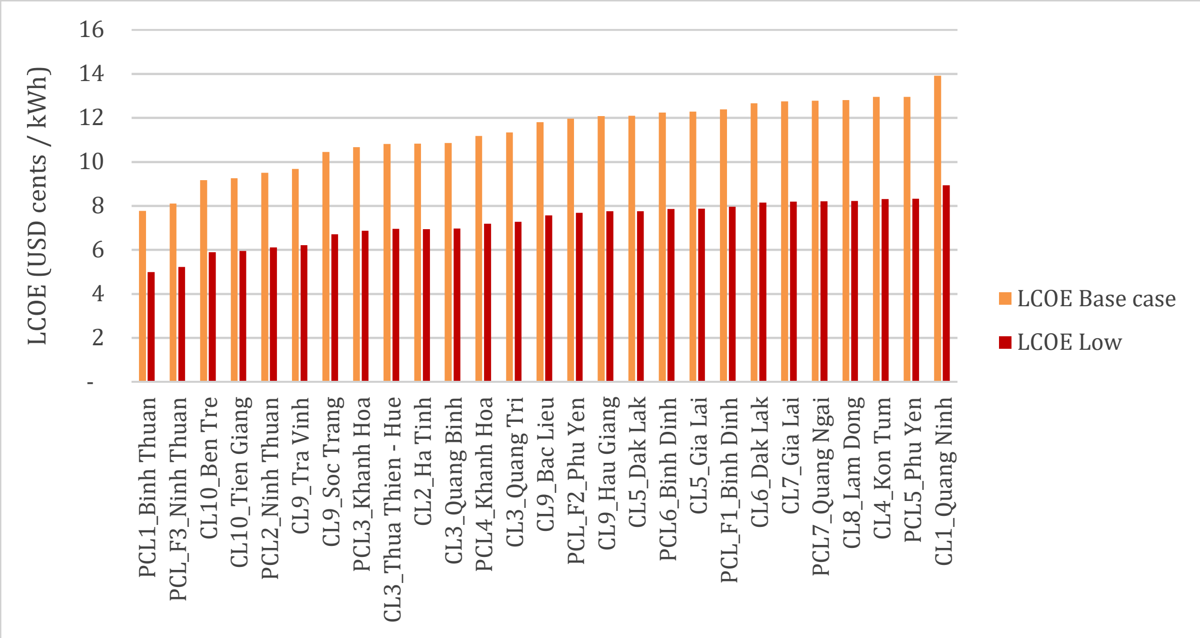
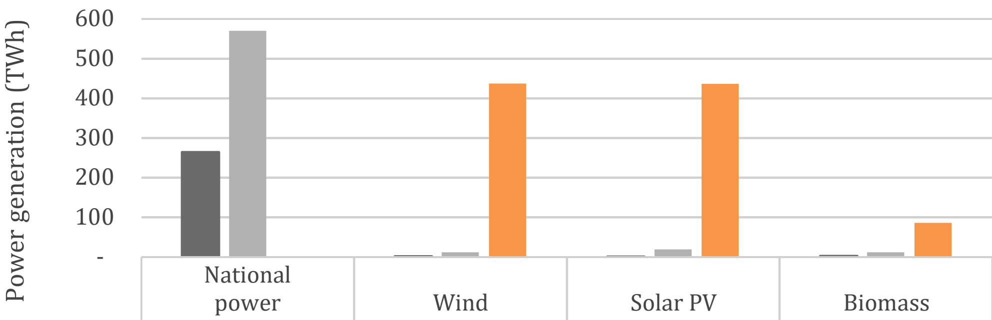


Figure 4: Compounded average LCOE (capacity-weighted across wind class ranges) per cluster in $ct/kWh.

The results of the cluster analysis also indicate that the impact of the infrastructure on-costs is minimal, at least on the entire cluster level (it should be noted that some of the national clusters are very considerable in capacity size). The highest CapEx on-costs related to additional infrastructure development (yet not exceeding 4%) have been estimated for the relatively smaller clusters both nationally and within the selected provinces (size range of 50-70 MW). **The results (based on the given sample of clusters) also indicate that the size of the cluster exhibits higher impact on the infrastructure costs than the infrastructure proximity per se.** Furthermore, the LCOE analysis highlights the importance of wind resource quality (and the corresponding full-load hours of production) as a critical determinant of cost competitiveness of a wind power project.

Implications for RE development planning

Alongside solar PV (national technical potential estimated at 339 GW) and biomass for power production (current national technical potential estimated at 10 GW; increasing to over 13 GW towards 2030), wind presents a very significant potential (NTP estimated at 214 GW) for RE development in Vietnam. The estimated NTP for wind, solar PV and biomass (and the associated total potential annual power generation estimates) vastly exceed the RE development targets set out by PDP 7 revised, as illustrated by Figure 52.



	National power demand	Wind	Solar PV	Biomass
Sum of PDP 7 rev. 2020	265	2	1	3
Sum of PDP 7 rev. 2030	570	12	19	12
Sum of NTP 2020		437	436	86

Figure 5: National Technical Potential (NTP) power generation estimates for wind, solar PV and biomass compared to the national power demand projections in PDP 7 revised for 2020 and 2030, respectively. (Please see Appendix X for full comparison.) Unit: power generation / demand in TWh.

By 2030, PDP 7 revised envisions 6 GW of wind and 12 GW of solar PV in the Vietnamese power system, corresponding to 2.1 and 3.3 % (and 2.1% for biomass) of the total national power production, respectively. The analysis suggests that the abundance of technically feasible RE potential could allow for significantly higher shares of RES generation in the Vietnamese power system in the future.

Whilst the overall wind resource quality in Vietnam is relatively low, large potential also for wind resource areas exceeding 6 m/s of mean annual wind speed have been identified nationally, reaching 52 GW. Based on the LCOE Base Case assumptions representative of the current situation in Vietnam, these areas could be developed at a cost range of 6-10 $ct/kWh. Provided increasing maturation of the wind power industry in Vietnam and further improvements and cost reductions in wind power technology globally, the LCOE for areas with lower wind resource quality in the medium term could decrease to a cost range of 8-13 $ct/kWh, making them more cost competitive. Prerequisites for a mature market development have been listed in the paragraph below.

The infrastructure cost parameter analysis, as well as the LCOE perspective on wind energy resource 'clusters' has highlighted that the on-cost borne by additional infrastructure development (transmission grid and road) can be negligible, provided that the cost is shared across the entire cluster. In power system and RE deployment planning perspective, this could suggest that it would be socio-economically advantageous to coordinate infrastructure development in the long-term, taking into account prospective wind power project development areas.

Wind power project siting on agricultural land is common practice internationally. The operation of wind power projects does not impede farming activities, whilst providing additional income opportunities to the local land-owners and residents (e.g. through job creation). Obstacles (e.g. procedural or regulatory) to wind power project development on agricultural land could therefore pose a significant challenge for large scale and cost-efficient wind power deployment in Vietnam, given the very significant (and superior) wind resource potential located on agricultural land.

Prerequisites for successful RE development

Significant RE resource potential does not guarantee successful RE project development per se. A number of important preconditions are required in order to enable and encourage the development of a viable RE industry (based on "Up-Scaling of Wind Power in Viet Nam - Capacity Needs Assessment for Wind Power" (GIZ, 2016) and "LCOE of current wind projects in Viet Nam and recommendations for an improved support mechanism" (GIZ, 2017)):

- Adequate legal and regulatory framework;
  - Streamlined procedures to mitigate lengthy permitting process;
- Adequate support level for RE development:
  - More support needed in nascent markets, to compensate the high risk and enable service and human capital development;
  - Support can be gradually reduced once the market matures;
- Opportunities for RE-focused education;
- RE-focused engineering disciplines at universities and vocational education and training possibilities to be encouraged.

1 Introduction

In order for the Government of Viet Nam to economically optimize the integration of variable renewable energy into the energy system for the national benefit and achieve the long-term objectives of utilizing RE and reducing the GHG emission, an energy planning exercise is required.

In this context, the Danish Energy Agency (DEA) is undertaking a study for model-based power sector scenarios, using the Balmorel model[1]. This model has been used in collaboration with the government of Vietnam in 2015, and has proved its value with a pilot model of the Vietnamese energy mix creating optimal dispatch on an hourly basis, as well as optimal generation and transmission development planning. A group of experts has been trained on the model's key features and input data was reviewed according to feedback. Following this, the DEA and it local partners have decided to further develop the model, build up the local capacities to operate it, and prepare an energy outlook up to 2050 for the country based on the results obtained.

Among the inputs for this modelling exercise, renewable energy resources and investment costs are crucial. With its long-standing experience in renewable energy in Vietnam and its first-hand data, GIZ is collaborating with the Danish Energy Agency on this preliminary step.

The main objective of the current study was to obtain improved high-level RES resource potential data for planning activities of the future Vietnamese power sector. The main focus is on land-based wind power, whereby data has been collected and analyzed using GIS, to arrive at theoretical potential, and technical and economic feasibility. The data was then adapted for use in the Balmorel model in the long-term power system planning scenarios.

The current report presents the details and results of the land-based wind resource mapping GIS analysis, as well as provides the Levelised Cost of Energy (LCOE) perspective on selected wind resource clusters characterized by above-average wind resource. A more detailed wind resource mapping analysis has been carried out for selected six provinces: Binh Thuan, Ninh Thuan, Khanh Hoa, Phu Yen, Binh Dinh and Quang Ngai. In addition, an overview of regional solar PV and biomass (for use in power production) resource potentials in Vietnam has been provided for context.

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[1] Please see Appendix I for more information

2 Study methodology

The analysis of land-based wind resources within the current study will follow the resource potential estimation approach whereby the total (theoretical) resource potential is constrained (based on topography and land use limitations, population density and infrastructure proximity etc.) to represent the technically feasible potential. The technically feasible potential will thereafter be evaluated using economic criteria, in this case infrastructure proximity (distance to roads and transmission grid) and projected annual wind power generation. Market factors (e.g. support schemes, regulatory national targets, value of electricity) are not within the scope of the current study, as illustrated in Figure 6.

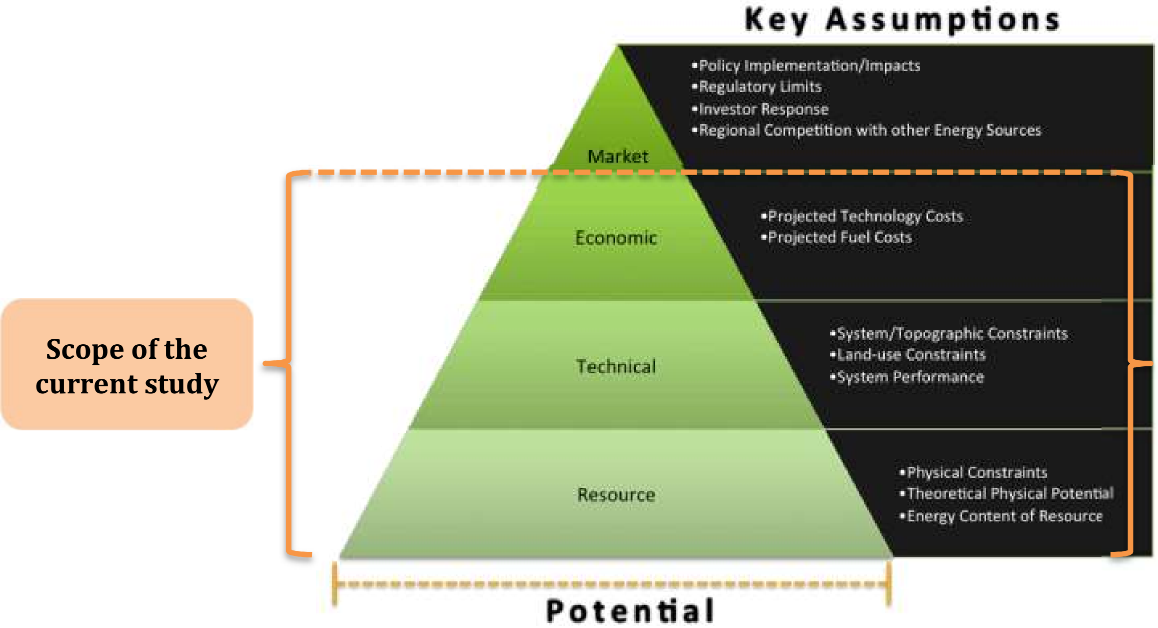

Figure 6. Levels of resource potential. Illustration source: (NREL, 2012)

2.1 GIS analysis framework

The following analysis steps have been applied within the study:

- GIS layer with annual resource for wind is plotted, representing the theoretical resource potential, and covering all of Vietnam
- GIS layers representing topology, land use, protected areas and population etc. are added. Based on the exclusion criteria applied (see section Screening criteria), the technical resource potential is estimated by excluding the areas where wind power project development would not be possible (e.g. on steep slopes, in national parks, in urban areas etc.)
    - National results for technical potential land-based wind resource potential are presented
- Technical potential areas characterised by significant proportion of adjacent above-average wind resource cells are selected and grouped into 'clusters'
- GIS data on electricity grid is collected and plotted, along with the GIS layer of the road network. For each technical potential 'cluster' identified, distance to roads and transmission grid is determined
- Based on the hourly wind speed time series data set, the annual energy production per 'cluster' is estimated
- Levelised Cost of Electricity (LCOE) overview is provided for the selected 'clusters', taking into account the infrastructure proximity (and their associated costs), as well as the estimated annual energy production
- In addition, more detailed provincial land-based wind resource GIS analysis is carried out for selected six provinces: Binh Thuan, Ninh Thuan, Khanh Hoa, Phu Yen, Binh Dinh and Quang Ngai

Figure 7 provides an illustration of the analysis steps.

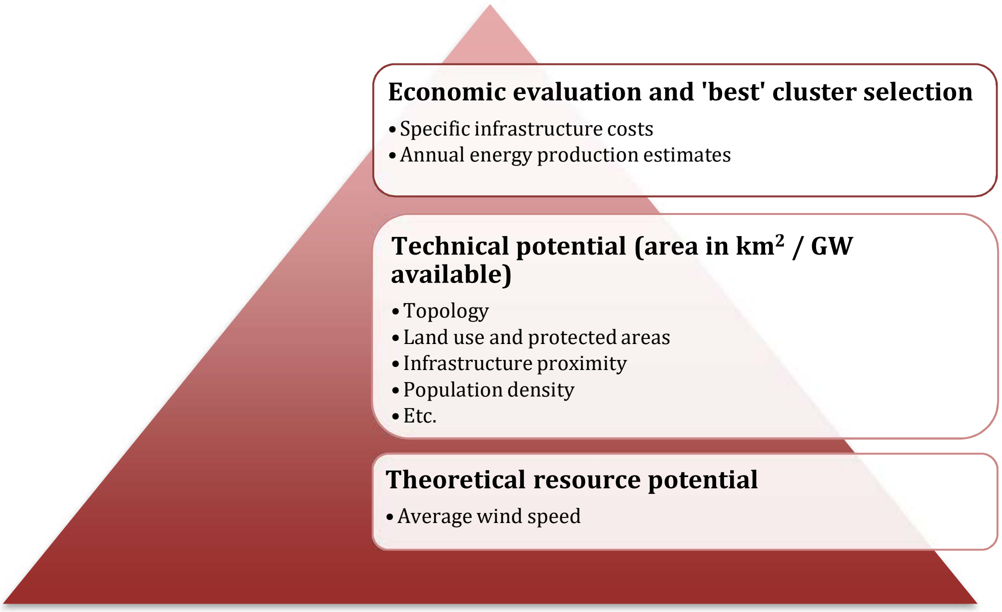

Figure 7. Illustration of the analysis steps in the current study

2.2 Screening criteria

This section summarizes the screening criteria limits (**exclusion** criteria) used in the GIS analysis. I.e. the table summarizes the characteristics of areas not deemed to be suitable for land-based wind power project development – and henceforth removed from the national potential in the process of the GIS analysis.

For some of the exclusion areas a distance [to excluded area] criterion is used to account for a buffer zone between an excluded area and a possible wind power project development site. The exclusion criteria limits and the buffer zone distances have been derived from international sources reporting on similar analyses (whilst taking into account Vietnam-specific conditions to the extent possible). The international sources used for reference have been listed in the Source column.

Table 4: Wind power resource technical potential estimation exclusion criteria

Dimension	Exclusion criteria	Distance	Source
Wind speed	Under 4.5 m/s		(IRENA, 2016)
Topography	Slope over 30%		(Yang, 2013), (Rodman & Meentemeyer, 2006)
Altitude	Over 2000m		(IRENA, 2016)
Population density	Over 500 persons/km^2	500m	(IRENA, 2016), (Yang, 2013)
Protected areas	Listed as protected area	1km	WDPA[2], (Yang, 2013), (Rodman & Meentemeyer, 2006)

[2] https://www.iucn.org/theme/protected-areas/our-work/world-database-protected-areas

Coast	Proximity to coast	100m	(Stenz, Malaney, Gillman, & Crill, 2010)
Land use (NTP)	Urban areas	1 km	(Stenz, Malaney, Gillman, & Crill, 2010), (IRENA, 2016), (NREL, 2012)
	Water bodies	100m	
	Forests (cover > 15%) and flooded trees (e.g., Mangroves)	100m	
	Roads and railroads	250m	
Land use (detailed provincial analysis)	Commercial, Industrial and Non-Agricultural Land	1km	(Stenz, Malaney, Gillman, & Crill, 2010)
	National Defense and Religious Land	1km	(Stenz, Malaney, Gillman, & Crill, 2010)
	Residential and Public Land	1km	(Stenz, Malaney, Gillman, & Crill, 2010)
	Special Forest Land	1km	(Yang, 2013), (Rodman & Meentemeyer, 2006)
	Transportation	250m	(Stenz, Malaney, Gillman, & Crill, 2010)
	Water bodies	100m	(Stenz, Malaney, Gillman, & Crill, 2010)

The wind speed exclusion criterion removes the areas where average annual wind speeds would not be sufficient for wind power projects, based on (IRENA, 2016).

The topography exclusion criterion removes the areas where siting of wind power projects would not be possible due to the steepness of the terrain. Slope thresholds used in wind power-related GIS analyses varies greatly in international literature, ranging from 9% to 40% in the sources reviewed. Slope threshold of 30% has been selected for the purposes of the current study used in (Yang, 2013), based on (Rodman & Meentemeyer, 2006).

The altitude exclusion criterion removes high-altitude areas that are not conducive for wind power project development (IRENA, 2016). The IRENA study states, however: “A maximum altitude of 2000 m was considered as a limitation for wind power installation for this analysis. However, this preliminary assessment should not be interpreted as a statement against wind development above that level.” It should be noted that in the case of Vietnam, the land area exceeding 2000m height threshold is negligible.

The population density exclusion criterion is employed to avoid proximity to population centers and as a proxy to buildings, with the assumptions that buildings are where people are and that the denser the population per km^2 the denser the built-up area and potentially higher the buildings. The population density exclusion criterion threshold of 500 persons / km^2 is based on (IRENA, 2016). In addition, 500m buffer zone area exclusion criterion is further added based on (Yang, 2013), reported to correspond to a distance providing acceptable sound pressure levels (between 40 and 55 dB) for the people living in the vicinity of wind turbine locations (HGC Engineering, 2007).

The protected areas exclusion criterion is used to remove the areas where large scale construction projects are likely to be prohibited, e.g. nature reserves, national parks, protected landscapes etc. based on World Database on Protected Areas (WDPA). In addition, a buffer zone exclusion criterion is further added to account for the possible limitations of construction in the immediate vicinity to the protected areas due to noise and visual impact concerns. Buffer zone threshold of 1000m has been applied in the current analysis, derived from state parkland buffer zone threshold used in (Yang, 2013), based on (Rodman & Meentemeyer, 2006).

The coast exclusion criterion is used to remove areas in close proximity to the coast. No specific planning regulations for Vietnam have been identified, hence a 100m buffer zone threshold has been applied based on (Stenz, Malaney, Gillman, & Crill, 2010).

The land use exclusion criterion removes the areas where siting of wind power projects would not be possible, e.g., in cities and residential areas, on commercial or industrial land, in lakes and rivers, in forests and on roads and railroads (NREL, 2012), (IRENA, 2016). In addition, buffer zone thresholds have been added to each of the exclusion criteria based on (Stenz, Malaney, Gillman, & Crill, 2010).

Finally, the more detailed land use data for the more detailed provincial analysis has been analyzed and corresponding land use exclusion criteria have been set forth as for the National Technical Potential analysis, with the buffer zone exclusion criteria adapted from (Stenz, Malaney, Gillman, & Crill, 2010) and (Yang, 2013).

The terrain roughness exclusion criterion has been evaluated within the current analysis, but found not to be relevant. Hence it is not included in the analysis.

The exclusion criteria have been applied step-wise so as to allow for the assessment for the individual impact of each of the criteria.

2.3 Other assumptions

The GIS analysis defines the available land area for wind and solar. In order to convert the land area into an estimate for wind power generation capacity, footprint assumptions are being used. Wind and solar generation have different land-use footprints, and in reality, these vary depending on the specifics of the individual project. Table 5 presents the footprint assumption of wind and solar PV energy projects used in the current study, respectively[3].

Total area is the "available area", i.e. corresponding to the technically feasible area found in the GIS analysis. The direct area is the area covered by the installations (wind turbine, solar collectors, transformers). The difference between total area and direct area is the area that still can be used for other purposes, e.g. agriculture.

Table 5. Typical key values for footprints for wind and solar projects ('greenfield' site). In the last column, standard values of 3000 and 1500 full-load hours are assumed for wind and solar.

	Typical capacity per km^2 (total area)	Direct area use compared to total area	Typical generation (total area)	Typical generation (direct area)
Wind power	3 MW/km^2	10%	9 GWh/km^2	90 GWh/km^2
Solar power	33 MW/km^2	75%	50 GWh/km^2	67 GWh/km^2

2.4 Economic analysis

Levelised Cost of Electricity (LCOE) approach will be employed in the current study. The LCOE is the total cost of installing and operating a project expressed in dollars per kilowatt-hour of electricity generated by the system over its life. Adaptation of the LCOE calculator developed by (Agora Energiewende, 2014) has been employed in this study[4].

The inputs used in the LCOE calculation are as follows:

1. Capital expenditure (CapEx)
    a. Wind power plant CapEx (excluding infrastructure)

[3] Based on Renewable Energy World (2013) for solar and (NREL, 2009) for wind. The NREL report features a detailed discussion on challenges related to defining the footprint areas.
[4] https://www.agora-energiewende.de/en/topics/-agothem-/Produkt/produkt/106/Calculator+of+Levelized+Cost+of+Electricity+for+Power+Generation+Technologies/

    b. Additional infrastructure costs
        i. Individual infrastructure element (road and transmission grid) costs
        ii. Distance estimates from the cluster evaluated to the closest grid and road point
2. Operation and maintenance (O&M) costs
3. Weighted average cost of capital (WACC)
4. Plant lifetime
5. Annual energy production (AEP) estimates

3 GIS analysis data sources

This section details the data sources used in the GIS land-based wind resource mapping analysis. Distinction is made between the national and detailed provincial-level (Binh Thuan, Ninh Thuan, Khanh Hoa, Phu Yen, Binh Dinh and Quang Ngai) analyses. In general, most spatial data used in the analysis were downloaded from publicly available sources. Thereby most commonly used datasets have been selected and the ones most up-to-date. The data sources used both in the national and the provincial-level analysis is described first, followed by data sources used only in national, or provincial-level analysis.

3.1 Data sources used in national and detailed provincial analysis

- **Global Wind Atlas wind map by DTU.** Initial data exist in form of a GIS layer of average wind speed (m/s) and average wind power density[5] (W/m^2) for 1 x 1 km grid (Figure 8). The methodology underlying this data employs large scale wind climate data, atmospheric reanalysis data, from meteorological centres around the world, which is generalized. The set of generalized wind climates are then applied in microscale modelling system. The modelling process is made up of a calculation for the local wind climates every 250 m at three heights, 50, 100 and 200 m. Local wind climate characteristics are then aggregated up to a 1 km grid. The wind speeds at 100 m were used in this analysis.

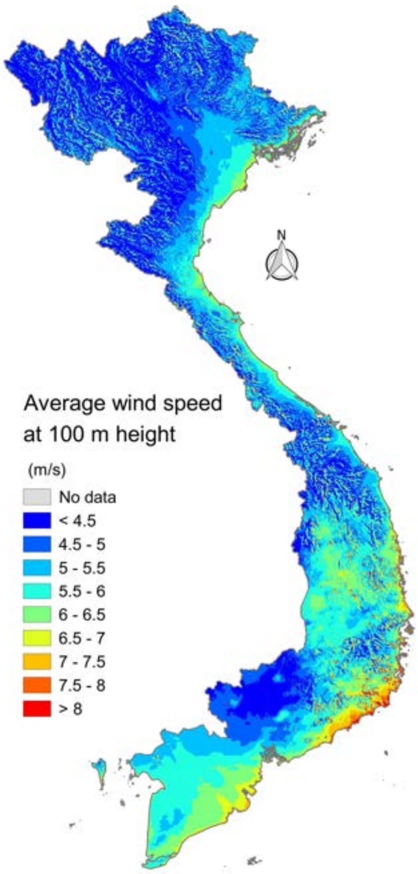

Figure 8. The Global Wind Atlas wind map by DTU for Viet Nam.

[5] Power density depends on the wind speed to the power of 3 and will better reflect the value of the wind resource.

- **Topology.** NASA Shuttle Radar Topographic Mission (SRTM) Digital Elevation Database v4.1. The SRTM has provided digital elevation data (DEMs) for over 80% of the globe. This data is currently distributed free of charge by USGS and is available for download from the National Map Seamless Data Distribution System, or the USGS ftp site. The 90 m spatial resolution data product was used in this analysis[6]. See Figure 9. From the DEM, terrain slope and elevation was derived.

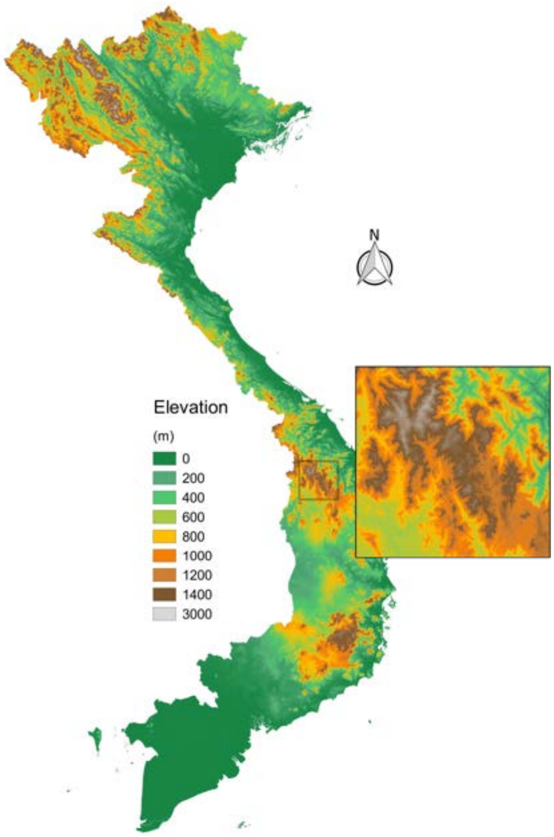

Figure 9. NASA SRTM topology data.

[6] See: www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1

- **Population density.** AsiaPop provides estimates of numbers of people residing in each 100x100m grid cell. Through integrating census, survey, satellite and GIS datasets in a flexible machine-learning framework, high resolution maps of population count and densities for 2000-2020 are produced, along with accompanying metadata[7].

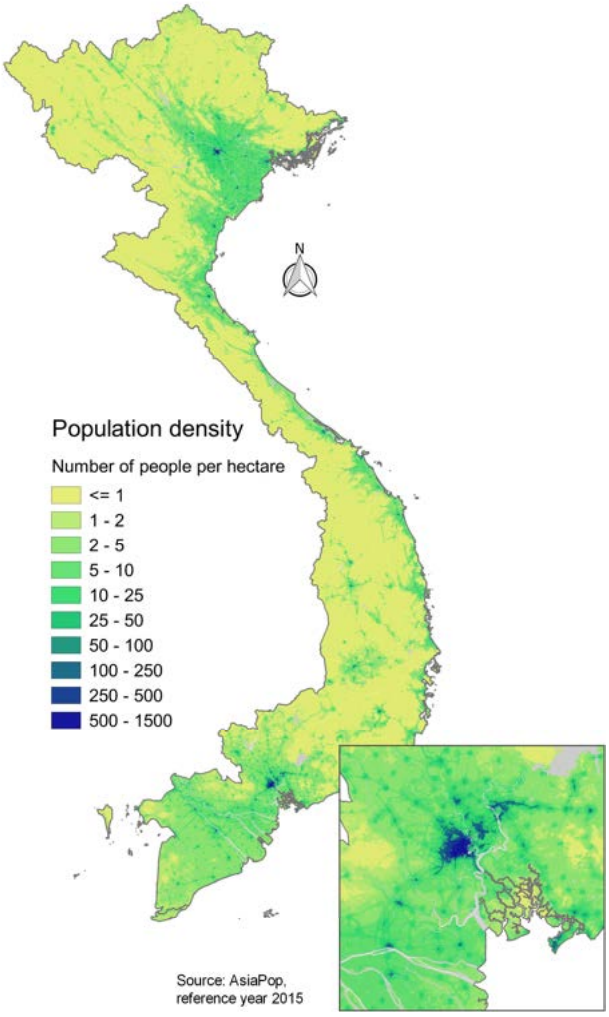

Figure 10. Population density from AsiaPop.

[7] See: www.worldpop.org.uk/data/summary/?contselect=Asia&countselect=Vietnam&typeselect=Population

- **Protected areas 2016.** The World Database on Protected Areas (WDPA) is the most comprehensive global database on terrestrial and marine protected areas[8]. WDPA is a joint project between the United Nations Environment Programme (UNEP) and the International Union for Conservation of Nature (IUCN). It is compiled and managed by the UNEP World Conservation Monitoring Centre (UNEP-WCMC), in collaboration with governments, non-governmental organisations, academia and industry. See Figure 11.

Figure 11. Protected areas for Viet Nam extracted from the World Database on Protected Areas (WDPA).

[8] See: protectedplanet.net/

- **Administrative data.** Global Administrative Areas (GADM) is a spatial database of the location of the world's administrative boundaries for use in GIS and similar software. Administrative areas in this database are countries and lower level subdivisions such as provinces etc. GADM version 2.8 was used. See Figure 12.

Figure 12. Provinces of Viet Nam extracted from the Global Administrative Areas (GADM) v2.8 database.

- **Grid (transmission lines).** Grid of 220 kV transmission lines has been developed and provided by the Institute of Energy. See Figure 13.

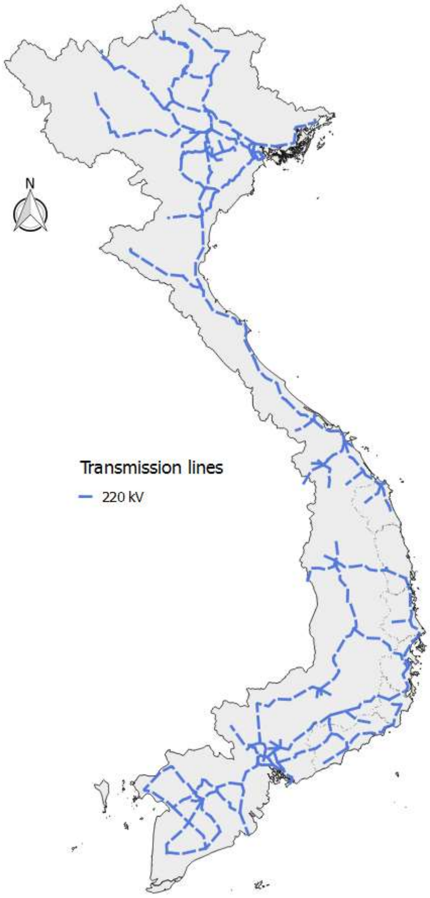

Figure 13. 220 kV transmission lines.

3.2 Data sources only used in the national analysis

- **Land Cover map and water mask for Vietnam.** The European Space Agency's Climate Change Initiative (ESA CCI) land cover map for 2015 was used in the analysis. The map comes at 300 m spatial resolution. The land cover map contains in total 36 classes. For the analysis, relevant CCI land cover classes have been aggregated as presented in Table 6. The water/no water mask produced under the same initiative has a 150x150 m spatial resolution[9].

[9] See: Source: http://maps.elie.ucl.ac.be/CCI/viewer/

Table 6. CCI Land Cover Classes used in the national analysis and aggregations

CCI Land Cover Class	Aggregation
Tree cover flooded fresh or brackish water Tree cover flooded saline water	Flooded trees
Tree cover broadleaved evergreen closed to open (>15%) Tree cover broadleaved deciduous closed (>40%) Tree cover needle leaved evergreen closed (>40%) Tree cover needle leaved deciduous closed (>40%)	Forest
Urban areas	Urban areas
Cropland rainfed Cropland rainfed - Herbaceous cover Cropland rainfed - Tree or shrub cover Cropland irrigated or post-flooding	Agricultural land

Figure 14 illustrates the ESA CCI land cover map and the water bodies mask.

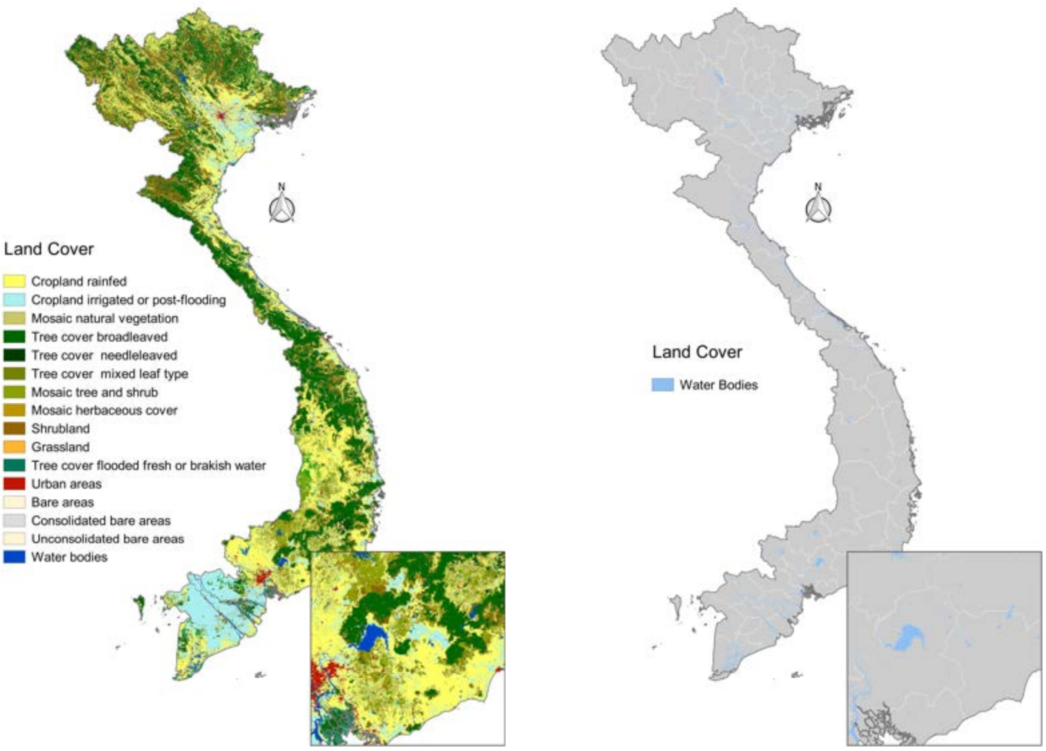

Figure 14. ESA CCI Land cover map (left) and water bodies mask (right).

- **Roads and railways.** The OpenStreetMap (OSM) project (www.openstreetmap.org) has collected an enormous amount of free spatial data and the database is growing every day[10]. For the national analysis primary roads, motorways and railways were used (Figure 15).

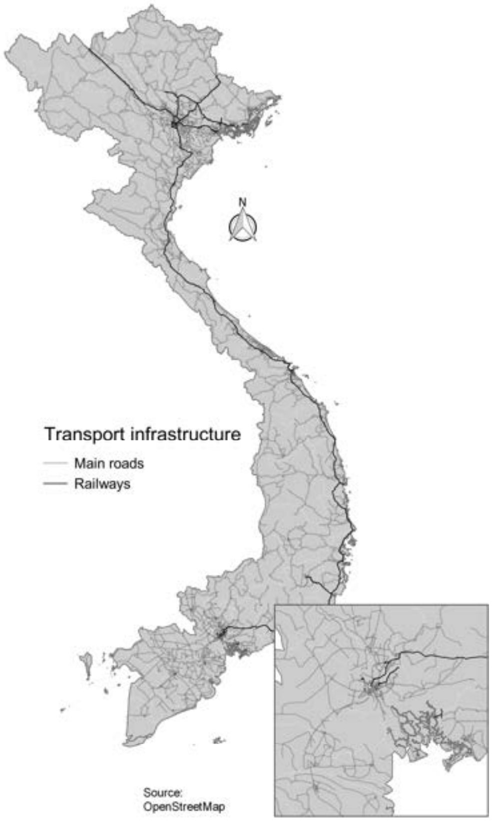

Figure 15. Main roads and railways for Viet Nam.

[10] See: www.openstreetmap.org

3.3 Data sources used in the detailed provincial analysis

- **Land Cover map of 6 provinces.** Detailed land cover maps based on the data of the Ministry of Natural Resources and Environment and updated using SPOT (provided by Spot Image[11]). The maps were provided as shapefiles and contain 9 land cover classes aggregated to suit wind energy potential analysis (Figure 16).

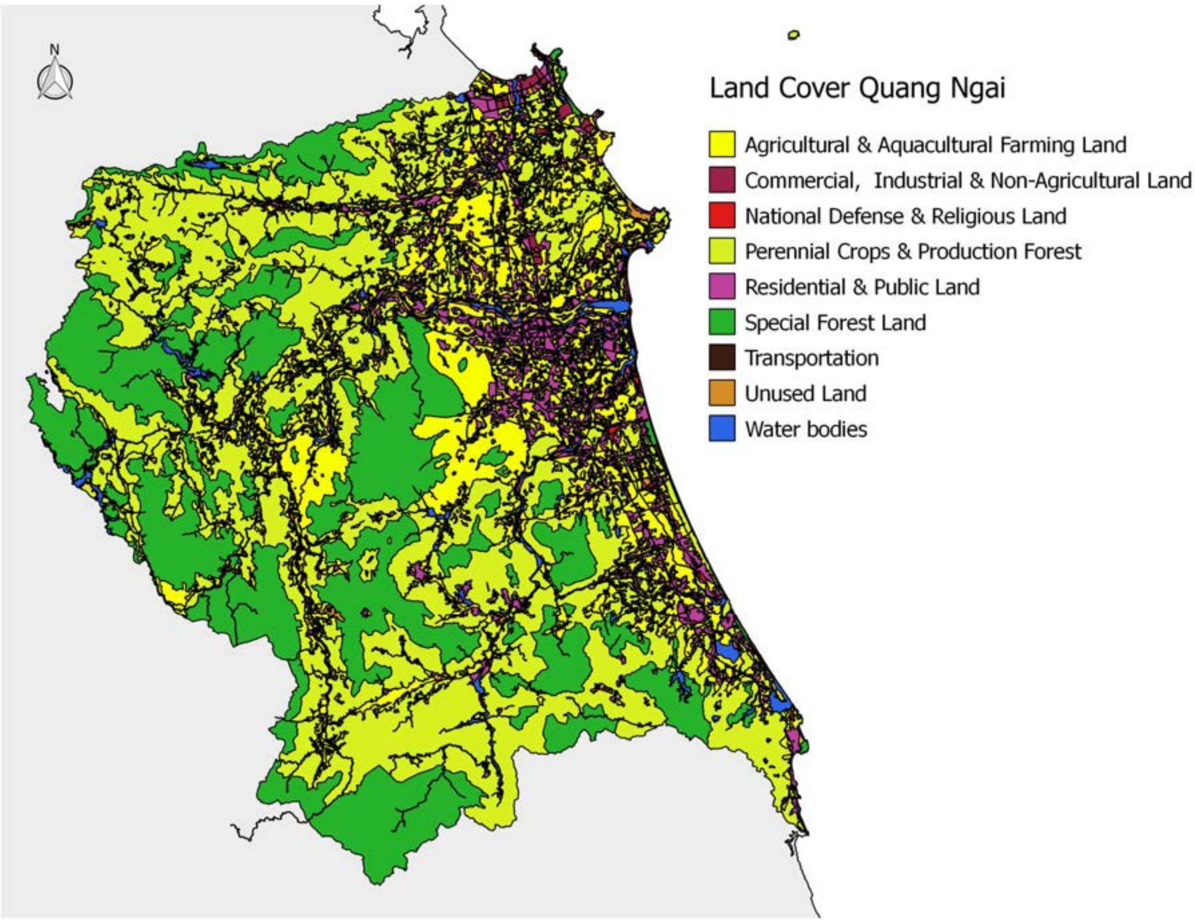

Figure 16. Land cover data used for specialised analysis of 6 provinces provided by local consultant. As an example, the land cover map of Quang Ngai is presented.

[11] http://www.intelligence-airbusds.com/en/143-spot-satellite-imagery

- **Grid (transmission lines).** Grid of 110 KV transmission lines has been developed and provided by the Institute of Energy, based on data and information collected and provided by the respective provincial high voltage (110KV) companies (Figure 17).

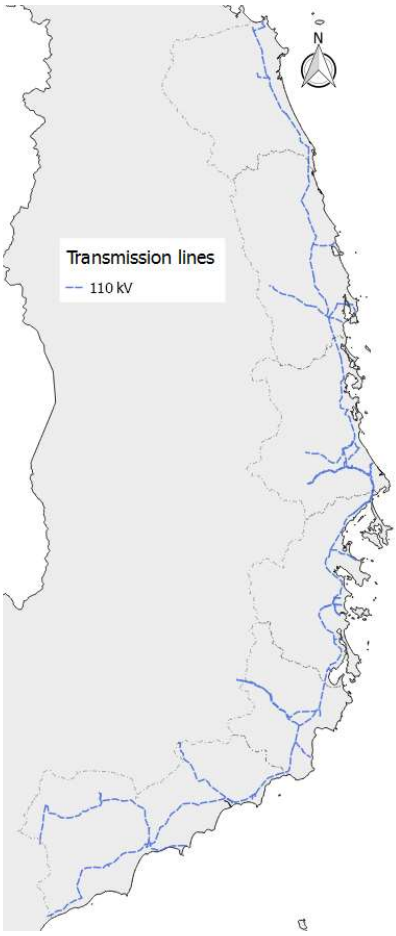

Figure 17. 110 KV transmission lines for six provinces in Viet Nam.

4 LCOE analysis data sources and inputs

This section describes and presents the data sources, assumptions and inputs used in the LCOE analysis.

4.1 Wind power project costs and characteristics

Table 7 provides an overview of the key land-based wind power project cost and characteristic parameters used in the LCOE analysis. Two LCOE cases are developed: LCOE Base Case and LCOE Low. LCOE Base Case is based on assumptions deemed to be representative of the situation in Vietnam currently. LCOE Low, in turn, can be interpreted as the assumptions projected to be representative of the near- to mid-term future as the wind power industry in Vietnam would mature, economies of scale would develop, and the cost levels would increasingly converge with the international averages.

Table 7: Overview of key wind power project cost and characteristic parameters used in the cluster LCOE analysis

	LCOE Base Case	**LCOE Low**
Plant CapEx (excl. infrastructure) *(USD/kW)*	1870	1500
O&M costs *(USD/kW/year)*	50	45
Project lifetime *(Years)*	20	22
WACC *(%)*	10.8%	7%

Plant CapEx estimate for LCOE Base Case has been based on the average across feasibility studies for 23 projects in Vietnam – adjusted for cost reduction reported on the purchase price for wind turbine (data provided by GIZ). The LCOE Low case CapEx value represents an estimate of the average global investment cost in the medium term based on IEA World Energy Outlook investment cost projections for onshore wind in 2030 (IEA, 2016). Average of the investment costs for Europe, US, China and India has been used.

O&M costs corresponding to 45 EUR/kW/year (ca 50 USD/kW/year at exchange rate of June 2017) have been selected to represent the LCOE Base Case (IEA Wind Task 26, 2016). Projected cost reductions in the O&M costs in the medium term have been represented in the LCOE Low case, in line with (IEA Wind Task 26, 2016).

Standard 20 years project lifetime assumption has been made for LCOE Base Case, whereas the projected project lifetime improvements in the medium term have been represented in the LCOE Low case, reaching 22 years (IEA Wind Task 26, 2016).

A high Weighted Average Cost of Capital (WACC) value of 10.8% has been selected for the LCOE Base Case to represent the present high financing costs for wind power projects in Vietnam. The estimate has been based on data provided by GIZ, presented in Table 8.

Table 8: Assumptions used in the estimation of WACC for the LCOE Base Case. Data source: GIZ.

WACC component	**Value**
Return on Debt (%)	10%
Return on Equity (%)	15%
Debt-Equity ratio	75 / 25
Effective corporate tax rate (accounting for tax exemptions applicable)	5%

For the LCOE Low case, WACC of 7% has been selected to represent the global trends of decreasing cost of financing of renewable power projects. As the wind industry develops in Vietnam, it is also to be expected that the WACC rates would decrease and increasingly converge with the levels observed internationally (e.g. roughly in line with the baseline values for global average cost of financing reported in (IEA Wind Task 26, 2016)).

4.2 Infrastructure costs

Infrastructure cost will be applied in the LCOE analysis in combination with the infrastructure proximity (closest point from the cluster centroid to the transmission grid and to main roads, respectively) information per cluster obtained in the GIS analysis. Table 9 presents the infrastructure element cost assumptions used in the analysis, based on data from Ministry of Construction of Vietnam Decision No. 1161/QĐ-BXD, dated 15/10/2015.

Table 9: Infrastructure cost components used in the analysis. Data provided by GIZ

ID	Infrastructure element	Price range: Average	Price range: Low	Price range: High	Unit
110kVsc	110 kV line, single circuit	50,000	45,000	55,000	*USD/km*
110kVdc	110 kV line, double circuit	87,500	75,000	100,000	*USD/km*
220kVdc	220 kV line, double circuit	385,000	360,000	410,000	*USD/km*
ss110kV	Substation 110 kV	2,100,000	1,700,000	2,500,000	*USD*
ss220kV	Substation 220 kV	8,000,000	7,000,000	9,000,000	*USD*
RGpt	Road, gravel, plain terrain	185,000	170,000	200,000	*USD/km*
RGmt	Road, gravel, mountains	220,000	210,000	230,000	*USD/km*
RPpt	Road, paved, plain terrain	370,000	350,000	390,000	*USD/km*
RPmt	Road, paved, mountains	445,000	430,000	460,000	*USD/km*

Table 10 provides an overview of the approach used in allocating the different infrastructure elements and their associated costs to the wind power clusters depending on the size of the cluster (expressed in capacity in MW).

Table 10: Infrastructure element and cost range assumptions used based on project size ranges

Size range (MW) From	To	Connection type	Substation	Road type	Price range
0	10	110kVsc	ss110kV	RGpt	Low
11	50	110kVsc	ss110kV	RGpt	Low
51	100	110kVsc	ss110kV	RPpt	Average
101	150	110kVdc	ss110kV	RPpt	High
151	300	220kVdc	ss220kV	RPpt	Low (Road High)
301	450	220kVdc	ss220kV	RPpt	Average (Road High)
451	600	220kVdc	ss220kV	RPpt	High

Based on the data and cost assignment approach illustrated above, a parameter variation has been carried out to assess the infrastructure cost impact on the project costs (as an on-cost to the plant CapEx), depending on the project size and infrastructure proximity. Table 11 provides examples of the parameter variation analysis (please see a more comprehensive overview in Appendix II - Infrastructure cost variation depending on project size and infrastructure proximity).

Table 11: Infrastructure cost variation (as an on-cost to plant CapEx) depending on project size and infrastructure proximity

Project size (MW)	Distance to road (km)	Distance to grid (km)	Road on-cost (on plant CapEx)	Grid on-cost (on plant CapEx)	Combined infrastructure on-cost (on plant CapEx)
10	10	10	9%	11%	21%
30	10	10	3%	4%	7%
100	10	10	2%	1%	3%
300	10	10	1%	2%	3%
400	10	10	1%	2%	2%
600	10	10	0%	1%	2%
10	20	20	18%	14%	32%
30	20	20	6%	5%	11%
100	20	20	4%	2%	6%
300	20	20	1%	3%	4%
400	20	20	1%	2%	3%
600	20	20	1%	2%	2%

The parameter variation analysis appears to suggest that for projects (clusters) exceeding ca 100 MW located within 0-20km infrastructure proximity, the additional on-cost arising from the infrastructure development are minor. E.g. for a 100 MW project (cluster) situated in 20km distance both from the nearest transmission grid interconnection point, and the closest main road, the total on-cost on the basis of plant CapEx would not exceed 6%.

4.2.1 Allocation of infrastructure costs in the LCOE calculation

Important assumption in relation to the allocation of the infrastructure costs is made in the LCOE calculation. For each of the 'clusters' evaluated, coordinated planning of the infrastructure (transmission grid expansion and road construction) is assumed for each cluster within the boundaries of a province. I.e. the costs associated with the additional transmission infrastructure development and road construction (a cluster-specific lump sum) are distributed equally across the power production estimated within the cluster. In other words, each 'cluster' is regarded as a single project (or a coordinated set of projects). This can be regarded as the least-cost perspective towards infrastructure development and the respective costs.

For clusters exceeding 600 MW capacity in size, however, the infrastructure costs for a 600 MW-equivalent project within the respective cluster are multiplied in line with the total cluster size. E.g. a cluster of 1200 MW size would be applied double infrastructure costs estimated for a 600 MW-large project within the respective cluster.

4.3 Annual Energy Production estimation

In order to arrive at the annual energy production (AEP) estimate to be used in the LCOE analysis, hourly wind speed time series per province (63 locations nationally) have been used. Hourly wind speed time series have been kindly provided by DTU Vindenergi (work-in-progress output from the wind resource mapping component of the activity Resource Mapping and Geospatial Planning Vietnam under contract to The World Bank). Hourly wind speed time series of a 'normal' wind year (i.e. the year with the median annual average wind speed out of a sample of 9 modelled years) have been selected. Figure 18 provides an overview of the locations for which hourly wind speed time series data is available (indicated with red triangles).

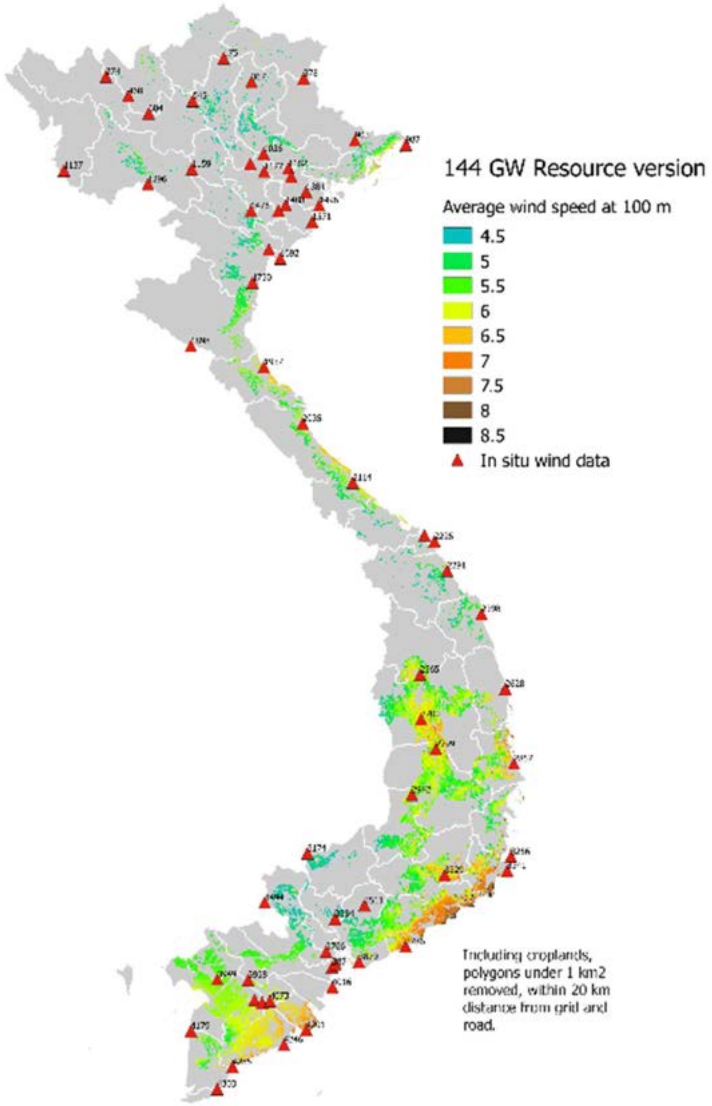

Figure 18: Modelled hourly wind speed time series locations nationally (indicated with red triangles). The underlying resource map is consistent with the 'NTP 20km infrastructure proximity' scenario (used for illustration).

Figure 19 provides an illustrative example of the hourly wind speed time series per province used in the analysis.

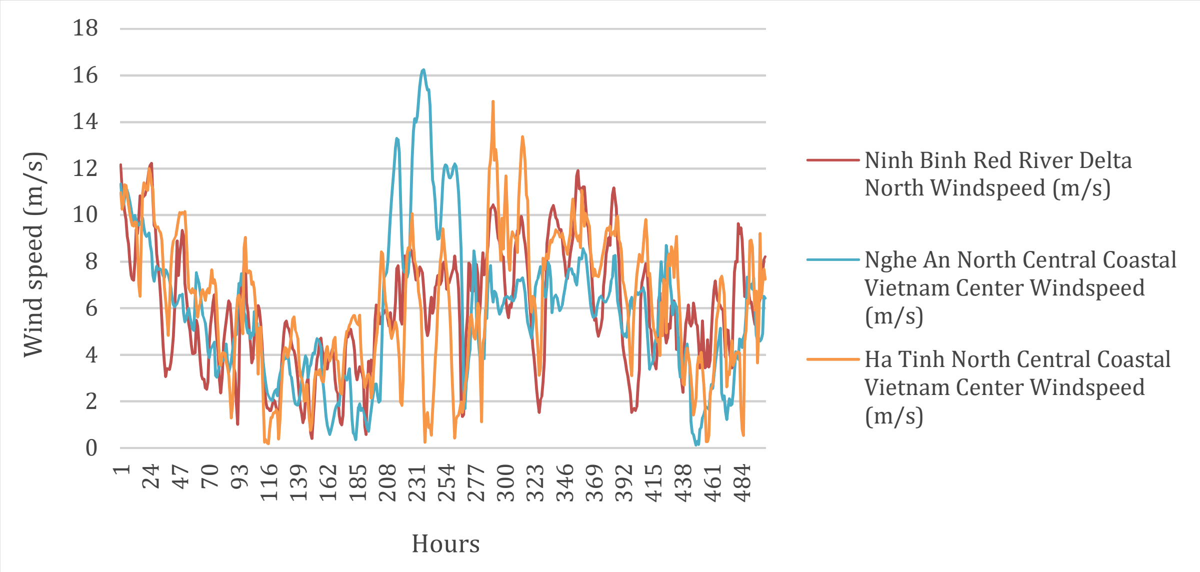

Figure 19: Example of hourly wind speed time series (Ninh Binh, Nghe An and Ha Tinh provinces) over a 3-week period

The hourly wind speed time series data is then combined with a power curve representing a low specific power turbine technology (200 W/m2) to arrive at an annual power production estimate. Since the AEP would be used for the LCOE calculation of clusters of wind resource, not individual turbines, a smoothing assumption has been applied. Smoothening approach is based on (Dalla Riva, 2016). The power curve used for FLH estimation (smoothened) is presented in Figure 20 (along with the power curve before smoothening has been applied).

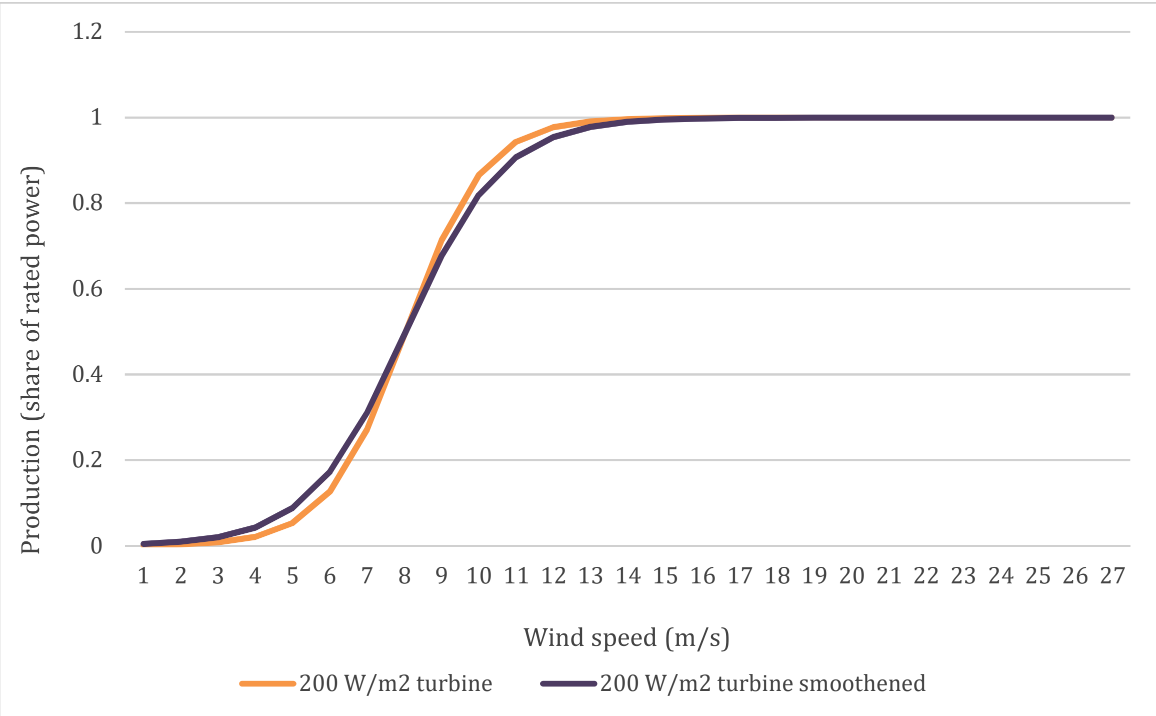

Figure 20: Power curve used in the wind power energy production calculation (before and after smoothening). Calibrated to correspond to the expected production of a 200 W/m2 turbine under normal conditions.

Since hourly wind speed time series data has been available for a limited number of locations (63 locations nationally), linear function between average annual wind speed and the full-load hours of production has been derived, as presented in Figure 21, based on the production calculated for the 63 locations. The linear function provides very good fit to the underlying data ($R^2 = 0.97$).

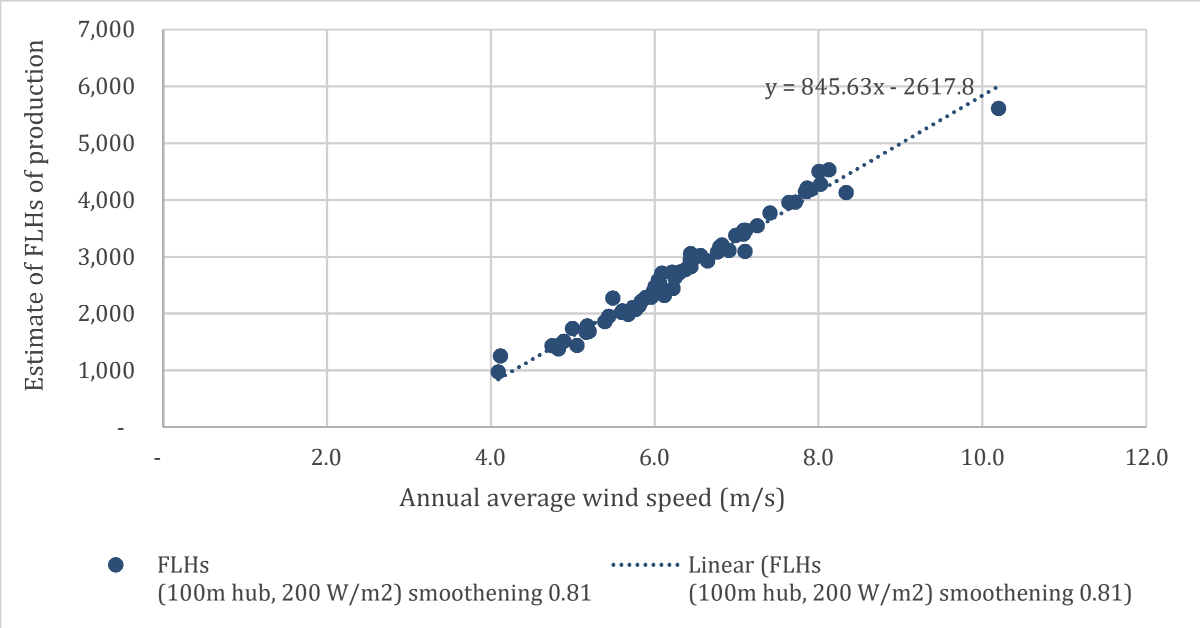

Figure 21: Calculated FLHs of each of the 63 wind speed time series locations (based on the power curve) and the linear best fit function (R^2 of 0.9744)

Based on the linear function derived, average FLHs estimates per annual average wind speed ranges used in the analysis have been calculated, presented in Table 12. The FLHs correspond to the expected production of a cluster of 200 W/m2 wind turbines with 100 metre hub height.

Table 12: Average FLHs estimates per annual average wind speed ranges used in the analysis, representative of a cluster of 200 W/m2 wind turbines with hub height of 100 metres

Annual average wind speed (m/s)	Average estimated FLHs	Average estimated CFs (%)
4.5-5 m/s	1,399	16%
5-5.5 m/s	1,822	21%
5.5-6 m/s	2,245	26%
6-6.5 m/s	2,667	30%
6.5-7 m/s	3,090	35%
7-7.5 m/s	3,513	40%
7.5-8 m/s	3,936	45%
8+ m/s	4,359	50%

5 Limitations

The results of the present study are meant for top-level power system development planning purposes on a regional level, and are not to be used for individual RE project site selection. The analysis results are subject to the accuracy of input data sources available.

5.1 Wind energy resources

Wind energy resource potential data used in the present study is based on meteorological modelling, and not on-site measurements. The limitations stated for the DTU Global Wind Atlas wind resource maps (used as input in the current study) include the following[12]:

- No mesoscale modelling in Global Wind Atlas
  - Mesoscale modelling captures variance both in space and time, missing from the reanalyses
  - Mesoscale modelling will increase accuracy of the atlas, by capturing features such as gap flow, barrier jets, low level jets, and sea breezes better
  - Mesoscale modelling set-up can be tailored to the country meteorological and geographical settings
- No verification of numerical wind atlas outputs

[12] Full limitations description: http://globalwindatlas.com/index.html

Comparison of modelled wind speeds and on-site measurements

Figure 22 illustrates the difference between the modelled wind time series and in-situ measurements. Modelled wind speeds for 2003 to 2011 are provided by DTU Vindenergi (work-in-progress output from the wind resource mapping component of the activity Resource Mapping and Geospatial Planning Vietnam under contract to The World Bank) for 63 regions. The coordinates for the wind speed profile are chosen as the 90th percentile best location within each region.

Measured wind speeds for 9 locations are based on data by GIZ for one year, June 2012 - May 2013. The average annual wind speeds of the 9 locations are compared to the modelled wind speeds from the nearest corresponding locations in the DTU data.

The measured wind speeds appear to be consistently lower than the modelled values. The wind speeds are not directly comparable however as they describe slightly different locations and different years. In the comparison, the discrepancy in measurement height (GIZ: 80m, DTU: 100m) is adjusted for according to the wind power law using an exponent of 0.12-0.15.

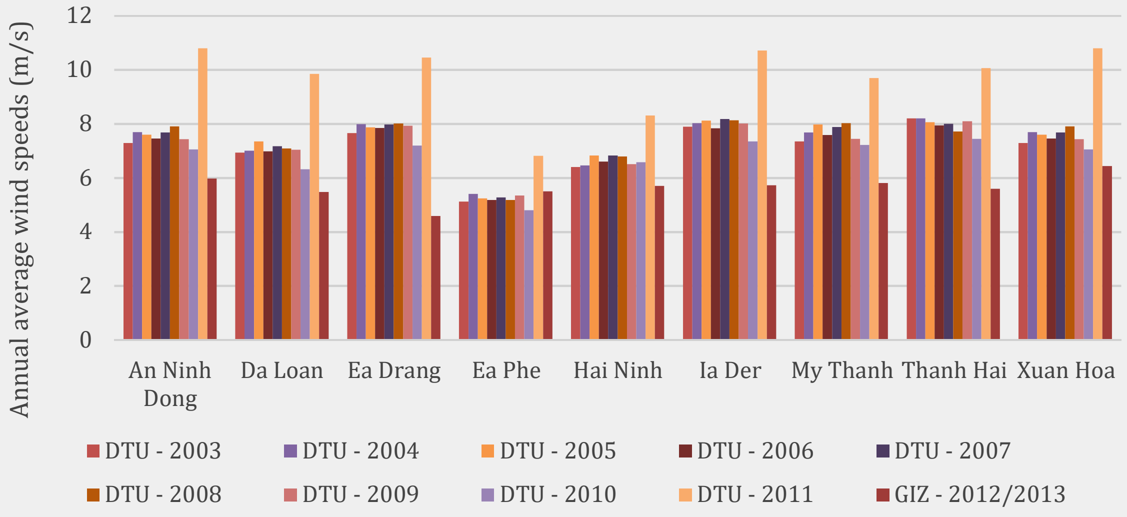

Figure 22: Average annual wind speeds of 9 measurement masts by GIZ (for 2012/2013) compared to modelled DTU wind speeds from nearby locations (for 2003-2011).

For the national analysis, proximity to transmission lines has only been based on the 220kV grid because 110kV data was not available for the entire country and the cluster will connect to the transmission lines. In addition, only the existing transmission grid and road network infrastructure has been considered and represented.

For the provincial analysis land use maps were provided by the local consultant and were used as such. No information was provided regarding classification quality and mapping accuracy.

All areas listed under the World Database on Protected Areas (WDPA) for Viet Nam were excluded as potential suitable land not considering the wide range of protected areas, including national protected areas recognised by the government, areas designated under regional and international conventions, privately protected areas and indigenous peoples' and community conserved territories and areas.

Only primary roads were extracted from OpenStreetMap (OSM) and used in the national analysis, because transportation of wind turbines requires large enough infrastructure. Moreover, the positional accuracy of major roads is likely to be higher than of smaller transport infrastructure features. OSM is a community mapping effort with varying data quality.

The LCOE analysis is only indicative of overall project costs, and does not reflect the specific conditions of the individual cluster beyond the inputs used in the calculation. Similarly, LCOE Low case illustrates one potential technology and cost development projection, and is subject to high degree of uncertainty. E.g. further wind turbine technology cost reductions beyond the current projections would lower the LCOE. Conversely, failure of the wind industry to develop in line with the projections might limit the extent of capital cost and financing reductions, thereby increasing the LCOE Low case.

6 Results

This section describes and presents the GIS analysis results for land-based wind resource mapping, as well as provides an LCOE perspective on selected wind resource clusters. In addition, more detailed results are presented for selected six provinces: Binh Thuan, Ninh Thuan, Khanh Hoa, Phu Yen, Binh Dinh and Quang Ngai. Furthermore, an overview of regional solar PV and biomass (for use in power production) resource potentials in Vietnam is provided for context.

6.1 National wind resource mapping

This section describes and presents the GIS analysis results for national land-based wind resource mapping.

6.1.1 National exclusion criteria

The impact of each exclusion criterion is illustrated with corresponding maps below. Table 13 shows the land area (km^2) impact of each exclusion criterion.

As a first step in the analysis, all areas with wind speeds lower than 4.5 m/s at 100 m height were removed and then all the protected areas including a 1km buffer (Figure 23). The protected area criterion removed more than 43,000 km^2 of potential land (Table 13).

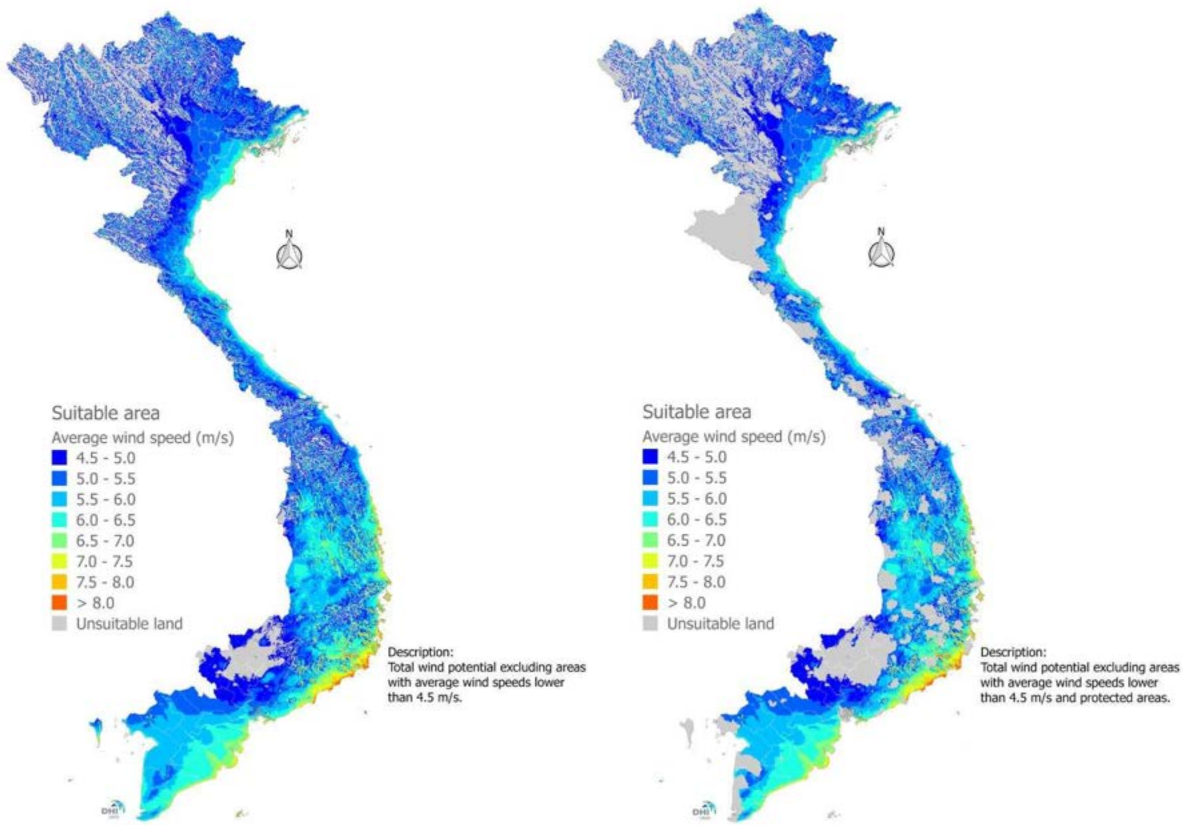

Figure 23. Suitable areas after removing locations with wind speeds lower than 4.5 m/s (left) and after removing protected areas (right).

Subsequently, all areas located higher than 2000m above sea level were removed followed by densely populated regions (population > 500 persons/km^2) incl. a 500m buffer to these areas (Figure 24). While only small areas in the north were removed by applying the altitude criterion (767km^2), the population density criterion removed relatively large areas in the main metropolitan areas - Hanoi and Ho Chi Minh City – as well as some patches along the coast, in total 55,320 km^2.

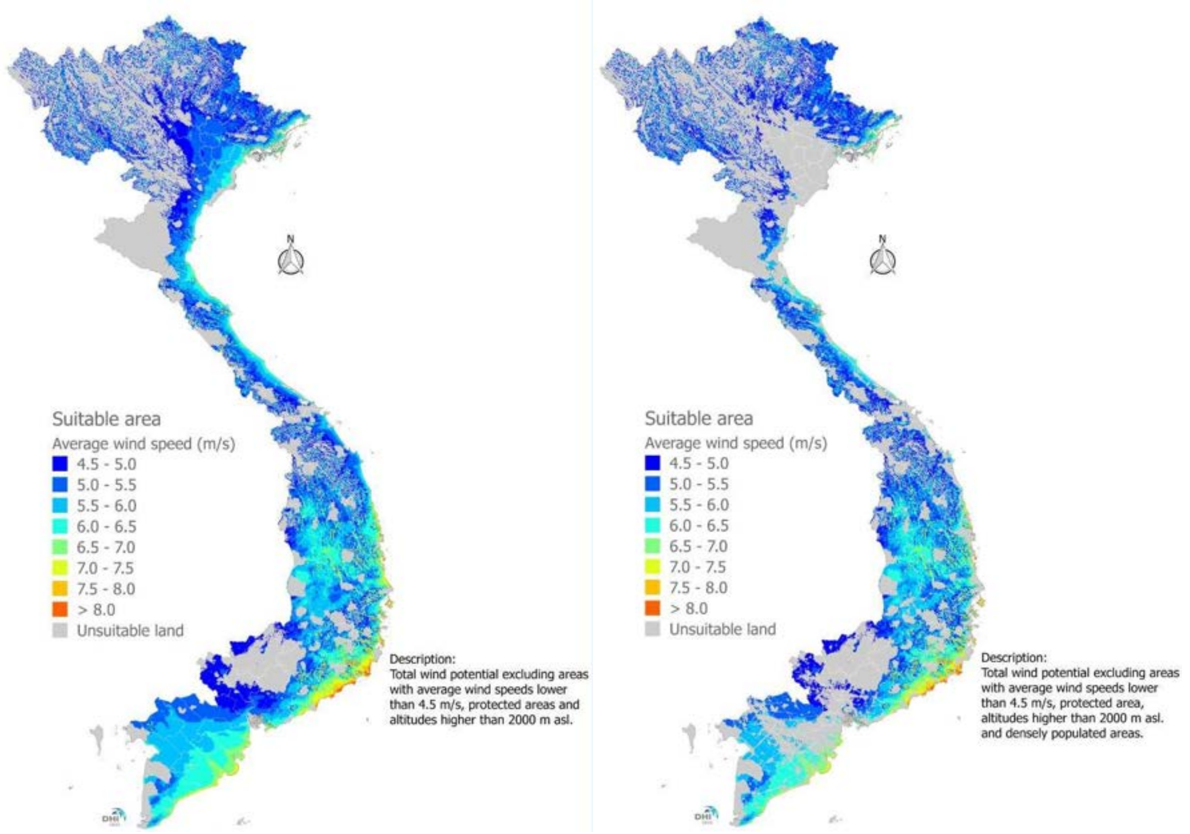

Figure 24. Suitable areas after removing areas located higher than 2000m asl (left) and densely populated areas including a 500m buffer (right).

Thereafter, all the water bodies (incl. 100m buffer) and urban areas (incl. 1km buffer) were removed. Clearly, urban areas are closely linked to densely populated areas (removed in the previous step), hence the impact of urban area removal is minor, as can be seen in Figure 25 and Table 13.

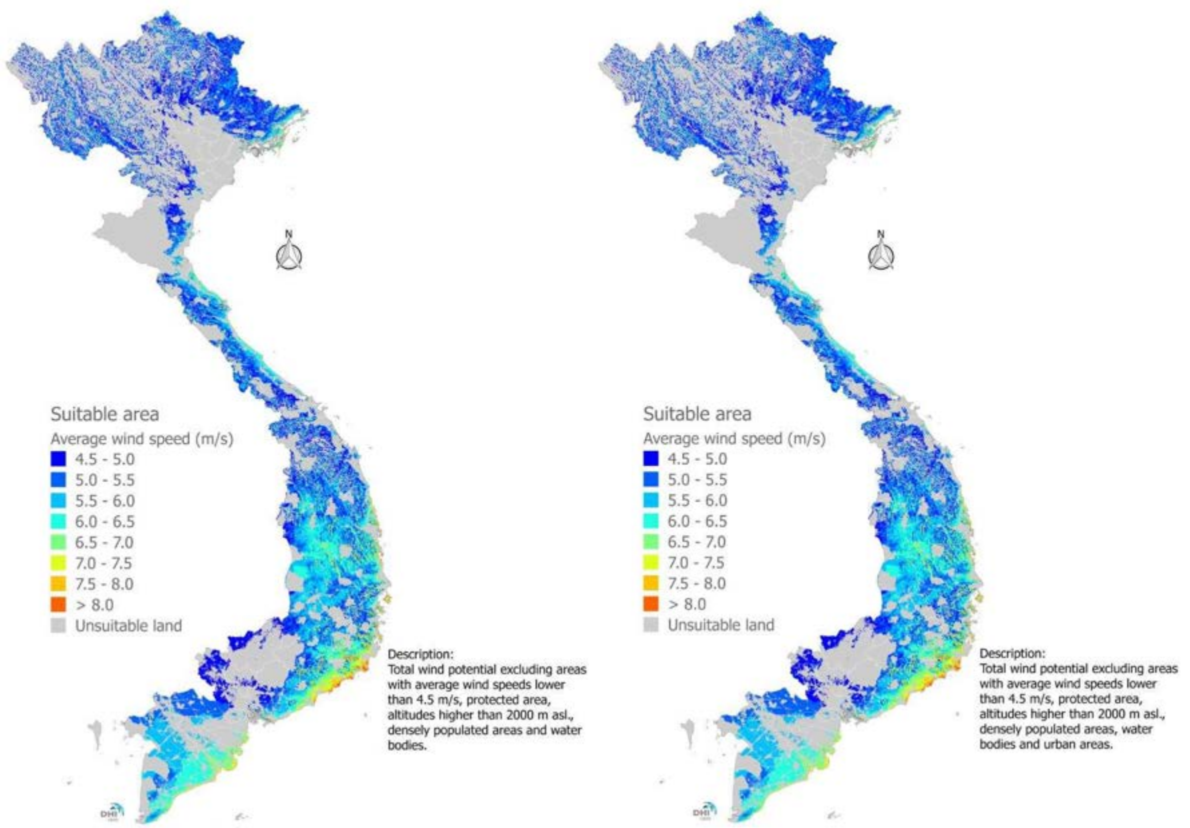

Figure 25. Suitable areas after removing water bodies including a 100m buffer (left) and urban areas including a 1km buffer (right).

Then the land cover classes flooded trees (usually mangroves) and forests were removed from the suitable area, both with an additional 100m buffer around all the forested polygons (Figure 26). Especially in central Viet Nam the removal of forest areas had a significant impact. While the land cover class flooded trees excluded 904km^2, the forest areas removed 48,604km^2 of potentially suitable land.

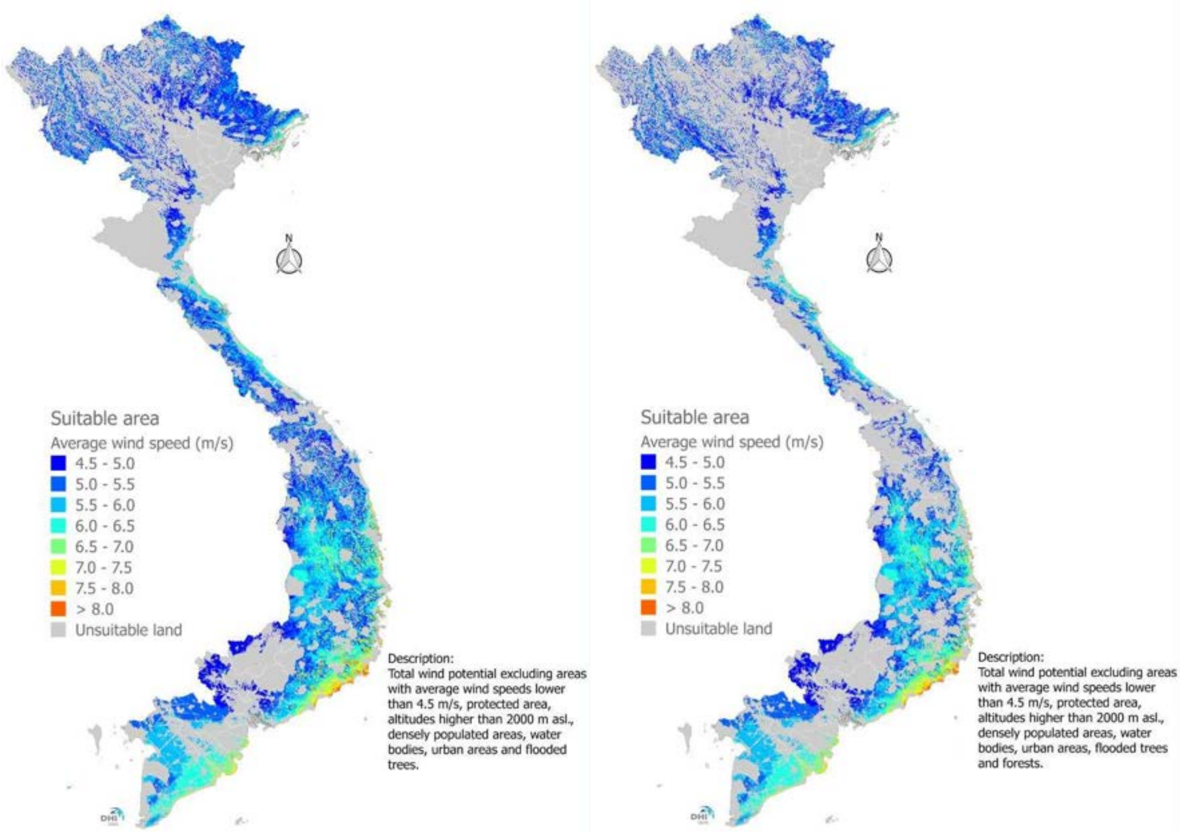

Figure 26. Suitable areas after removing flooded trees (left) and forests (right), both with a 100m buffer to the excluded area.

Then all areas with slopes > 30% and roads and railroads including 250m buffers were removed (Figure 27).

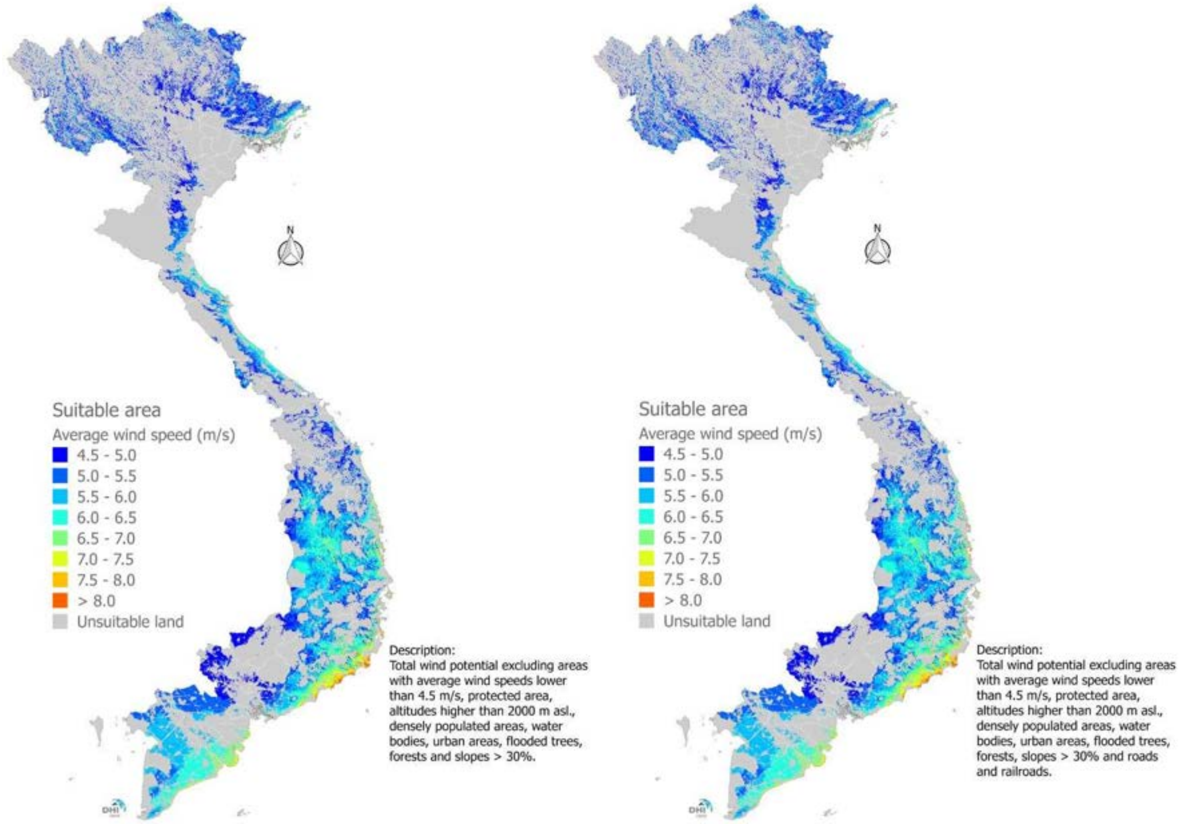

Figure 27. Suitable areas after removing slopes > 30% (left) and roads and railroads including a 250 m buffer (right).

Finally, all areas within 100m distance to the coast were removed and the data layer was cleaned for areas smaller than 1km^2 to obtain the national technical potential Figure 28. (The NTP without croplands is shown in Figure 29.)

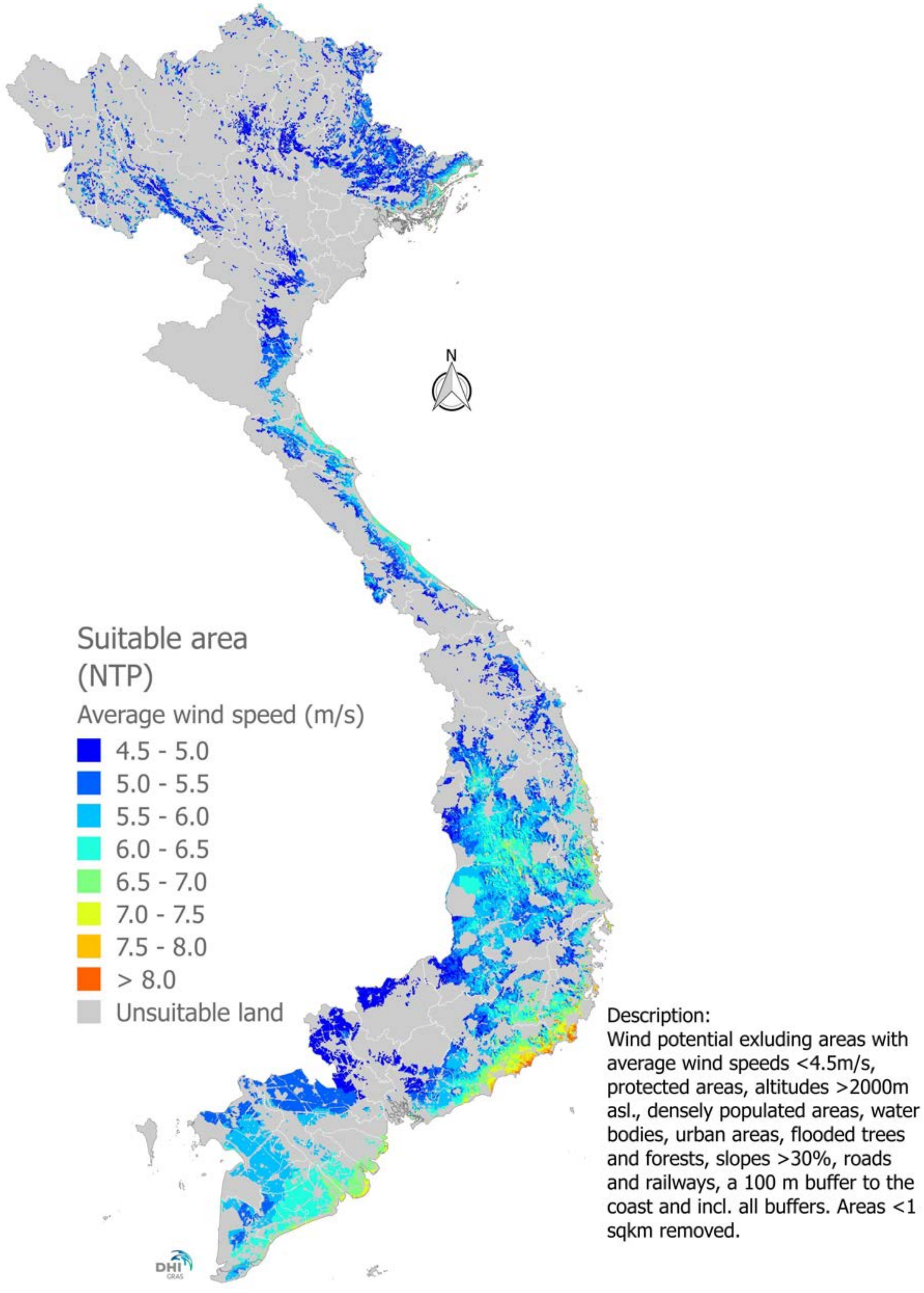

Figure 28. National Technical Potential (NTP) for Viet Nam.

Table 13 provides an overview of individual and cumulative impact of each exclusion criterion.

Table 13. Suitable land area and impact of each exclusion criterion

	Criterion	Suitable Area (km^2)	Difference (km^2)
	Total Area Viet Nam (incl. Islands)*	328,537	
	Wind potential (>6 m/s)	54,681	270,713
	Wind potential (>4.5 m/s)	251,898	76,639
minus	Protected areas and 1 km buffer	208,529	43,369
minus	Altitude > 2000	207,762	767
minus	Population Density and 500m buffer	152,442	55,320
minus	Water and 100m buffer	147,198	5,244
minus	Urban areas and buffer 1km	145,944	1,254
minus	Flooded trees (single pixels eliminated)	145,040	904
minus	Forest > 15% coverage and if available > 40% coverage and buffer 100m	96,436	48,604
minus	Slope > 30% (single pixels eliminated)	79,750	16,686
minus	Roads 250 m buffer	77,545	2,205
minus	Railroad 250 m buffer	77,382	163
minus	Coastline 100 m buffer	77,281	101
minus	Areas under 1km^2	71,562†	5,719
minus	Agricultural land (croplands)	36,941	40,340
minus	Areas under 1km^2	29,601‡	7,340

**based on Global Administrative Areas (GADM) data; †represents National Technical Potential (NTP); ‡represents NTP No croplands.*

6.1.2 National wind resource potential scenarios

This section describes and presents the national land-based wind resource potential depending on different parameters regarding infrastructure proximity (roads and transmission grid) and availability of agricultural land. Table 14 provides an overview of the scenarios analysed.

Table 14: National land-based wind power potential scenarios analysed

Scenario	Proximity to closest road	Proximity to closest transmission grid point	Availability of agricultural land
National Technical Potential (NTP)	Unrestricted	Unrestricted	Available
NTP 20km	20 km	20 km	Available
NTP 10km	10 km	10 km	Available
NTP No croplands	Unrestricted	Unrestricted	Not available
NTP No croplands 20km	20 km	20 km	Not available
NTP No croplands 10km	10 km	10 km	Not available

The maps below show the suitable areas for the different national land-based wind technical potential scenarios (Figure 29 to Figure 31).

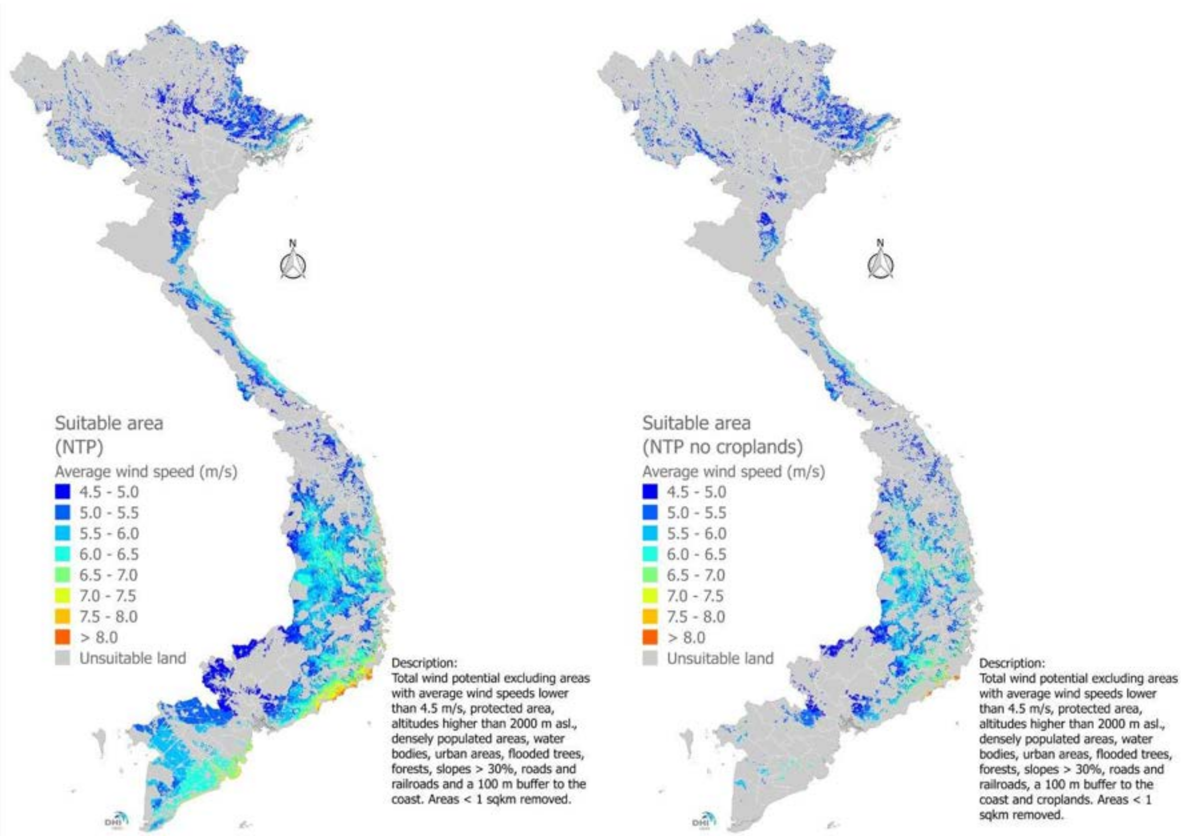

Figure 29. Map of suitable areas illustrating the NTP 215 GW scenario (left) and the NTP No croplands 89 GW scenario (right).

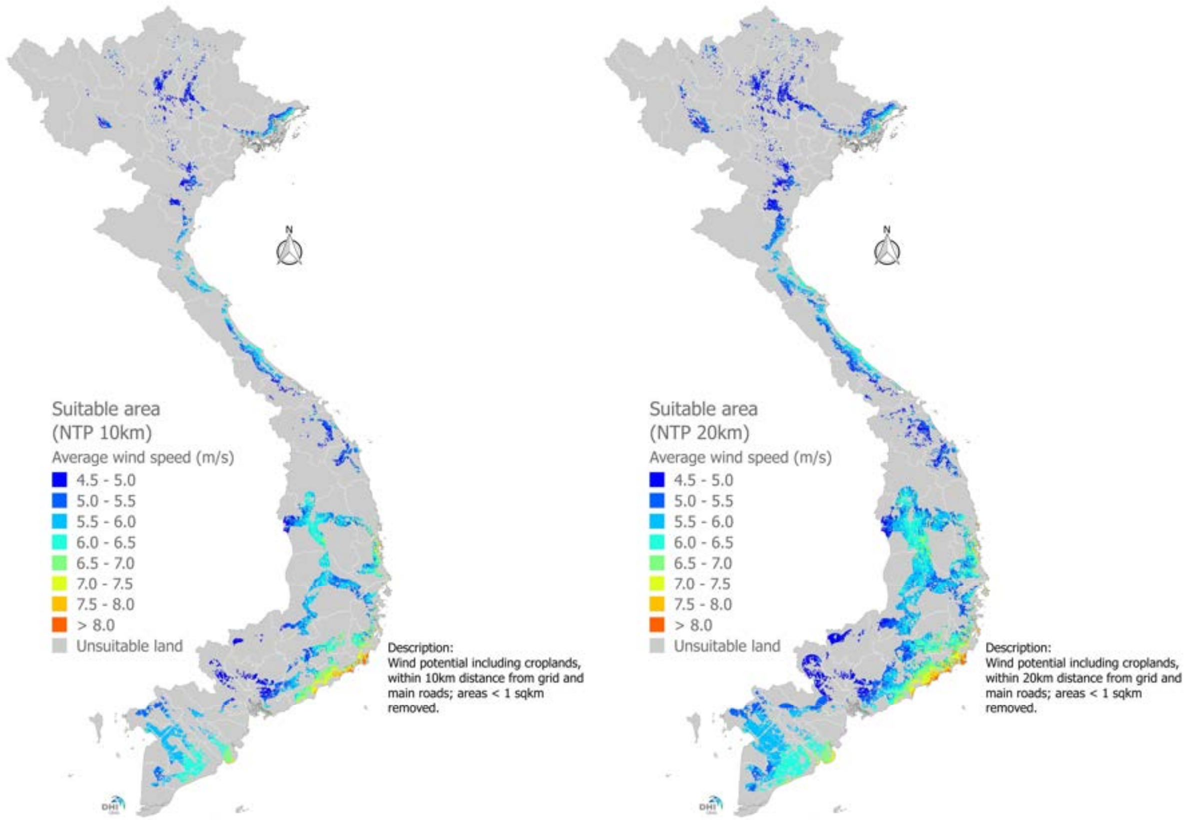

Figure 30. Map of suitable areas illustrating the NTP 10km 78 GW scenario (left) and the NTP 20km 143 GW scenario (right).

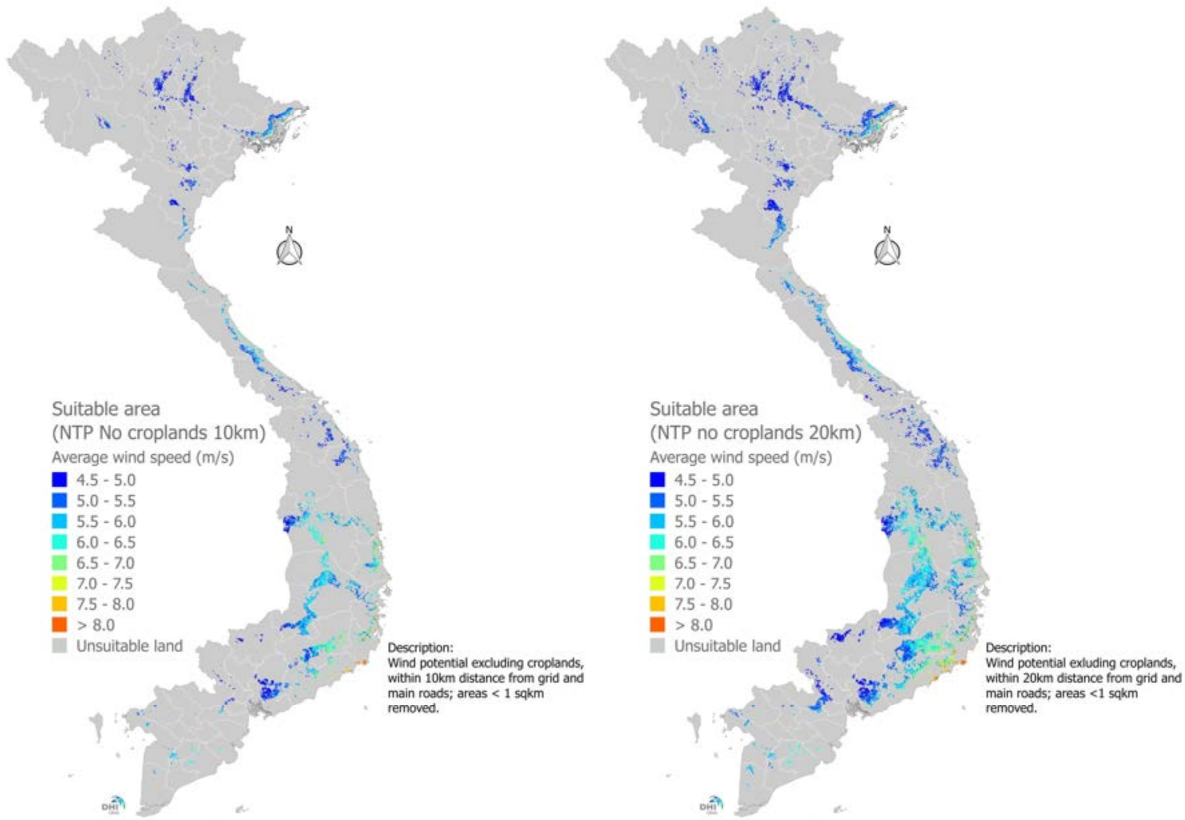

Figure 31. Map of suitable areas illustrating the NTP No croplands 10km 27 GW scenario (left) and the NTP No croplands 20km 54 GW scenario (right).

Table 15 provides an overview of the different national land-based wind technical potential scenarios across regions and wind speed ranges, expressed in the available land area and the corresponding wind power capacity in GW (obtained using wind power project footprint assumption of 3 MW/km^2). More detailed wind speed range overview is presented in the cluster analysis.

Table 15: National technical potential scenarios across regions and wind speed ranges (expressed in km^2 and MW)

	Technical potential land area (km2)				Technical potential wind capacity (MW)			
Wind speed range	***North***	***Central***	***South***	***TOTAL***	***North***	***Central***	***South***	***TOTAL***
National technical potential (NTP)								
4.5 - 5.0 m/s	5,167	4,720	3,945	**13,832**	15,501	14,160	11,835	**41,496**
5.0 - 5.5 m/s	3,086	10,150	5,400	**18,636**	9,258	30,450	16,200	**55,908**
5.5 - 6.0 m/s	954	14,600	6,127	**21,681**	2,862	43,800	18,381	**65,043**
6.0 - 6.5 m/s	281	7,866	3,345	**11,492**	843	23,598	10,035	**34,476**
6.5 - 7.0 m/s	104	2,487	949	**3,540**	312	7,461	2,847	**10,620**
7.0 - 7.5 m/s	11	1,323	217	**1,551**	33	3,969	651	**4,653**
7.5 - 8.0 m/s	2	543	19	**564**	6	1,629	57	**1,692**
Over 8.0 m/s	1	264	0	**265**	3	792	-	**795**
TOTAL	**9,606**	**41,953**	**20,002**	**71,561**	**28,818**	**125,859**	**60,006**	**214,683**
TOTAL (6+ m/s)	**399**	**12,483**	**4,530**	**17,412**	**1,197**	**37,449**	**13,590**	**52,236**
NTP 20km infrastructure proximity								
4.5 - 5.0 m/s	2,407	3,032	2,348	**7,787**	7,221	9,096	7,044	**23,361**
5.0 - 5.5 m/s	944	6,567	2,715	**10,226**	2,832	19,701	8,145	**30,678**
5.5 - 6.0 m/s	391	10,266	5,195	**15,852**	1,173	30,798	15,585	**47,556**
6.0 - 6.5 m/s	147	5,766	3,013	**8,926**	441	17,298	9,039	**26,778**
6.5 - 7.0 m/s	44	2,225	582	**2,851**	132	6,675	1,746	**8,553**
7.0 - 7.5 m/s	5	1,225	135	**1,365**	15	3,675	405	**4,095**
7.5 - 8.0 m/s	0	526	18	**544**	-	1,578	54	**1,632**
Over 8.0 m/s	0	255	0	**255**	-	765	-	**765**
TOTAL	**3,938**	**29,862**	**14,006**	**47,806**	**11,814**	**89,586**	**42,018**	**143,418**
TOTAL (6+ m/s)	**196**	**9,997**	**3,748**	**13,941**	**588**	**29,991**	**11,244**	**41,823**
NTP 10km infrastructure proximity								
4.5 - 5.0 m/s	1,346	1,531	1,218	**4,095**	4,038	4,593	3,654	**12,285**
5.0 - 5.5 m/s	579	3,398	1,281	**5,258**	1,737	10,194	3,843	**15,774**
5.5 - 6.0 m/s	259	5,386	2,700	**8,345**	777	16,158	8,100	**25,035**
6.0 - 6.5 m/s	104	3,039	1,872	**5,015**	312	9,117	5,616	**15,045**
6.5 - 7.0 m/s	16	1,407	292	**1,715**	48	4,221	876	**5,145**
7.0 - 7.5 m/s	0	900	35	**935**	-	2,700	105	**2,805**
7.5 - 8.0 m/s	0	346	10	**356**	-	1,038	30	**1,068**
Over 8.0 m/s	0	134	0	**134**	-	402	-	**402**
TOTAL	**2,304**	**16,141**	**7,408**	**25,853**	**6,912**	**48,423**	**22,224**	**77,559**
TOTAL (6+ m/s)	**120**	**5,826**	**2,209**	**8,155**	**360**	**17,478**	**6,627**	**24,465**

NTP No croplands								
4.5 - 5.0 m/s	3,314	3,169	1,416	**7,899**	9,942	9,507	4,248	**23,697**
5.0 - 5.5 m/s	2,008	5,833	1,367	**9,208**	6,024	17,499	4,101	**27,624**
5.5 - 6.0 m/s	648	6,547	534	**7,729**	1,944	19,641	1,602	**23,187**
6.0 - 6.5 m/s	169	2,952	123	**3,244**	507	8,856	369	**9,732**
6.5 - 7.0 m/s	64	860	23	**947**	192	2,580	69	**2,841**
7.0 - 7.5 m/s	9	305	3	**317**	27	915	9	**951**
7.5 - 8.0 m/s	1	144	3	**148**	3	432	9	**444**
Over 8.0 m/s	1	110	0	**111**	3	330	-	**333**
TOTAL	**2,304**	**16,141**	**7,408**	**25,853**	**6,912**	**48,423**	**22,224**	**77,559**
TOTAL (6+ m/s)	**120**	**5,826**	**2,209**	**8,155**	**360**	**17,478**	**6,627**	**24,465**
NTP No croplands 20km infrastructure proximity								
4.5 - 5.0 m/s	1,631	2,008	911	**4,550**	4,893	6,024	2,733	**13,650**
5.0 - 5.5 m/s	641	3,529	914	**5,084**	1,923	10,587	2,742	**15,252**
5.5 - 6.0 m/s	258	4,181	332	**4,771**	774	12,543	996	**14,313**
6.0 - 6.5 m/s	73	2,199	114	**2,386**	219	6,597	342	**7,158**
6.5 - 7.0 m/s	29	697	9	**735**	87	2,091	27	**2,205**
7.0 - 7.5 m/s	5	249	3	**257**	15	747	9	**771**
7.5 - 8.0 m/s	0	131	3	**134**	-	393	9	**402**
Over 8.0 m/s	0	101	0	**101**	-	303	-	**303**
TOTAL	**2,637**	**13,095**	**2,286**	**18,018**	**7,911**	**39,285**	**6,858**	**54,054**
TOTAL (6+ m/s)	**107**	**3,377**	**129**	**3,613**	**321**	**10,131**	**387**	**10,839**
NTP No croplands 10km infrastructure proximity								
4.5 - 5.0 m/s	930	979	491	**2,400**	2,790	2,937	1,473	**7,200**
5.0 - 5.5 m/s	366	1,704	420	**2,490**	1,098	5,112	1,260	**7,470**
5.5 - 6.0 m/s	159	2,083	143	**2,385**	477	6,249	429	**7,155**
6.0 - 6.5 m/s	41	1,077	67	**1,185**	123	3,231	201	**3,555**
6.5 - 7.0 m/s	8	341	2	**351**	24	1,023	6	**1,053**
7.0 - 7.5 m/s	0	118	2	**120**	-	354	6	**360**
7.5 - 8.0 m/s	0	64	2	**66**	-	192	6	**198**
Over 8.0 m/s	0	50	0	**50**	-	150	-	**150**
TOTAL	**1,504**	**6,416**	**1,127**	**9,047**	**4,512**	**19,248**	**3,381**	**27,141**
TOTAL (6+ m/s)	**49**	**1,650**	**73**	**1,772**	**147**	**4,950**	**219**	**5,316**

Table 16 provides a summary overview of the estimated annual wind power production potential (based on a 'normal' wind year) based on the national technical potential scenarios. Production estimates based on 200 W/m^2 wind turbine technology with 100m hub height (please see section Annual Energy Production estimation). Mean annual wind speed steps of 0.1m/s used in the production calculation. Please see Appendix IX for detailed data tables.

Table 16: Estimated annual wind power production potential in TWh (for a 'normal' wind year) based on the national technical potential scenarios. Production estimates based on 200 W/m2 wind turbine technology with 100m hub height (please see section Annual Energy Production estimation) at 0.1m/s mean annual wind speed steps

Scenario (TWh)	***North***	***Central***	***South***	***TOTAL***
National Technical Potential (NTP)	42	274	120	**437**
NTP 20km	17	201	88	**306**
NTP 10km	10	111	47	**168**
NTP No croplands	27	121	16	**165**
NTP No croplands 20km	11	82	11	**104**
NTP No croplands 10km	6	40	5	**52**

The analysis suggests that clusters with high wind potential lie within relative proximity to infrastructure (0-10 and 10-20 km distance to closest transmission grid and / or road considered, as presented in Figure 32).

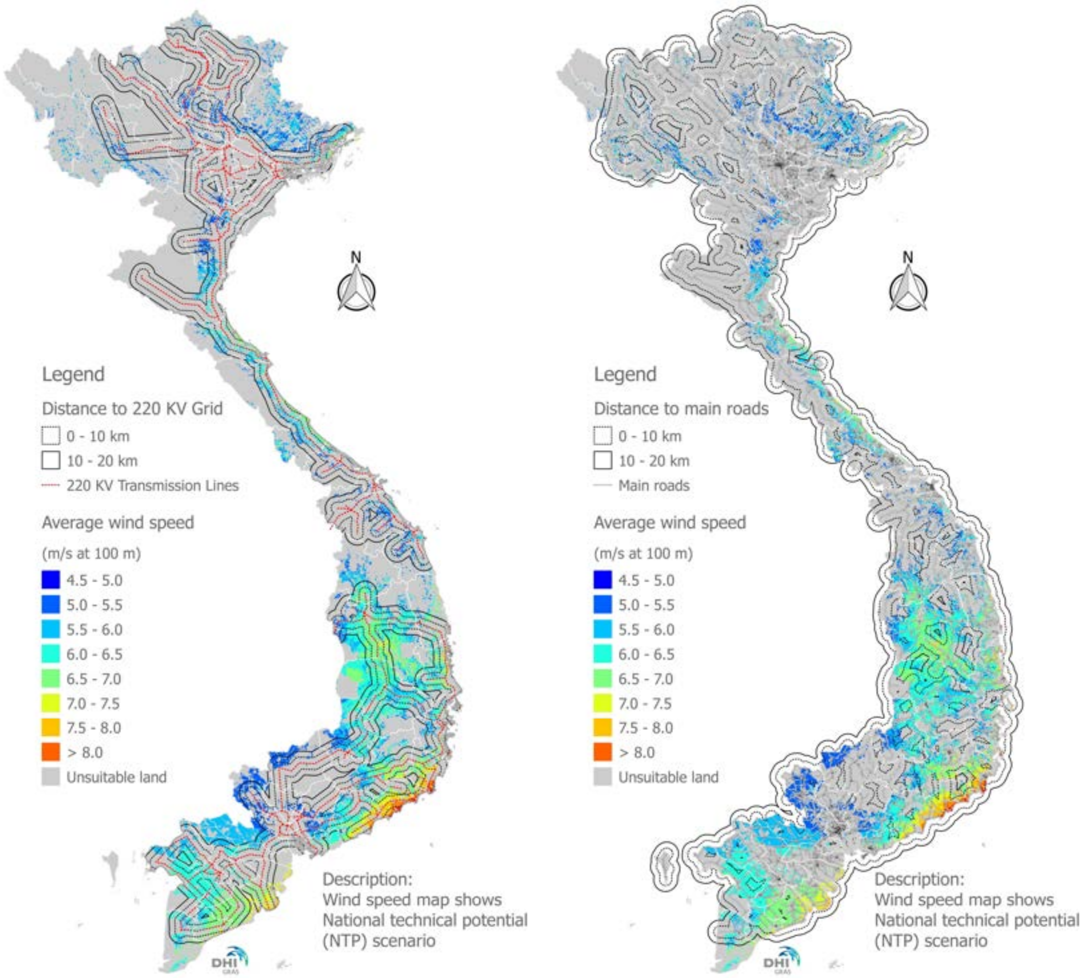

Figure 32. Map showing distance to the 220 KV transmission line grid (left) and distance to main roads (right).

6.2 Provincial wind resource mapping

This section describes and presents the GIS analysis results for provincial land-based wind resource mapping.

6.2.1 Provincial exclusion criteria

The impact of each exclusion criterion is illustrated with corresponding maps below.

Basis for the provincial wind resource mapping was the wind potential from the national wind resource mapping with the following exclusion criteria removed:

- Wind speeds lower than 4.5m/s
- Altitude higher than 2000m
- Densely populated areas (> 500 persons/km^2) including a 500m buffer
- Protected areas including a 1km buffer
- Areas within a 100m distance to the coast

The remaining areas are shown in Figure 33 – left. In Figure 33 – right, additional exclusion criteria were applied:

- Steep areas with slopes > 30% were removed
- All the areas covering relevant land use classes (commercial, industrial and non-agricultural land; national defense and religious land; residential and public land; special forest land; transportation as well as water bodies) incl. buffers as described in Table 4.

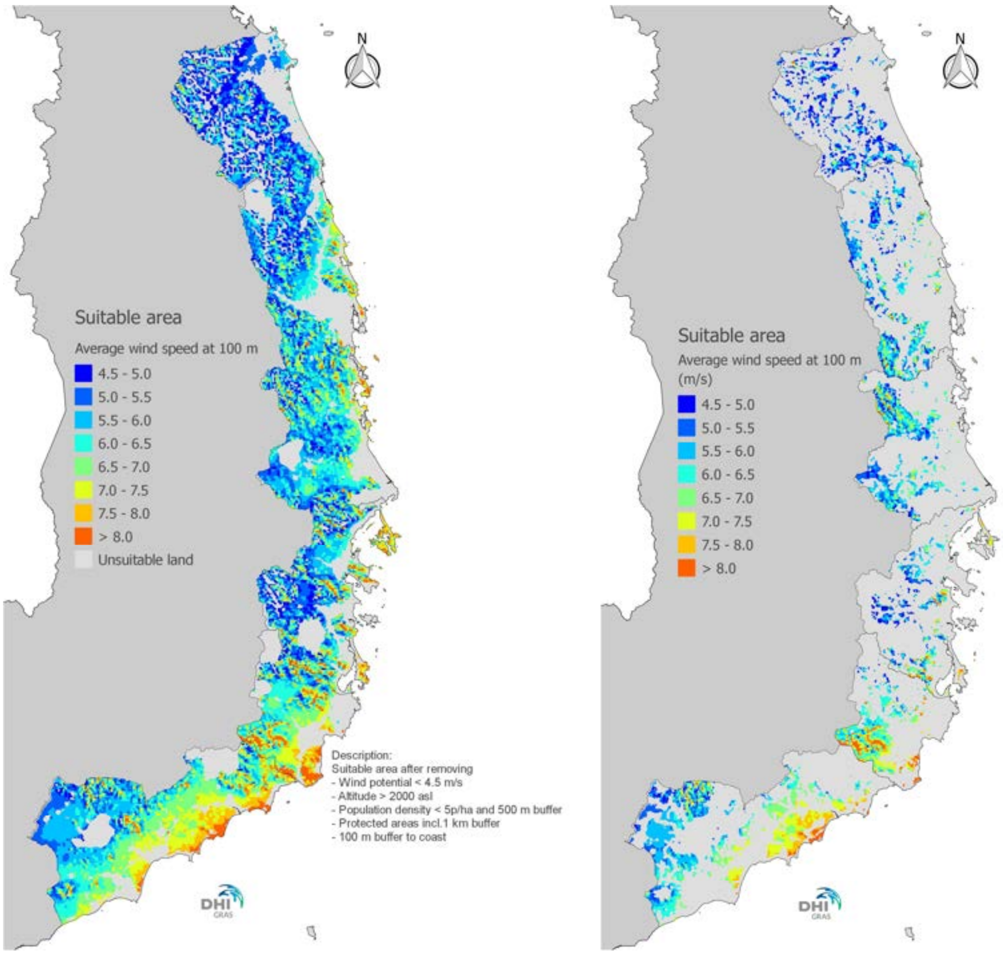

Figure 33. Wind potential after removing areas with wind speeds lower than 4.5m/s, altitudes higher than 2000m, high population density, protected areas and areas close to the coast (100m) (left), and finally after removing areas covering relevant land use classes as well as slope > 30% as defined in Table 4 (right).

Table 17 provides an overview of individual and cumulative impact of each exclusion criterion.

Table 17. Suitable land area and impact of each exclusion criterion for the provincial analysis.

	Criterion	Suitable Area (km^2)	Difference (km^2)
	Total Area of provicnes Binh Dinh, Binh Thuan, Khan Hoa, Ninh thuan, Phu Yen, Quang Ngai (incl. Islands)*	32,157	
minus	Wind potential (>4.5 m/s) (Binh Dinh, Binh Thuan, Khan Hoa, Ninh thuan, Phu Yen, Quang Ngai)	30,440	1,718
minus	Protected areas and 1 km buffer, Altitude > 2000 and Population Density and 500m buffer (output from national analysis)	21,927	8,513
minus	Coastline 100 m buffer	21,901	26
minus	Special Forest Land and buffer 100m	11,980	9,921
minus	Residential and Public Land and 1km buffer	6,306	5,674
minus	Commercial, Industrial and Non-Agricultural Land and 1 km buffer	6,148	158
minus	National Defense and Religious Land and 1 km buffer	6,024	124
minus	Transportation 250 m buffer	5,728	296
minus	Water bodies and 100m buffer	5,460	268
minus	Slope > 30%	4,092	1,368

**based on Global Administrative Areas (GADM) data;*

Table 18 provides an overview of the total technical potential for land-based wind power per province expressed in land area in km^2 and wind power capacity in MW.

Table 18: Technical potential for land-based wind power per province (expressed in land area in km^2 and wind power capacity in MW)

	Binh Dinh	Binh Thuan	Khanh Hoa	Ninh Thuan	Phu Yen	Quang Ngai
Technical potential land area (km^2)	616	1,610	308	509	673	378
Technical potential capacity (MW)	1,847	4,829	923	1,527	2,018	1,133

Figure 34 and Figure 35 present the distribution of the wind resource (expressed as average annual wind speed ranges) within the technical potential land area and capacity. (Please see Appendix VII for the data tables.)

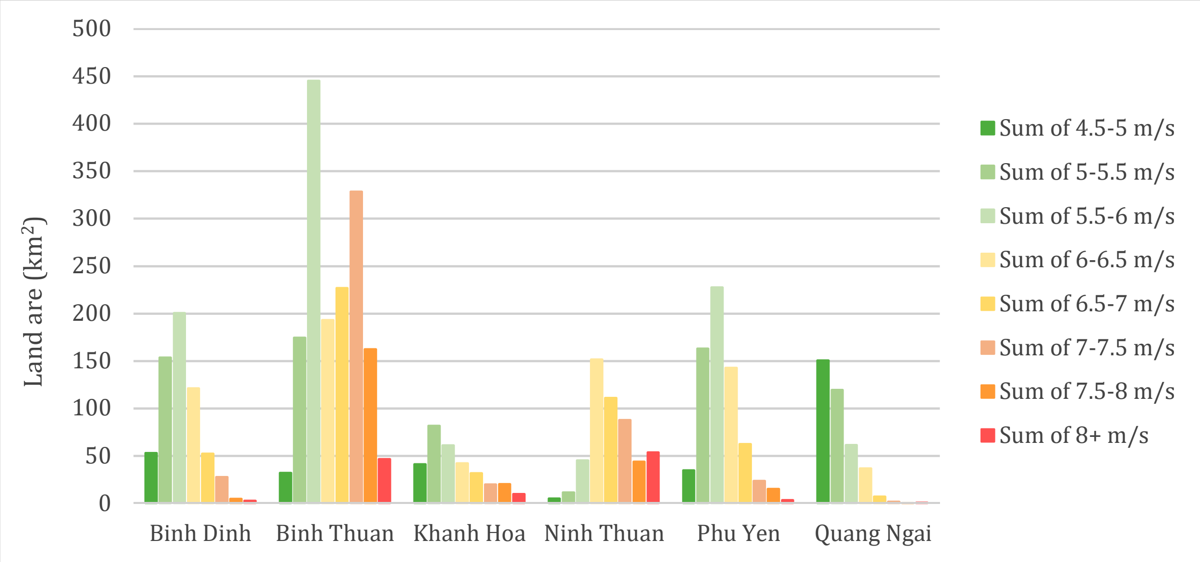

Figure 34: Wind technical potential overview per province (land area in km²), across average annual wind speed ranges.

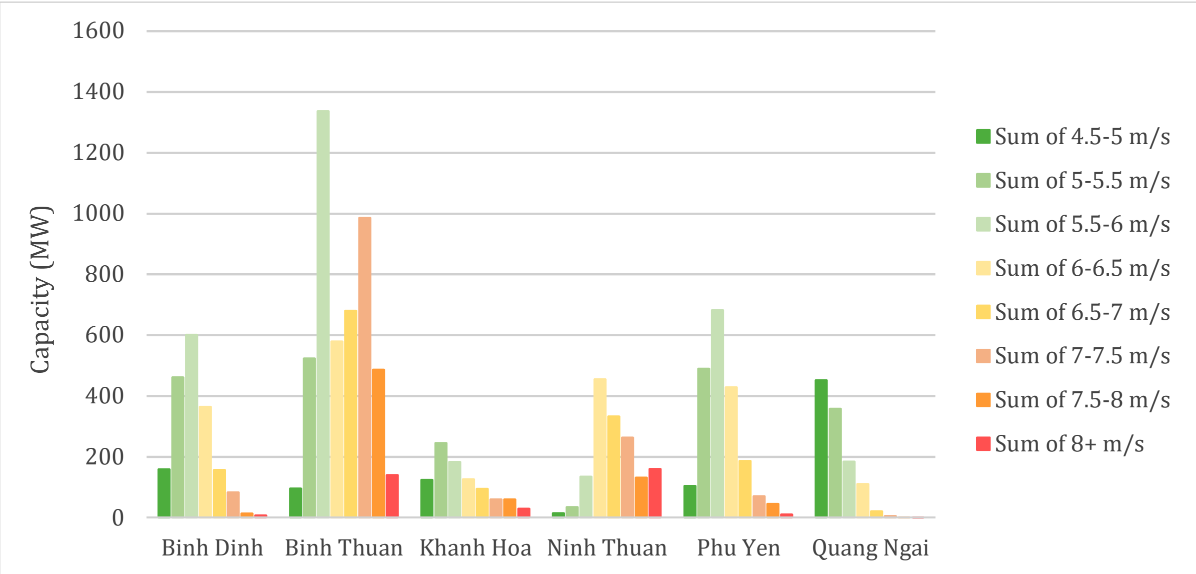

Figure 35: Wind technical potential overview per province (wind power capacity in MW), across average annual wind speed ranges.

In absolute terms, Ninh Thuan and Binh Thuan provinces appear to be endowed with the largest areas / highest capacity potential of wind sites reaching 7 and 8 m/s annual average wind speeds at 100m height.

6.3 LCOE perspective

This section presents an LCOE perspective of selected clusters of wind resource in Vietnam nationally, and within selected provinces.

6.3.1 Cluster analysis – national level

Areas characterised by significant proportion of adjacent above-average wind resource cells have been selected and grouped into ‘clusters’. The largest areas matching the characteristics that were spanning across several provinces have though been split into clusters such that each cluster belongs to a single province. Figure 36 provides an overview of the clusters selected, as well as the average annual wind speeds for each cluster.

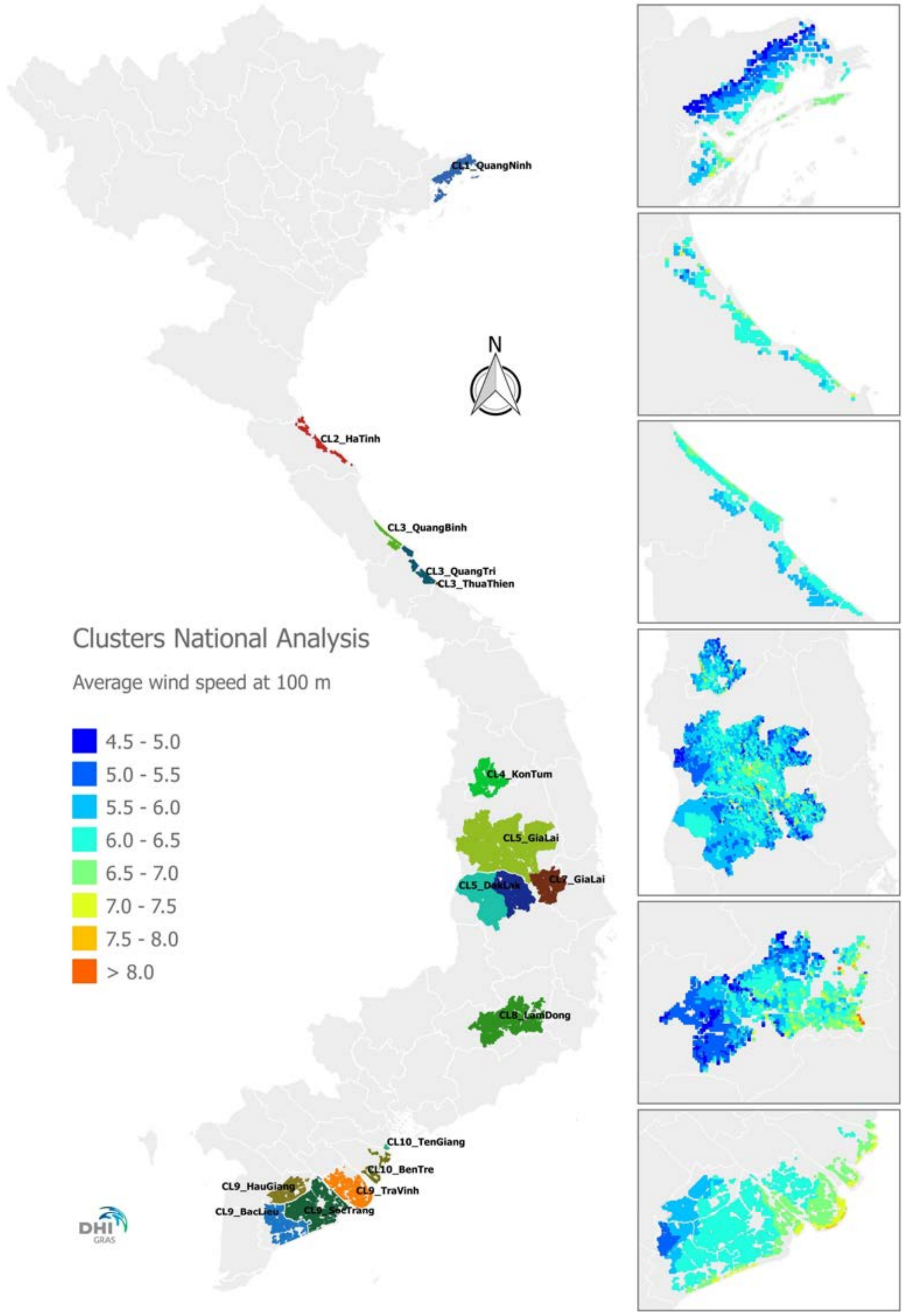

Figure 36. Location, size and wind potential of selected clusters. Selection was based on wind speeds and cluster size.

Table 19 provides an overview of the individual clusters and the total area of each cluster.

Table 19: Overview of the clusters selected and their total area in km² and capacity (MW)

Cluster ID	Province	Total area (km²)	Capacity (MW)
CL9	Bac Lieu	1,097	3,292
CL10	Ben Tre	211	632
CL5	Dak Lak	1,667	5,001
CL6	Dak Lak	2,356	7,069
CL5	Gia Lai	5,814	17,442
CL7	Gia Lai	1,029	3,086
CL2	Ha Tinh	256	767
CL9	Hau Giang	760	2,281
CL4	Kon Tum	1,000	3,001
CL8	Lam Dong	2,203	6,608
CL3	Quang Binh	192	575
CL1	Quang Ninh	556	1,668
CL3	Quang Tri	299	898
CL9	Soc Trang	1,918	5,754
CL3	Thua Thien - Hue	19	58
CL10	Tien Giang	23	68
CL9	Tra Vinh	941	2,823
TOTAL		**20,341**	**61,023**

Figure 37 and Figure 38 present the distribution of the wind resource (expressed as average annual wind speed ranges) within the technical potential capacity in each cluster. (Large and smaller clusters are presented separately for ease of overview.) (Please see Appendix III for the data tables detailing the capacity and land area.)

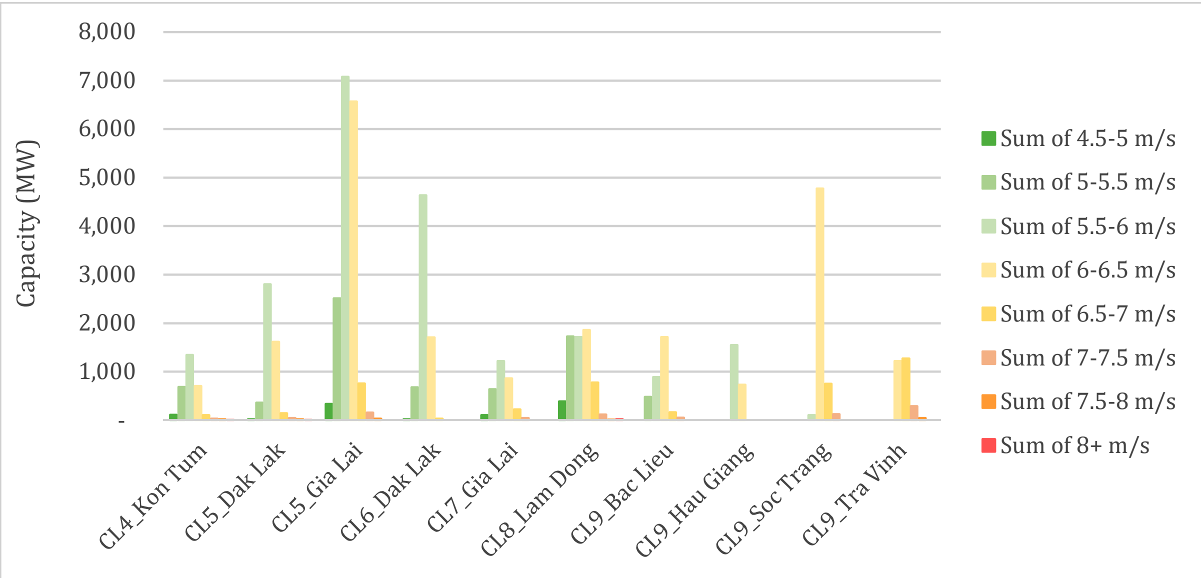

Figure 37: Wind technical potential overview per national cluster (wind power capacity in MW), across average annual wind speed ranges. Selection of the largest clusters.

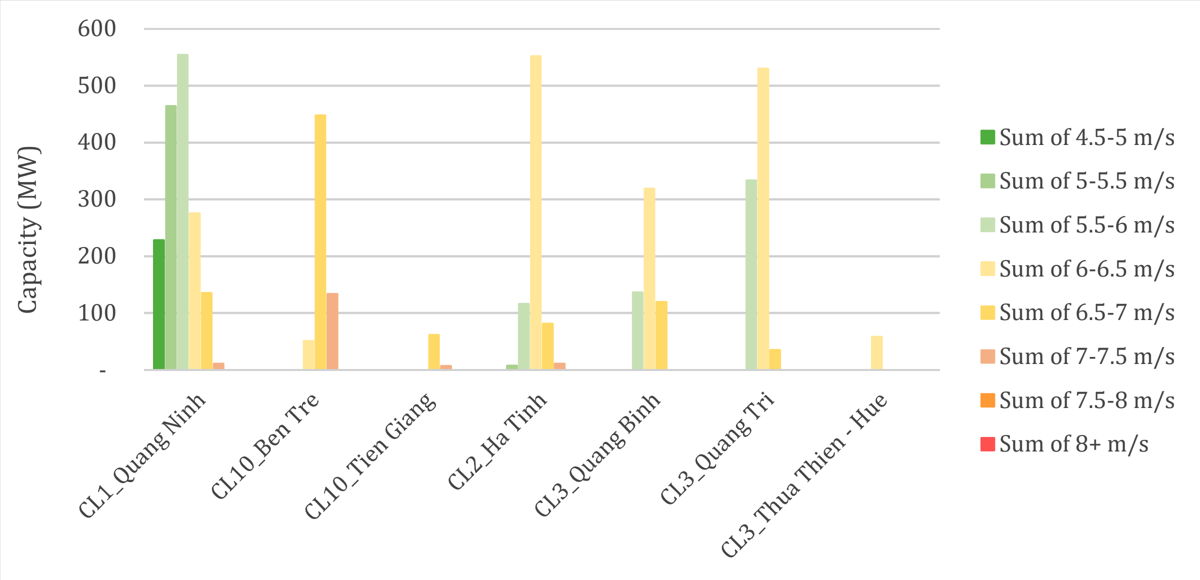

Figure 38: Wind technical potential overview per national cluster (wind power capacity in MW), across average annual wind speed ranges. Selection of the smaller clusters.

To calculate the clusters' proximity to infrastructure, for each cluster the centroid was derived. From the centroid, the distance to the closest 220 KV grid and main road was derived (Figure 39).

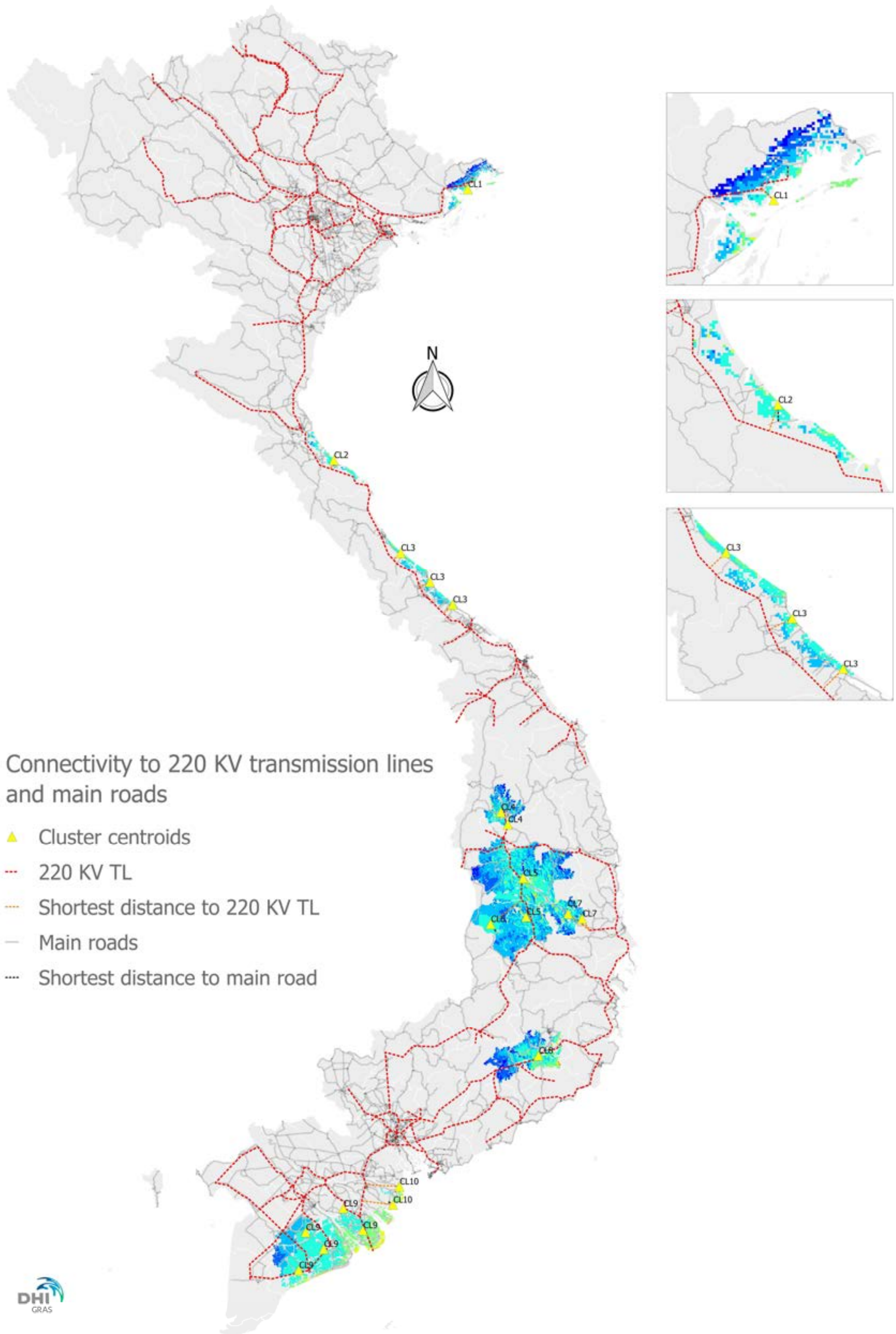

Figure 39. Map showing the connectivity of the clusters to infrastructure. Distances to grid and main roads were calculated from the cluster centroids.

Table 20 provides an overview of infrastructure proximity (220 kV grid and road) to the centroid of each cluster.

Table 20: Overview of infrastructure proximity (220 kV grid and road) to the centroid of each cluster.
** Distance calculated based on the centroid of core cluster with highest wind speeds.*

Cluster ID	Province	Distance to closest 220 kV grid point (km)*	Distance to closest road (km)*
CL9	Bac Lieu	3.0	4.0
CL10	Ben Tre	38.5	5.8
CL5	Dak Lak	5.1	2.4
CL6	Dak Lak	47.6	12.7
CL5	Gia Lai	3.5	2.9
CL7	Gia Lai	33.2	3.5
CL2	Ha Tinh	11.2	6.7
CL9	Hau Giang	17.4	2.4
CL4	Kon Tum	4.5	1.1
CL8	Lam Dong	1.5	5.5
CL3	Quang Binh	12.2	1.3
CL1	Quang Ninh	6.8	5.9
CL3	Quang Tri	13.8	0.4
CL9	Soc Trang	3.2	3.0
CL3	Thua Thien - Hue	15.7	0.4
CL10	Tien Giang	41.3	0.0
CL9	Tra Vinh	2.8	1.4

The infrastructure proximity data obtained from the GIS analysis suggests that the average distance from the cluster centroid to the closest major road is ca 3km (longest distance being 12.7km for CL5 in Dak Lak province). The average corresponding distance to the closest 220kV grid point is 15km (longest distance being 47 km for CL6 in Dak Lak province). Overall, the infrastructure proximity for the selected clusters can be assessed as non-prohibitive. For context, the threshold for grid connection proximity used in IRENA analysis in relation to wind power projects in Latin America has been set at 75 km (IRENA, 2016).

Appendix V provides detailed LCOE Base Case and LCOE Low values calculations based on the inputs described in section LCOE analysis data sources and inputs (including the full-load hours of productions estimates as a function of average annual wind speed ranges in each cluster), as well as the infrastructure proximity estimates derived as per above.

The LCOE Base Case and LCOE Low values are presented in Figure 40 and Figure 41.

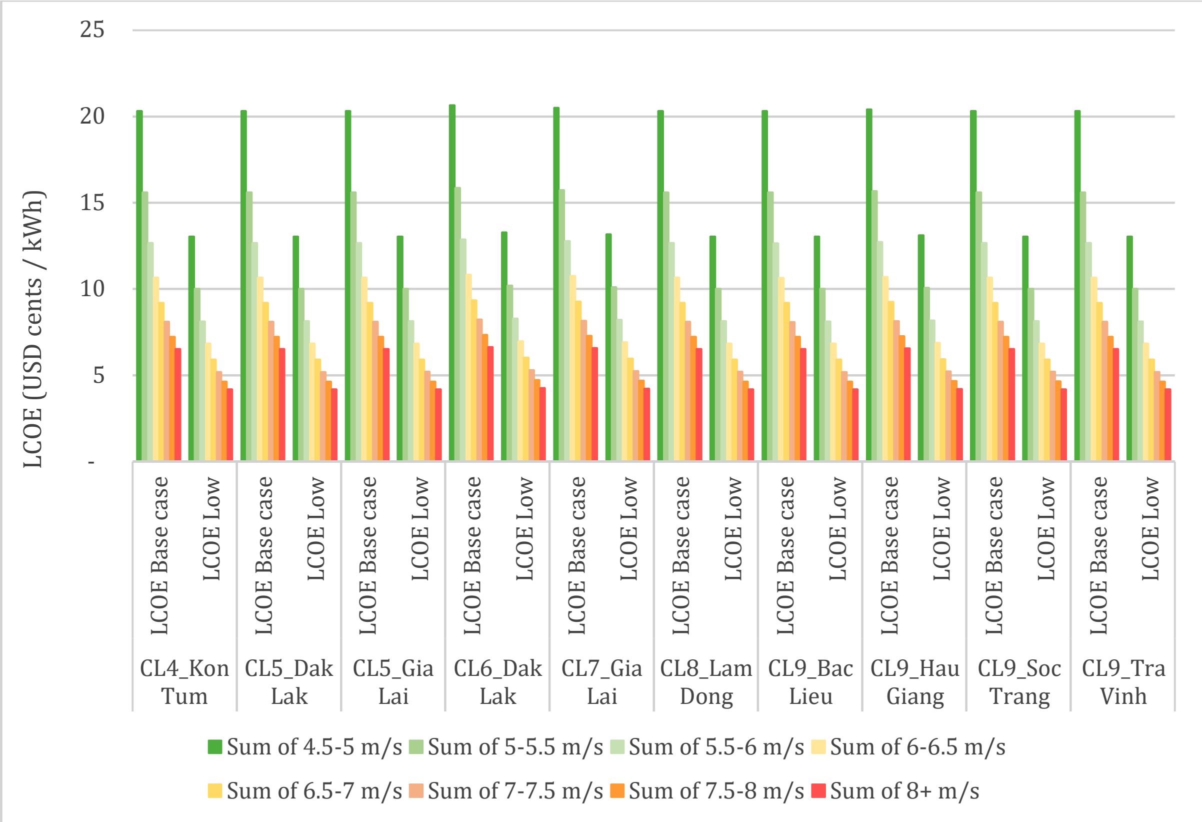

Figure 40: LCOE overview per cluster (LCOE Base Case and LCOE Low) across average annual wind speed ranges. Selection of the largest clusters.

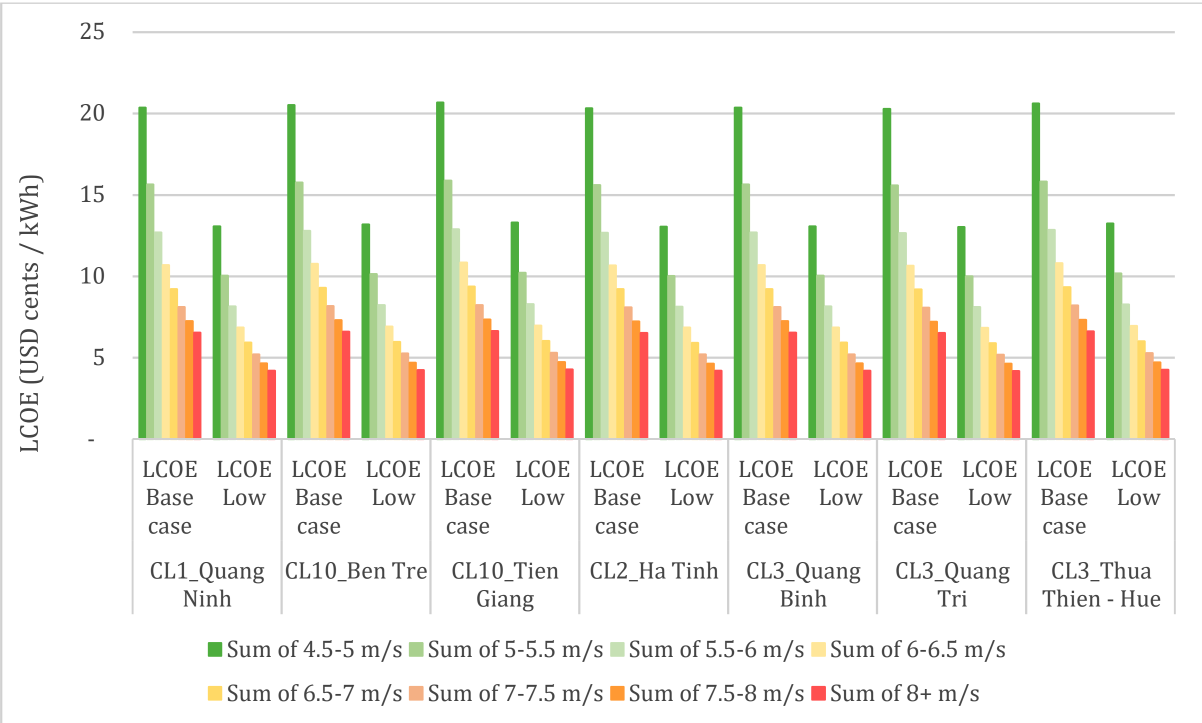

Figure 41: LCOE overview per cluster (LCOE Base Case and LCOE Low) across average annual wind speed ranges. Selection of the smaller clusters.

The LCOE Base Case analysis suggests good locations could be developed at LCOE range of ca 8.1 – 10.7 $ct/kWh (mean annual wind speeds of 6 - 7.5m/s at 100m height). In addition, limited 'best' locations could be developed down to under 7 $ct/kWh (mean annual wind speed over 7.5 m/s). The LCOE increases progressively along with decreasing wind resource quality, the 4.5-5 m/s mean annual wind speed locations reaching 20.4 $ct/kWh. (The LCOE levels have though been estimated assuming infrastructure cost sharing across the entire cluster, please see Allocation of infrastructure costs in the LCOE calculation section for a description of the approach used).

The results also indicate that the impact of the infrastructure on-costs is minimal, at least on the entire cluster level (it should be noted that some of the clusters are very considerable in capacity size; please see Allocation of infrastructure costs in the LCOE calculation section for a description of the approach used). The highest CapEx on-cost related to additional infrastructure development (yet only reaching 3.3%) has been estimated for the relatively smaller CL10 cluster of 68 MW in Tien Giang province.

The LCOE Low case analysis suggests that more favourable project development and technology conditions (e.g. in the medium term) could yield significant LCOE reductions, and the absolute reductions are most prominent for lower wind resource locations. LCOE Low is in the range of 4.2 – 6.9 $ct/kWh for locations with mean annual wind speed over 6 m/s, whereas locations with 4.5-5 m/s mean annual wind speed yield an average of 13.1 $ct/kWh, a significant reduction from the 20.4 $ct/kWh in the LCOE Base Case.

Of course, it should be noted that the LCOE Base Case analysis is only indicative of overall project costs, and does not reflect the specific conditions of the individual project (e.g. differences in administrative/permitting and financing conditions of larger versus smaller projects). Similarly, LCOE Low case illustrates one potential technology and cost development projection, and is subject to high degree of uncertainty.

6.3.2 Cluster analysis – provincial level

Within the provincial analysis, areas characterised by significant proportion of adjacent above-average wind resource cells have been similarly selected and grouped into 'clusters'. Figure 42 provides an overview of the first sample of clusters selected, as well as the average annual wind speeds within the clusters.

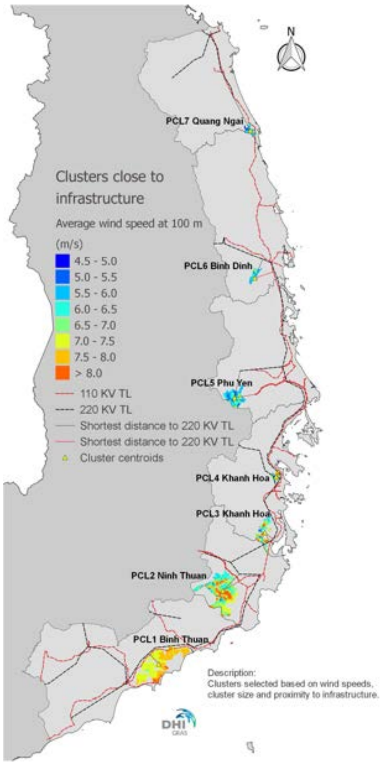

Figure 42. Clusters close to 110 and 220 KV transmission lines and proximity to grid.

In addition, three high wind resource clusters were selected that are far from the 110 and 220 KV transmission lines (> 20km), as illustrated by Figure 43. The clusters are located in the provinces Binh Dinh, Phu Yen and Ninh Thuan and are used to illustrate the impacts of additional infrastructure expenditure in particular.

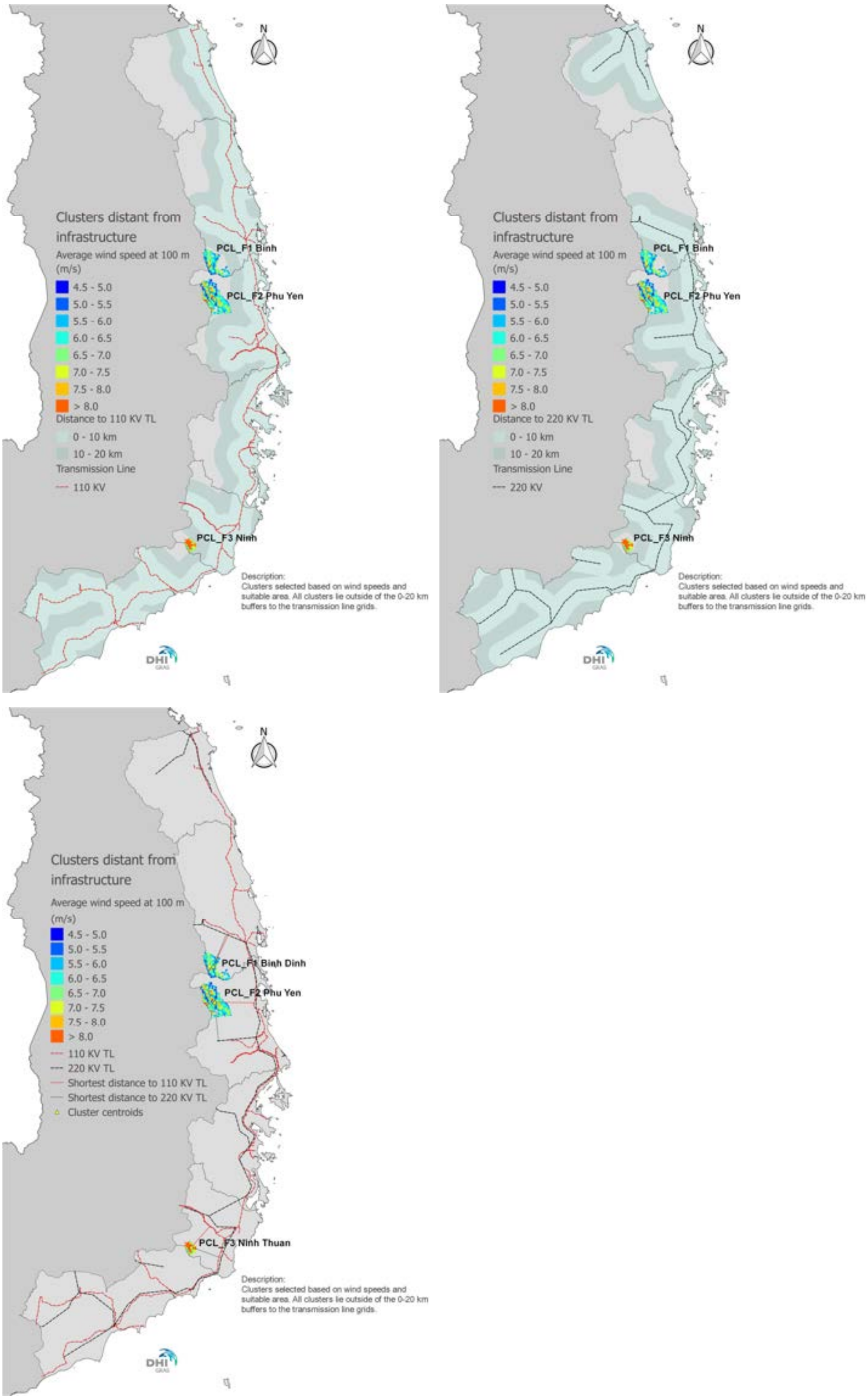

Figure 43. Clusters far away from transmission lines; 110 KV grid (upper left and 220 KV grid (upper right) and proximity to grid (lower left).

For each cluster, the centroid was calculated from which the distance to the closest transmission line was derived.

Table 21 provides an overview of the individual clusters, the total area and capacity of each cluster, as well as the infrastructure proximity.

Table 21: Overview of the clusters selected: their total area in km^2, capacity (MW), and infrastructure proximity (220 kV / 110 kV grid and road) to the centroid of each cluster.
** Distance calculated based on the centroid of core cluster with highest wind speeds.*
*** Distance to 110kV grid point used (due to the size of the project suitable for the connection)*

Cluster ID	Province	Total area (km^2)	Capacity (MW)	Distance to closest 220 kV grid point (km)*	Distance to closest 110 kV grid point (km)*	Distance to closest road (km)*
PCL1	Binh Thuan	339	1,017	10.8	9.3	3.6
PCL2	Ninh Thuan	285	855	17.5	13.7	7.3
PCL3	Khanh Hoa	56	168	7.7	7.3	0.3
PCL4	Khanh Hoa**	18	54	1.8	4.1	4.4
PCL5	Phu Yen	105	315	20.6	15.4	5.9
PCL6	Binh Dinh**	27	81	15.4	14.6	0.6
PCL7	Quang Ngai**	25	75	27.8	3.6	4.0
PCL_F1	Binh Dinh	138	414	25.9	29.7	9.8
PCL_F2	Phu Yen	220	660	32.1	32.1	6.7
PCL_F3	Ninh Thuan**	40	120	28.2	22.6	9.1

The infrastructure proximity data obtained from the GIS analysis suggests that the average distance from the cluster centroid to the closest major road is ca 5.2km (average of 3.7km for the less remote clusters, i.e. clusters denoted with ID of PCL). The longest distance from road for any cluster is 9.8km for PCL_F1 in Binh Dinh province. The average corresponding distance to the closest 220kV grid point is 18.8km (average of 14.5km for the less remote clusters). The longest distance to 220kV transmission grid point is 32.1km for PCL_F2 cluster in Phu Yen province. The proximity to 110kV infrastructure is close to that of 220kV (with the exception of e.g. PCL7 cluster in Quang Ngai province).

Overall, the infrastructure proximity for the selected provincial clusters can also be assessed as non-prohibitive. For context, the threshold for grid connection proximity used in IRENA analysis in relation to wind power projects in Latin America has been set at 75 km (IRENA, 2016).

Figure 44 presents the distribution of the wind resource (expressed as average annual wind speed ranges) within the technical potential capacity in each provincial cluster. Please see Appendix IV for the data tables detailing the capacity and land area.)

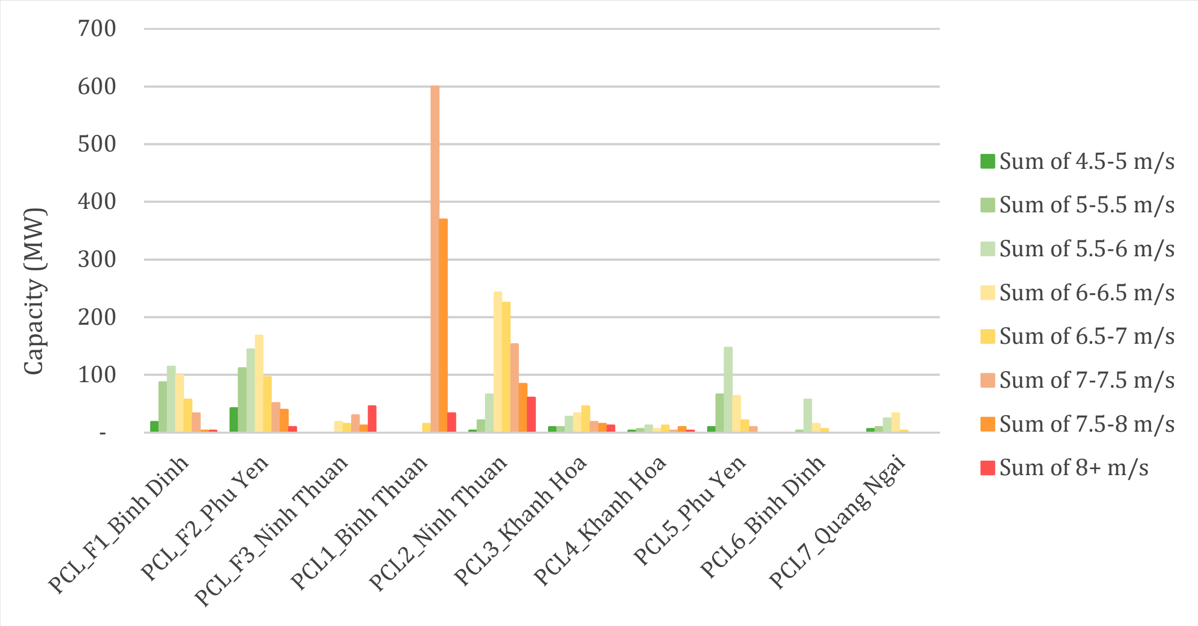

Figure 44: Wind technical potential overview per provincial cluster (wind power capacity in MW), across average annual wind speed ranges.

Based on the inputs described in section LCOE analysis data sources and inputs (including the full-load hours of productions estimates as a function of average annual wind speed ranges in each cluster), as well as the infrastructure proximity estimates derived as per above, the LCOE Base Case and LCOE Low values are calculated, presented in Figure 45 and Figure 46. (Please see Appendix VI for the detailed data tables.)

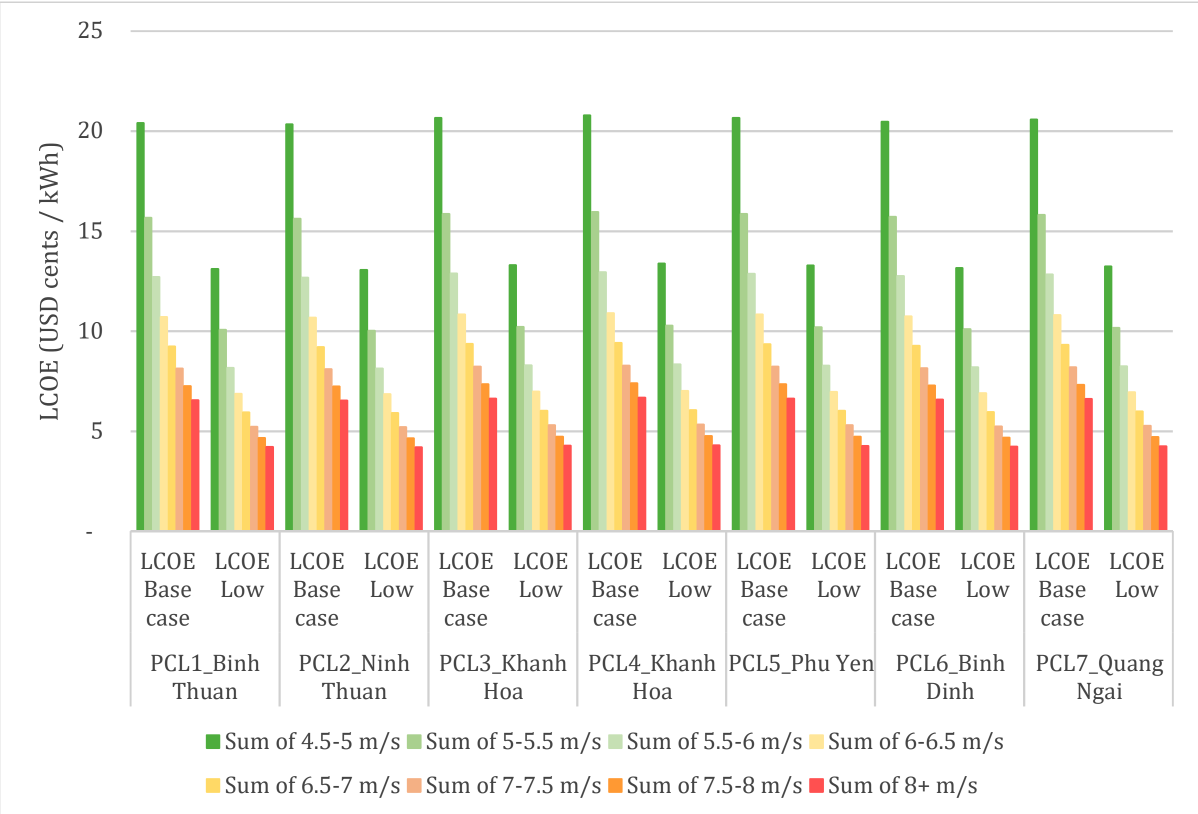

Figure 45: LCOE overview per provincial cluster (LCOE Base Case and LCOE Low) across average annual wind speed ranges. Selection of the clusters in close proximity to infrastructure

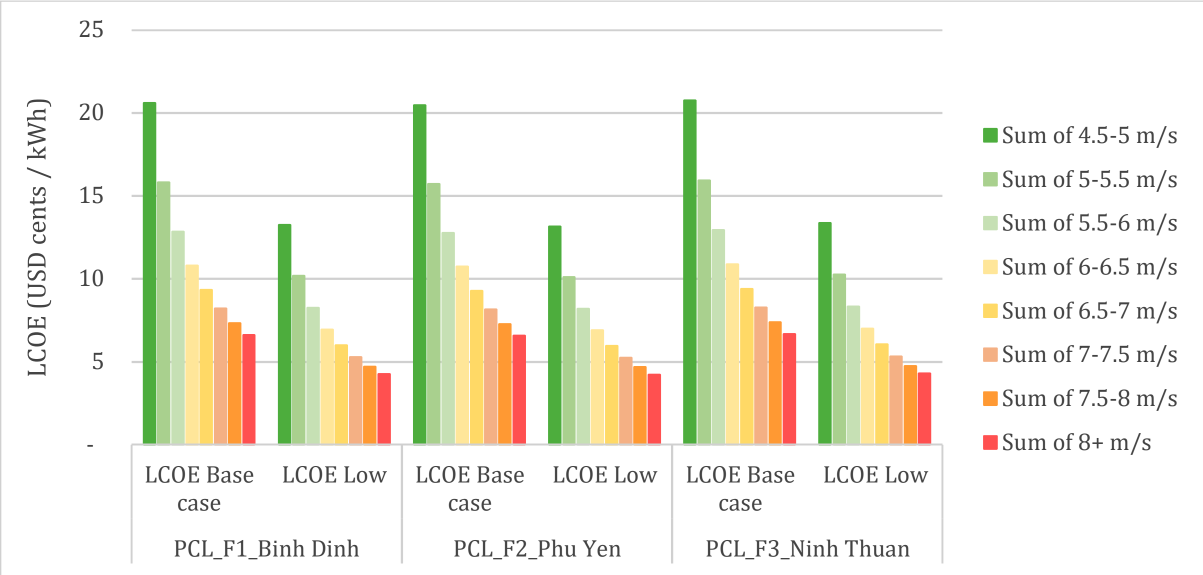

Figure 46: LCOE overview per provincial cluster (LCOE Base Case and LCOE Low) across average annual wind speed ranges. Selection of the clusters more remote from the infrastructure

The LCOE Base Case analysis suggests good locations could be developed at LCOE range of ca 8.2 – 10.8 $ct/kWh (mean annual wind speeds of 6 - 7.5m/s at 100m height). In addition, limited 'best' locations could be developed down to under 7 $ct/kWh (mean annual wind speed over 7.5 m/s). The LCOE increases progressively along with decreasing wind resource quality, the 4.5-5 m/s mean annual wind speed locations reaching 20.6 $ct/kWh, also consistent with the findings for the national clusters. (The LCOE levels have though been estimated assuming infrastructure cost sharing across the entire cluster, please see Allocation of infrastructure costs in the LCOE calculation section for a description of the approach used). The results also indicate that the impact of the infrastructure on-costs is minimal, at least on the entire cluster level. This holds true even among the sub-sample of the three clusters more remote from roads and transmission grid (denoted with PCL_F). The highest CapEx on-cost related to additional infrastructure development, reaching 3.9% has been estimated for the smallest of the clusters, namely PCL4 cluster of 54 MW in Khanh Hoa province. The results (based on the given sample of clusters) also indicate that the size of the cluster exhibits higher impact on the infrastructure costs than the infrastructure proximity per se.

The LCOE Low case analysis suggests that more favourable project development and technology conditions (e.g. in the medium term) could yield significant LCOE reductions, and the absolute reductions are most prominent for lower wind resource locations – perfectly in line with the findings from the national clusters. LCOE Low is in the range of 4.2 – 6.9 $ct/kWh for locations with mean annual wind speed over 6 m/s, whereas locations with 4.5-5 m/s mean annual wind speed yield an average of 13.2 $ct/kWh, a significant reduction from the 20.6 $ct/kWh in the LCOE Base Case; also, well in line with the national cluster analysis.

Of course, also in the provincial cluster analysis, it should be noted that the LCOE Base Case analysis is only indicative of overall project costs, and does not reflect the specific conditions of the individual project. Similarly, LCOE Low case illustrates one potential technology and cost development projection, and is subject to high degree of uncertainty.

6.3.3 Cluster analysis – overall comparison

Figure 47 provides an overview of the compound LCOE values per cluster (the LCOE per wind speed ranges of each cluster has been capacity-weighted).

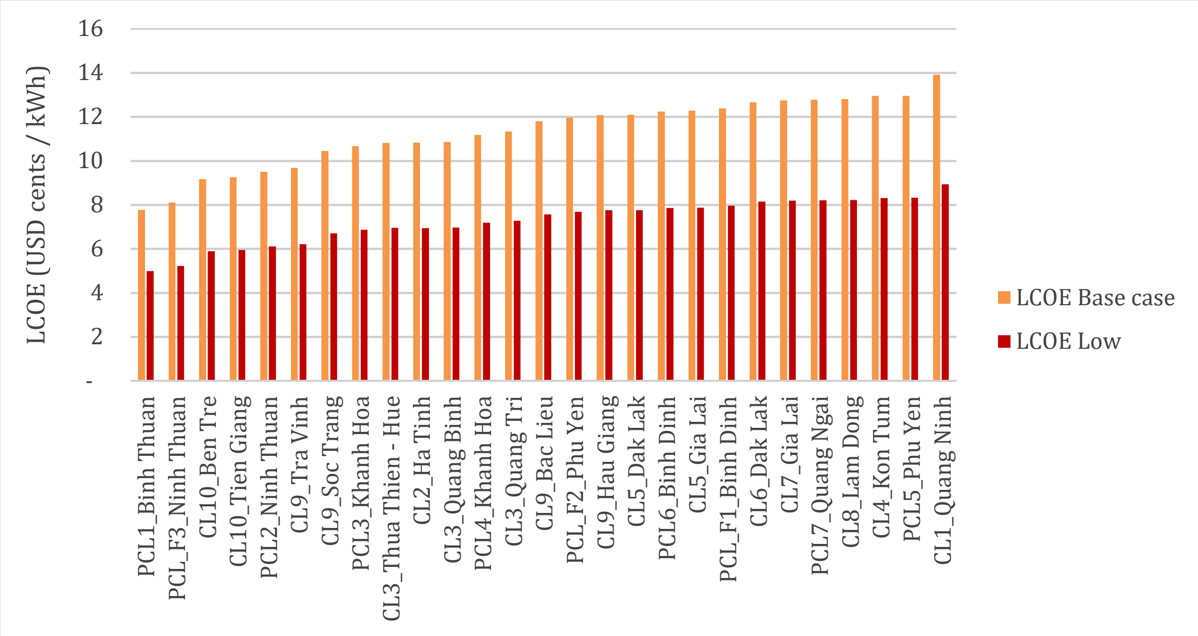

Figure 47: Compounded average LCOE (capacity-weighted across wind class ranges) per cluster in $ct/kWh.

Not surprisingly, the clusters with the lowest overall LCOE are located in the provinces with the best wind resource (Central and South regions), whilst the cluster with the highest LCOE is located in the North (Quang Ninh). Larger clusters that feature a wide spectrum of different wind resource sites (including large shares of lower wind speed sites) also generally exhibit higher LCOE values. Interestingly, a cluster with good wind resource yet in relatively longer distance from infrastructure (PCL_F3 in Ninh Thuan province) ranks among the lowest cost clusters, supporting the finding of the possibility of infrastructure costs becoming a minor factor in wind power project competitiveness. Overall, the LCOE of clusters range from just under 8 $ct/kWh to 14 $ct/kWh in LCOE Base Case, while decreasing to ca. 5-9 $ct/kWh range in the LCOE Low case.

It should be noted, however, that the clusters identified have been based exclusively on accumulation of feasible resource potential adjacent to above-average wind resource quality cells, and have been used for illustrative purposes. **The clusters hereby identified are not to be used as recommendations for wind power project site boundary selection.**

It should be noted that the LCOE values are highly dependent on the wind time series used. As discussed in Chapter 5, the wind series used in this study are subject to limitations connected to meteorological modelling as opposed to on-site measurements.

The results should also be seen in the context of the wind farm size assumed. Size-dependent infrastructure costs have been considered in the LCOE calculations, as documented in Appendix II. The wind farm size in the LCOE calculations has been based on the potential of the individual cluster. However smaller projects might have higher LCOEs, e.g. in the national cluster Bac Lieu, in the wind class 6-6.5 m/s, a 600 MW installation would have a Base Case LCOE of 10.65 $ct/kWh where a 30 MW farm would have LCOEs of 12.03 $ct/kWh (13% increase). The increase in LCOE when comparing a 30 MW farm to a 600 Mw farm is very dependent on the distance from roads and grid. On average, an increase of 20% can be expected in Base Case LCOEs when comparing wind farm size of 600 MW to 30 MW (22% in the Low Case). No size-dependence of the remaining capital costs has been included in the calculations, which might increase the LCOEs for small wind farms even further due wind farm costs that do not scale linearly with size.

6.4 Solar PV and biomass

This section briefly summarizes the national resource potential estimates for solar PV and biomass for context.

6.4.1 Solar PV resource potential

Table 22 provides an overview of the national theoretical and technical potential estimate for Vietnam elaborated by the Institute of Energy. The national technical potential has been estimated at 339 GW. It should be noted that the solar PV hereby presented is not coordinated with the land-based wind resource mapping analysis in the current study - each resource assessment assumes full land availability subject to the specific exclusion criteria applied (i.e. competing uses of land between wind and solar PV projects have not been considered).

Table 22: National solar PV resource potential (theoretical and technical) in Vietnam. Source: Institute of Energy.

Area	Theoretical potential (MWp)	Technical Potential (MWp)
Red River Delta	613,906	30,695
Northern midlands and mountainous	2,033,466	101,673
North and South-Central Coast	2,132,840	106,642
Central Highlands	808,973	40,449
South-East	397,493	19,875
Mekong River Delta	805,880	40,294
TOTAL	6,792,560	339,628

The resource potential has been estimated based on total arable land data per province for 2015 from the General Statistics Office of Vietnam, applied the following area subtraction coefficients (Table 23):

Table 23: Area exclusion criteria applied in the solar PV national resource mapping analysis. Source: Institute of Energy

Land type	Reduction share
Transport	-10%
Water surface	-15%
Slopes and mountains	-35%
Defense land	-10%
Cultural and religious land	-2%
Unsuitable land	-23%

Based on the regional solar PV technical potential estimates and annual FLH of production assumptions of 1100 for the North and 1400 for Central and South, the annual power production has been estimated at 436 TWh.

Figure 48 illustrates the national solar PV technical potential per region (the size of the yellow bubbles corresponds to the size of the regional technical potential), overlaid over national solar PV electricity output map by Solargis (available at Global Solar Atlas, ESMAP, the World Bank Group[13]).

[13] http://globalsolaratlas.info/

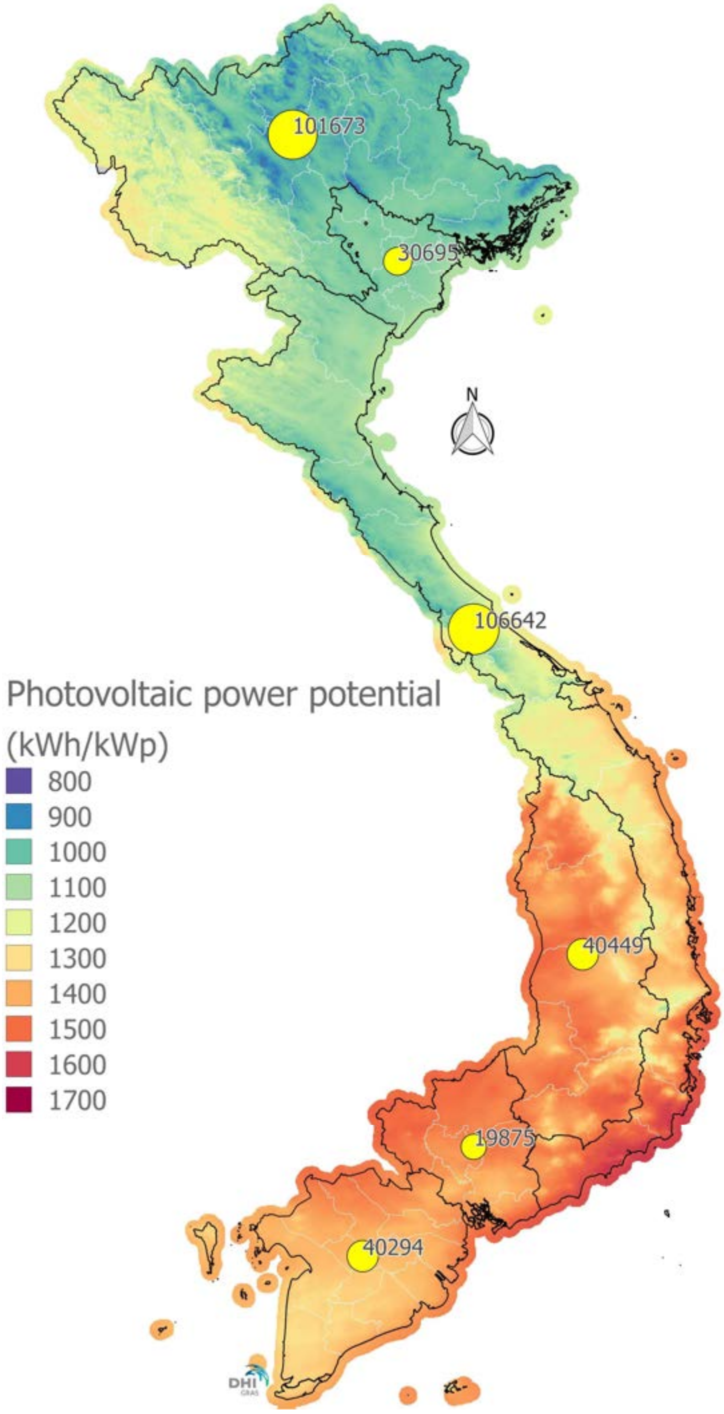

Figure 48: National technical solar PV resource potential per region (based on IoE analysis) in MW. Size of the yellow bubbles correspond to the size of the potential.
Base map: solar PV electricity output map. Source: Solargis 2017. Available at: Global Solar Atlas, ESMAP, the World Bank Group.

It should be noted that the results herein presented are not based on detailed GIS analysis, and should therefore be treated with caution. Comprehensive solar PV resource mapping in Vietnam is recommended for future analyses – and notable new analyses are currently on-going (though the results thereof have not been available at the time of writing of this report).

Earlier and on-going solar PV mapping studies include:

1) GIS and cost-benefit analysis of solar PV resource potential in Vietnam, a project initiated by the World Bank (the project has been suspended at the time of writing of the current report)
2) Earlier solar mapping study by AECID, including national technical potential estimate, available at the ESMAP website[14] (however, exclusion criteria based on land use have not been considered in the analysis)
3) GIS data on solar resource in Vietnam is available (among others, ESMAP Global Solar Atlas)

Solar PV investment cost projections

It should also be highlighted that significant additional technology cost reductions are projected for solar PV. Figure 49 provides an overview of the total system cost projections ("THE POWER TO CHANGE: solar and wind costs projection reduction to 2025" (IRENA, 2016)).

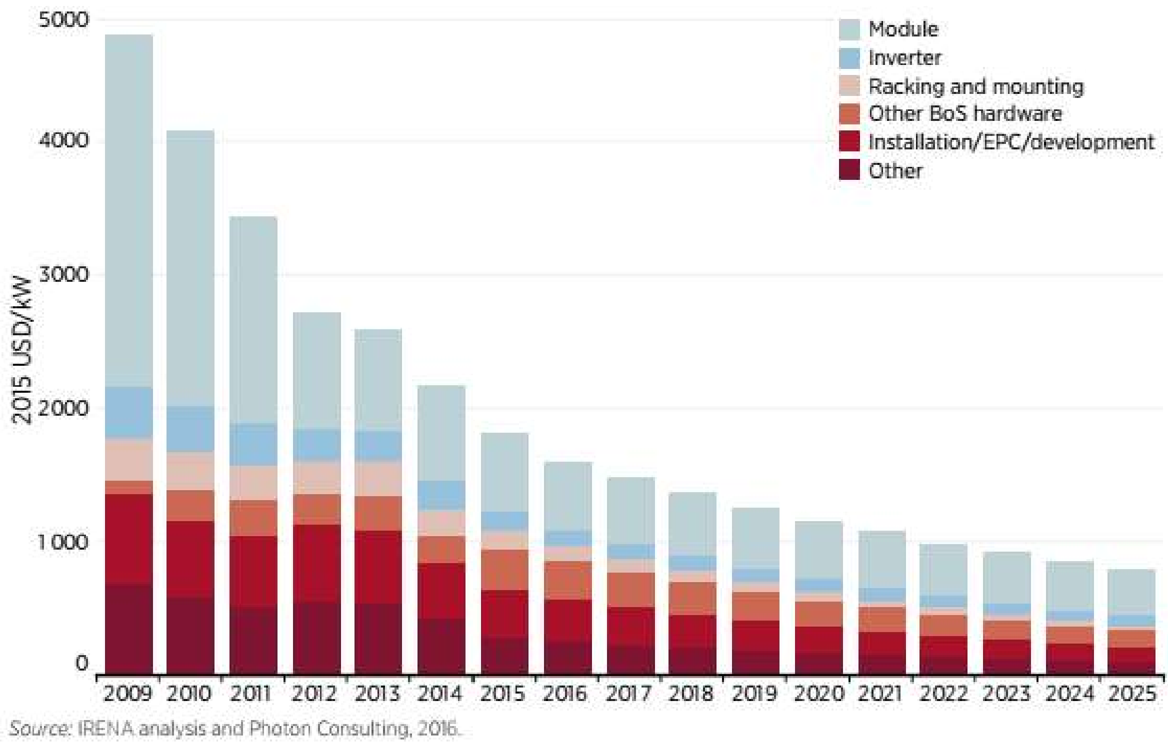

Figure 49: Learning curve projections for solar PV - Total system costs (USD2015/kW)

The considerable cost reductions projected would significantly improve the cost-competitiveness of solar PV projects. This can be deemed particularly important in Vietnam where the limited solar resource quality can be an obstacle for cost-efficient solar PV development presently.

6.4.2 Biomass resource potential

The biomass resource potential estimates for Vietnam are based on national biomass resource planning study by GIZ (GIZ, 2017). The national technical biomass capacity has been estimated at 10 GW at present, and reaching 13.6 GW towards 2030. Table 24 provides an overview of the national technical potential for 2020 and 2030 expressed in MW of capacity.

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[14] http://www.esmap.org/re_mapping_vietnam

Table 24: National technical potential for biomass in Vietnam in MW capacity for 2020 and 2030 (GIZ, 2017)

Types of biomass waste (MW)	Red River Delta	North mid-lands	N & S Central Coast	Central High-lands	South-east	Mekong River Delta	Total
			2020				
Energy wood	**256**	**981**	**1,087**	**522**	**359**	**450**	**3,654**
From Forest	104	670	674	251	90	52	**1,840**
Perennial plants	7	34	41	88	79	141	**391**
Others	145	277	372	183	189	257	**1,422**
Wood residues	**22**	**68**	**190**	**27**	**68**	**48**	**423**
Forest exploitation	7	30	45	6	4	8	**101**
Timber processing	16	41	144	21	61	39	**322**
Agricultural residues	**950**	**1,388**	**1,507**	**652**	**760**	**2,901**	**8,159**
Rice husk	170	100	170	35	32	556	**1,063**
Rice straw	584	342	584	118	109	1,906	**3,643**
Bagasse	8	88	292	76	177	233	**874**
Others	188	856	461	422	441	210	**2,579**
TOTAL	**1,228**	**2,437**	**2,784**	**1,201**	**1,187**	**3,399**	**12,236**
			2030				
Energy wood	**310**	**1,207**	**1,331**	**626**	**427**	**535**	**4,436**
From Forest	132	856	861	320	115	67	**2,351**
Perennial plants	10	43	49	97	93	170	**463**
Others	167	308	420	209	220	298	**1,622**
Wood residues	**24**	**77**	**196**	**28**	**64**	**48**	**436**
Forest exploitation	9	39	58	8	6	11	**130**
Timber processing	15	43	137	20	54	36	**306**
Agricultural residues	**993**	**1,560**	**1,631**	**742**	**860**	**2,985**	**8,772**
Rice husk	173	101	173	35	32	563	**1,077**
Rice straw	592	346	591	120	110	1,930	**3,689**
Bagasse	9	95	318	82	193	254	**952**
Others	221	1,015	550	503	523	243	**3,054**
TOTAL	**1,327**	**2,845**	**3,158**	**1,396**	**1,351**	**3,568**	**13,644**

Biomass resource technical potential per region in 2014, 2020 and 2030 in tons of biomass is presented in Appendix VIII. Figure 50 illustrated the envisioned biomass power project locations (based on data provided by GIZ) in the context of land use map of Vietnam.

Based on the national technical potential estimates and annual FLH of production assumptions of 7000 for biomass power plants, the annual power production has been estimated at 72, 86 and 96 TWh for 2014, 2020 and 2030, respectively.

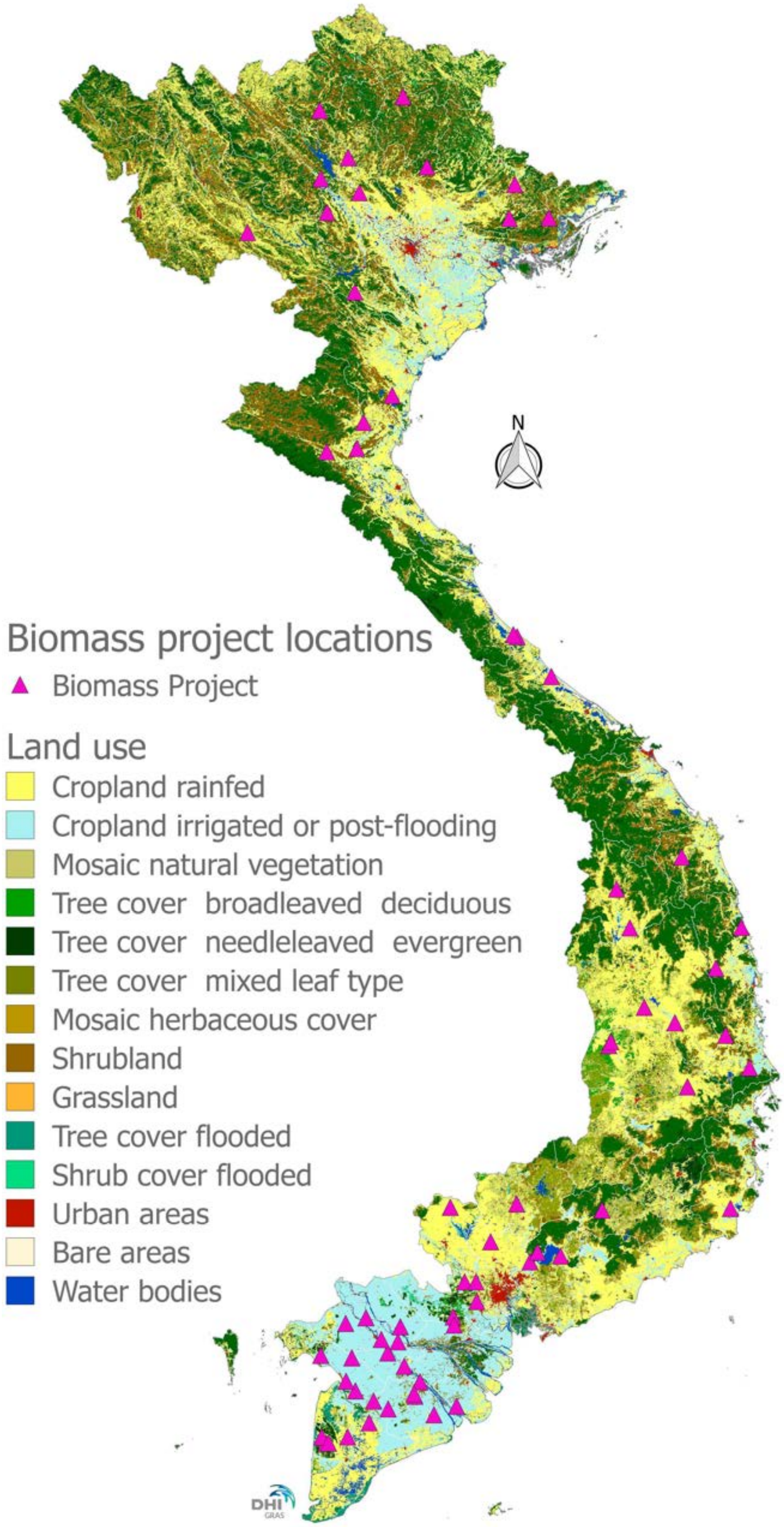


Figure 50: Envisioned biomass project locations based on data provided by GIZ. Base map: land use map of Vietnam.

Comprehensive biomass resource planning study has been completed by GIZ. The study is undergoing review by the MOIT at the time of writing this report.

Biomass plant investment costs

Table 25 presents illustrative biomass power plant investment costs estimated for Vietnam based on existing projects in Vietnam, as well as reference projects from neighboring countries (GIZ, 2017).

Table 25: Indicative biomass power plant investment cost estimated for Vietnam. Data source: (GIZ, 2017)

Biomass	Investment Cost (USD/kW)
Rice husk	1900
Woody biomass	2000
CHP Bagasse	1000
Rice straw	2200

7 Discussion and conclusion

The land-based wind resource GIS mapping analysis suggests that Vietnam is endowed with significant wind power potential. Starting from the entire Vietnamese area, several exclusion criteria were used to arrive at an estimate for the national technical potential (NTP). The GIS analysis steps highlight the relative share of importance of the different criteria towards the NTP. Almost a quarter of the total land area in Vietnam has been excluded based on mean annual wind speed threshold criterion, i.e. areas with mean annual wind speed not reaching 4.5m/s at 100m height. Further significant land exclusion criteria (i.e. resulting in large land exclusion areas) have been based on populated areas / population density, protected areas, forests, as well as areas characterized by high terrain steepness.

Based on these exclusion criteria and assuming a 3MW/ km^2 turbine footprint, The National Technical Potential (NTP) has been estimated at 214 GW. This is equivalent to nearly 437 TWh of annual wind power production (with a 200 W/m^2 wind turbine technology at 100m hub height). The largest share of this potential is in the Central region of Vietnam, exceeding 125 GW, followed by the South region at 60 GW. North is characterized by the lowest wind resource potential with technical potential at 29 GW.

The vast majority of the Vietnamese NTP is consists of areas with relatively low wind resource quality (mean annual wind speed of 4.5 – 6m/s at 100m height). However, ca 25% of the national NTP (52 GW) is located in areas with mean annual wind speed of 6m/s and higher. When only considering the higher quality wind resource, Central region still has the largest share with 37 GW where the South region has 14 GW. Only 1.2 GW of the higher quality wind resource is located in the North.

NTP scenarios

The alternative scenarios based on infrastructure proximity and availability of agricultural land provide further insights. It should though be noted that only existing infrastructure of transmission grid and roads has been included in the analysis (i.e. no envisioned development of the infrastructure network has been considered due to data availability). Hence, the infrastructure proximity of the wind resource areas could improve over time as infrastructure development continues.

- **Within 20km distance:** Over two thirds of the NTP (or 143 GW) are identified in the regions within 20 km distance, both from the closest 220kV transmission infrastructure point, and the closest major road
- **Within 10km distance**: Approximately one third (77GW) of the NTP is identified in the regions within 10 km distance, both from the closest 220kV transmission infrastructure point, and the closest major road. The analysis also suggests that clusters with high wind potential generally lie within relative proximity to infrastructure (i.e. within 0-10 and 10-20 km distance to closest transmission grid and / or road considered).
- **Within 20 km distance, no agricultural land**: An NTP of 54 GW is identified in the regions within 20 km distance, both from the closest 220kV transmission infrastructure point, and the closest major road, but excluding agricultural land.
- **Within 10 km distance, no agricultural land**: An NTP of 27 GW is identified in the regions within 10 km distance, both from the closest 220kV transmission infrastructure point, and the closest major road, but excluding agricultural land.

A significant share of the NTP lies on agricultural land (croplands), comprising 40 340 km^2 of the total NTP area. This corresponds to 126 GW of the NTP, and includes a high share of high wind resource potential of 6m/s and higher mean annual wind speed, especially in South (13.1 GW out of 13.6 GW in the NTP) and Central (24 GW out of 37 GW in the NTP). More than 80% of all NTP in the South is located on agricultural land (and over 95% of all high wind resource areas). The Central region still exhibits the highest resource potential (both in terms of capacity level and wind resource quality), but North exceeds South in terms of total resource potential (as well as in potential for high wind resource) in the cropland exclusion scenario. The availability of agricultural land for wind power project development is therefore a critical factor for wind power deployment in Vietnam.

Wind power and farming

Siting wind power projects on agricultural lands is a common practice internationally. The wind turbines are reported to have minor impact on farming and ranching activities – the turbines have a small footprint and "crops can be grown and livestock can be grazed right up to the base of the turbine" (NREL, 2003). At the same time, income from wind power projects can provide significant additional revenue stream to farmers and rural landowners. E.g. the annual revenue from wind farms to farming families and other rural landowners in the US has been estimated at USD 222 million (AWEA, 2016). BNEF analysis suggests that by 2030 rural landowners in the US are projected to earn up to USD 900 million in land lease revenues alone from wind power projects. In addition, diversification of revenue streams helps safeguard the farmers from highly volatile agricultural crop yields and commodity prices. This is accompanied by significant local tax revenue, e.g. property taxes that benefit the local communities (Bloomberg, 2016).

Figure 51: Wind turbines in rice paddy field, Japan. Illustration source: http://footage.framepool.com/en/shot/208589300-paddy-field-rice-electricity-generation-wind-turbine

Provincial wind resource mapping

The more detailed wind resource mapping analysis carried out for the selected six provinces (Binh Thuan, Ninh Thuan, Khanh Hoa, Phu Yen, Binh Dinh and Quang Ngai) suggests significant wind resource potential. The total technical potential across the six provinces exceeds 12 GW, with Binh Thuan, Phu Yen and Binh Dinh demonstrating the highest contributions (4.8 GW, 2 GW and 1.8 GW, respectively). Binh Thuan and Ninh Thuan stand out in particular in relation to prevalence of high wind resource quality potential – technical potential of areas with mean annual wind speeds of 6 m/s or higher exceed 2.8 GW and 1.3 GW, respectively.

The GIS analysis steps highlight the relative share of importance of the different exclusion criteria towards the provincial technical potential. Only ca 5% of the total land area in the selected provinces has been excluded based on mean annual wind speed threshold criterion, i.e. areas with mean annual wind speed at 100m height not reaching 4.5m/s (in the NTP the share reached 25%). Similar to the NTP, further significant land exclusion criteria (i.e. resulting in large land exclusion areas) have been based on populated areas / population density, protected areas, forests, as well as areas characterized by high terrain steepness. Another criterion (specific to the provincial analysis) resulting in major additional land exclusion area has been residential and public lands.

The analysis also suggests that, akin to the findings of the NTP analysis, clusters with high wind potential in the selected provinces generally lie within relative proximity to infrastructure (i.e. within 0-10 and 10-20 km distance to closest transmission grid and / or road considered). Overall, the infrastructure proximity for the selected clusters can be assessed as non-prohibitive. For context, the threshold for grid connection proximity used in IRENA analysis in relation to wind power projects in Latin America has been set at 75 km (IRENA, 2016).

LCOE analysis

The LCOE analysis explored 'clusters', i.e. areas characterised by significant proportion of adjacent above-average wind resource cells, both nationally, and within the six selected provinces. The clusters identified have been based exclusively on accumulation of feasible resource potential adjacent to above-average wind resource quality cells, and have been used for illustrative purposes. The clusters hereby identified are not to be used as recommendations for wind power project site boundary selection.

It should be noted that the LCOE values are highly dependent on the wind time series used. As discussed in Chapter 5, the wind series used in this study are subject to limitations connected to meteorological modelling as opposed to on-site measurements.

The results should also be seen in the context of the wind farm size assumed. Size-dependent infrastructure costs have been considered in the LCOE calculations, as documented in Appendix II. The wind farm size in the LCOE calculations has been based on the potential of the individual cluster. However smaller projects might have higher LCOEs, e.g. in the national cluster Bac Lieu, in the wind class 6-6.5 m/s, a 600 MW installation would have a Base Case LCOE of 10.65 $ct/kWh where a 30 MW farm would have LCOEs of 12.03 $ct/kWh (13% increase). The increase in LCOE when comparing a 30 MW farm to a 600 Mw farm is very dependent on the distance from roads and grid. On average, an increase of 20% can be expected in Base Case LCOEs when comparing wind farm size of 600 MW to 30 MW (22% in the Low Case). No size-dependence of the remaining capital costs has been included in the calculations, which might increase the LCOEs for small wind farms even further due to wind farm costs that do not scale linearly with size.

Two LCOE cases were developed: LCOE Base Case and LCOE Low. LCOE Base Case is based on assumptions deemed to be representative of the situation in Vietnam currently. LCOE Low, in turn, can be interpreted as the assumptions projected to be representative of the near- to mid-term future as the wind power industry in Vietnam would mature, economies of scale would develop, and the cost levels would increasingly converge with the international averages.

Of course, it should be noted that the LCOE Base Case analysis is only indicative of overall project costs, and does not reflect the specific conditions of the individual project. Similarly, LCOE Low case illustrates one potential technology and cost development projection, and is subject to high degree of uncertainty. The LCOE levels have been estimated assuming infrastructure cost sharing across the entire cluster, please see Allocation of infrastructure costs in the LCOE calculation section for a description of the approach used.

- **LCOE Base Case**: Overall, the LCOE of clusters range from just under 8 $ct/kWh to 14 $ct/kWh in the LCOE Base Case. However, most of the clusters are within the 9.5-12.5 $ct/kWh range.
    - **Good locations (6 - 7.5m/s):** The LCOE Base Case analysis suggests good locations could be developed in an LCOE range of ca 8 – 11 $ct/kWh
    - **Best locations (+ 7.5m/s):** In addition, limited 'best' locations could be developed down to under 7 $ct/kWh
    - **Worst locations (4.5 - 5m/s):** The LCOE increases progressively along with decreasing wind resource quality, the 4.5-5 m/s mean annual wind speed locations reaching ca. 20 $ct/kWh.
- **LCOE Low Case:** The LCOE Low case analysis suggests that more favourable project development and technology conditions could yield significant LCOE reductions (e.g. in the medium term), and the absolute reductions are most prominent for lower wind resource locations – both nationally, and within the selected provinces. Overall, the LCOE of clusters range from just 5 $ct/kWh to 9 $ct/kWh in the in the LCOE Low Case. However, most of the clusters are within the 6-8 $ct/kWh range.
    - **Good locations (6 - 7.5m/s):** The LCOE Low Case analysis suggests good locations could be developed in an LCOE range of 5.2 – 6.9 $ct/kWh.
    - **Best locations (+ 7.5m/s):** Limited 'best' locations could be developed in the range of 4.2 – 4.7 $ct/kWh.
    - **Worst locations (4.5 - 5m/s):** Locations with 4.5-5 m/s mean annual wind speed yield an average of ca. 13 $ct/kWh, which is a significant reduction from the 20 $ct/kWh in the LCOE Base Case.

The compound LCOE values per cluster (the capacity-weighted LCOE values per wind speed ranges of each cluster) indicate that the clusters' lowest overall LCOE are located in the provinces with the best wind resource (Central and South regions), whilst the cluster with the highest LCOE is located in the North (Quang Ninh). Larger clusters that feature a wide spectrum of different wind resource sites (including large shares of lower wind speed sites) also generally exhibit higher LCOE values. Interestingly, a cluster with good wind resource yet in relatively longer distance from infrastructure (PCL_F3 in Ninh Thuan province) ranks among the lowest cost clusters, supporting the finding of the possibility of infrastructure costs becoming a minor factor in wind power project competitiveness.

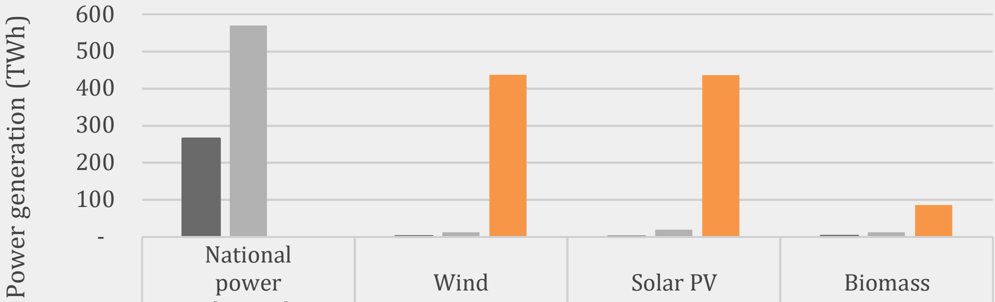
The results of the cluster analysis also indicate that the impact of the infrastructure on-costs is minimal, at least on the entire cluster level (it should be noted that some of the national clusters are very considerable in capacity size). The highest CapEx on-costs related to additional infrastructure development (yet not exceeding 4%) have been estimated for the relatively smaller clusters both nationally and within the selected provinces (size range of 50-70 MW). The results (based on the given sample of clusters) also indicate that the size of the cluster exhibits higher impact on the infrastructure costs than the infrastructure proximity per se. Furthermore, the LCOE analysis highlights the importance of wind resource quality (and the corresponding full-load hours of production) as a critical determinant of cost competitiveness of a wind power project.

Implications for RE development planning

Alongside solar PV (national technical potential estimated at 339 GW) and biomass for power production (current national technical potential estimated at 10 GW; increasing to over 13 GW towards 2030), wind presents a very significant potential (NTP estimated at 214 GW) for RE development in Vietnam.

NTP in the context of projections of PDP 7 revised

The estimated NTP for wind, solar PV and biomass (and the associated total potential annual power generation estimates) vastly exceed the RE development targets set out by PDP 7 revised, as illustrated by Figure 52. By 2030, PDP 7 revised envisions 6 GW of wind and 12 GW of solar PV in the Vietnamese power system, corresponding to 2.1 and 3.3 % (and 2.1% for biomass) of the total national power production, respectively. The analysis suggests that the abundance of technically feasible RE potential could allow for significantly higher shares of RES generation in the Vietnamese power system in the future.



	National power demand	Wind	Solar PV	Biomass
Sum of PDP 7 rev. 2020	265	2	1	3
Sum of PDP 7 rev. 2030	570	12	19	12
Sum of NTP 2020		437	436	86

Figure 52: National Technical Potential (NTP) power generation estimates for wind, solar PV and biomass compared to the national power demand projections in PDP 7 revised for 2020 and 2030, respectively. (Please see Appendix X for full comparison.) Unit: power generation / demand in TWh.

Whilst the overall wind resource quality in Vietnam is relatively low, large potential also for wind resource areas exceeding 6 m/s of mean annual wind speed have been identified nationally, reaching 52 GW. Based on the LCOE Base Case assumptions representative of the current situation in Vietnam, these areas could be developed at a cost range of 6-10 $ct/kWh. Provided increasing maturation of the wind power industry in Vietnam and further improvements and cost reductions in wind power technology globally, the LCOE for areas with lower wind resource quality in the medium term could decrease to a cost range of 8-13 $ct/kWh, making them more cost competitive. Prerequisites for a mature market development have been listed in the paragraph below.

The infrastructure cost parameter analysis, as well as the LCOE perspective on wind energy resource 'clusters' has highlighted that the on-cost borne by additional infrastructure development (transmission grid and road) can be negligible, provided that the cost is shared across the entire cluster. In power system and RE deployment planning perspective, this could suggest that it would be socio-economically advantageous to coordinate infrastructure development in the long-term, taking into account prospective wind power project development areas.

Considerable cost reductions are projected also for solar PV technology. This development would significantly improve the cost-competitiveness of solar PV projects. This can be deemed particularly important in Vietnam where the limited solar resource quality can be an obstacle for cost-efficient solar PV development presently. IRENA estimates dramatic cost reduction in system costs of 57% between 2015-2025 (1.8 USD15/W to 0.8 USD/W in 2015 and 2025 respectively), for the LCOE of utility scale PV this would mean a reduction from 0.13 USD/kWh to 0.055 USD/kWh or a 59% drop ("THE POWER TO CHANGE: solar and wind costs projection reduction to 2025" (IRENA, 2016)).

Wind power project siting on agricultural land is common practice internationally. The operation of wind power projects does not impede farming activities, whilst providing additional income opportunities to the local land-owners and residents (e.g. through job creation). Obstacles (e.g. procedural or regulatory) to wind power project development on agricultural land could therefore pose a significant challenge for large scale and cost-efficient wind power deployment in Vietnam, given the very significant (and superior) wind resource potential located on agricultural land.

Prerequisites for successful RE development

Significant RE resource potential does not guarantee successful RE project development per se. A number of important preconditions are required in order to enable and encourage the development of a viable RE industry (based on "Up-Scaling of Wind Power in Viet Nam - Capacity Needs Assessment for Wind Power" (GIZ, 2016) and "LCOE of current wind projects in Viet Nam and recommendations for an improved support mechanism" (GIZ, 2017)):

- Adequate legal and regulatory framework;
    - Streamlined procedures to mitigate lengthy permitting process;
- Adequate support level for RE development:
    - More support needed in nascent markets, to compensate the high risk and enable service and human capital development;
    - Support can be gradually reduced once the market matures;
- Opportunities for RE-focused education;
- RE-focused engineering disciplines at universities and vocational education and training possibilities to be encouraged.

8 Recommendations for future analyses

Further refinement of the solar PV resource potential mapping in Vietnam is expected. Comprehensive GIS study has been initiated by the World Bank, but was suspended at the time of writing of this report. In addition, solar resource planning initiatives are envisioned by the GIZ.

Long-term power system development and RE integration study towards 2050 using the Balmorel model has been completed, and at the time of writing of this report, is undergoing review by the MOIT. The study analyzes integration of renewables and dispatch from a power system balance perspective, and is expected to be launched in 2017. The study using the Balmorel model is an initiative within the Danish-Vietnamese cooperation (DEA/MOIT), supported by the current study.

National biomass resource potential planning towards 2030, a study by GIZ, has been completed, and at the time of writing of this report, is undergoing review by the MOIT.

References

Agora Energiewende. (2014). *Calculator of Levelized Cost of Electricity for Power Generation Technologies.* Agora Energiewende.

AWEA. (2016, March 22). *American Wind Energy Association*. Retrieved from Wind power pays $222 million a year to rural landowners: http://www.awea.org/MediaCenter/pressrelease.aspx?ItemNumber=8609

Bloomberg. (2016, October 6). *Bloomberg Businessweek*. Retrieved from Wind Is the New Corn for Struggling Farmers: https://www.bloomberg.com/news/articles/2016-10-06/wind-is-the-new-corn-for-struggling-farmers

Dalla Riva, A. (2016). *System Value of Wind Power - An Analysis of the Effects of Wind Turbine Design (Economic dispatch modelling of medium-term system implications of advanced wind power technologies).* Copenhagen: DTU.

GIZ. (2016). *Up-Scaling of Wind Power in Viet Nam - Capacity Needs Assessment for Wind Power.* HaNoi: GIZ.

GIZ. (2017). *Draft National Biomass Energy Planning Period until 2020, with a Vision to 2030.* Hanoi: GIZ.

GIZ. (2017). *LCOE of current wind projects in Viet Nam and recommendations for an improved support mechanism.* HaNoi: GIZ.

HGC Engineering. (2007). *Wind Turbines and Sound: Review and Best Practice Guidelines.* Howe Gastmeier Chapnik Limited.

Hungerford, L., Luna, J., & Sennott, T. (n.d.). *Wind Farm Locational Analysis.* Portland State University.

IEA. (2016). *Next Generation Wind and Solar Power - from Cost to Value.* Paris: OECD / IEA.

IEA. (2016). *World Energy Outlook 2016.* Paris: OECD/IEA.

IEA Wind Task 26. (2016). *Wiser, R., Jenni, K., Seel, J., Hand, M., Lantz, E., Smith, A. Forecasting Wind Energy Costs & Cost Drivers - The Views of the World's Leading Experts.* IEA Wind Task 26.

IRENA. (2016). *INVESTMENT OPPORTUNITIES IN LATIN AMERICA - SUITABILITY MAPS FOR GRID-CONNECTED AND OFF-GRID SOLAR AND WIND PROJECTS.* Abu Dhabi: IRENA. Retrieved from http://www.irena.org/DocumentDownloads/Publications/IRENA_Atlas_investment_Latin_America_2016.pdf

IRENA. (2016). *THE POWER TO CHANGE: solar and wind costs projection reduction to 2025.*

NREL. (2003). *Wind Energy for Rural Economic Development.* US Department of Energy.

NREL. (2009). *Land-Use Requirements of Modern Wind Power Plants in the United States.* Golden: NREL. Retrieved from http://www.nrel.gov/docs/fy09osti/45834.pdf

NREL. (2012). *U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis.* Golden: NREL. Retrieved from http://www.nrel.gov/docs/fy12osti/51946.pdf

Rodman, L. C., & Meentemeyer, R. K. (2006). A geographic analysis of wind turbine placement in Northern California. *Energy Policy*, 2137-2149.

Stenz, T., Malaney, J., Gillman, W., & Crill, C. (2010). *A GIS-Driven Approach to Siting a Prospective Wind Farm in South Central Wisconsin.* University of Wisconsin–Madison.

Yang, Z. (2013). *Using GIS to Determine Wind Energy Potential in Minnesota, USA.* Winona: Saint Mary's University of Minnesota University Central Services Press.

Appendix I

Data requirements for power system modelling using the Balmorel model

The Balmorel model has two main tasks:

- Find optimal dispatch in an existing electricity system, e.g. the current Vietnamese system. Based on description of all individual power plants the model finds the hourly generation per plant that corresponds to the minimum total costs.
- Optimal investment in new generation and transmission. As with optimal dispatch the model find the solution that gives the minimum total costs for a specific year.

Generation from wind turbines are very specific to the location. It can therefore be relevant to describe a number of sites for location of potential wind farms. A wind area can be defined as an area with:

- Similar wind resource (where the same hourly wind profile can be used)
- Where the investment and connection costs are of similar size, i.e. same distance to the electricity transmission grid, same distance to good quality roads (for large and heavy transport).

The model can be exposed to restriction, e.g. about the share of renewable energy of about maximum CO2 emission. The model will then find the path with minimum total costs to fulfil these restrictions.

When investing in wind and solar three main parameters are in play:

- The local wind and solar resource
- The investment costs (where connection and transport cost are specific to the individual site)
- The value of electricity. Each transmission region has an individual electricity price for each hour.
    - The price (or the value of electricity) is the marginal cost for the hour for that location. If e.g. a wind turbine supply an extra MWh, some other power plant will reduce the generation. The reduction will per definition take place on the most expensive power plant.
    - If significant wind capacity exists in a region, the marginal value of more wind-based generation tends to be low (because the most expensive generation has already been removed)
- The extra investment in transmission capacity.
    - Regions with a lot of wind and solar capacity will typically also need extra transmission capacity.

With full foresight (one of the major assumption in the model) there is only one solution. This solution will distribute the new renewable energy between solar and wind, and will distribute in on areas based on the above aspects. All wind will not be located at the best wind resource – because the value of electricity is better in other regions, or because the integration costs are lower.

Using the results of the GIS analysis, relevant wind and solar resource potential areas will be identified, e.g. defined as the best resource areas available for wind, with similar wind profiles (e.g. +/- 5% of full load hours) and with similar connection and transport costs. The procedure to find the areas could start with a target number of areas, e.g. 20 areas (with at least five in each of the three transmission regions). Then the best similar areas can be found.

Appendix II

Infrastructure cost variation depending on project size and infrastructure proximity

Table 26: Overview of infrastructure cost variation depending on project size and infrastructure proximity

Project size (MW)	Distance to road (km)	Distance to grid (km)	Plant CapEx (excl. Infrastructure)	CapEx roads	CapEx grid connection	CapEx TOTAL	Road on-cost (on plant CapEx)	Grid on-cost (on plant CapEx)	Combined infrastructure on-cost (on plant CapEx)
10	10	10	18,700,000	1,700,000	2,150,000	22,550,000	9%	11%	21%
30	10	10	56,100,000	1,700,000	2,150,000	59,950,000	3%	4%	7%
100	10	10	187,000,000	3,700,000	2,600,000	193,300,000	2%	1%	3%
300	10	10	561,000,000	3,900,000	10,600,000	575,500,000	1%	2%	3%
400	10	10	748,000,000	3,900,000	11,850,000	763,750,000	1%	2%	2%
600	10	10	1,122,000,000	3,900,000	13,100,000	1,139,000,000	0%	1%	2%
10	20	20	18,700,000	3,400,000	2,600,000	24,700,000	18%	14%	32%
30	20	20	56,100,000	3,400,000	2,600,000	62,100,000	6%	5%	11%
100	20	20	187,000,000	7,400,000	3,100,000	197,500,000	4%	2%	6%
300	20	20	561,000,000	7,800,000	14,200,000	583,000,000	1%	3%	4%
400	20	20	748,000,000	7,800,000	15,700,000	771,500,000	1%	2%	3%
600	20	20	1,122,000,000	7,800,000	17,200,000	1,147,000,000	1%	2%	2%
10	30	30	18,700,000	5,100,000	3,050,000	26,850,000	27%	16%	44%
30	30	30	56,100,000	5,100,000	3,050,000	64,250,000	9%	5%	15%
100	30	30	187,000,000	11,100,000	3,600,000	201,700,000	6%	2%	8%
300	30	30	561,000,000	11,700,000	17,800,000	590,500,000	2%	3%	5%
400	30	30	748,000,000	11,700,000	19,550,000	779,250,000	2%	3%	4%

600	30	30	1,122,000,000	11,700,000	21,300,000	1,155,000,000	1%	2%	3%
10	40	40	18,700,000	6,800,000	3,500,000	29,000,000	36%	19%	55%
30	40	40	56,100,000	6,800,000	3,500,000	66,400,000	12%	6%	18%
100	40	40	187,000,000	14,800,000	4,100,000	205,900,000	8%	2%	10%
300	40	40	561,000,000	15,600,000	21,400,000	598,000,000	3%	4%	7%
400	40	40	748,000,000	15,600,000	23,400,000	787,000,000	2%	3%	5%
600	40	40	1,122,000,000	15,600,000	25,400,000	1,163,000,000	1%	2%	4%

Appendix III

Technical potential land area per national cluster across wind speed ranges

Table 27: Technical potential wind power land area per national cluster across wind speed ranges expressed in km²

Cluster ID	Province	4.5-5 m/s	5-5.5 m/s	5.5-6 m/s	6-6.5 m/s	6.5-7 m/s	7-7.5 m/s	7.5-8 m/s	8+ m/s	Total
CL9	Bac Lieu		160	296	571	54	16			**1,097**
CL10	Ben Tre				17	149	44			**211**
CL5	Dak Lak	6	121	933	539	47	14	5	1	**1,667**
CL6	Dak Lak	5	226	1,546	569	11				**2,356**
CL5	Gia Lai	112	838	2,359	2,190	252	53	10		**5,814**
CL7	Gia Lai	34	212	407	288	74	14			**1,029**
CL2	Ha Tinh		2	39	184	27	4			**256**
CL9	Hau Giang			516	244					**760**
CL4	Kon Tum	37	229	448	236	35	9	5	1	**1,000**
CL8	Lam Dong	129	575	571	620	258	39	4	6	**2,203**
CL3	Quang Binh			45	106	40				**192**
CL1	Quang Ninh	76	155	185	92	45	4			**556**
CL3	Quang Tri			111	177	12				**299**
CL9	Soc Trang			34	1,592	251	41			**1,918**
CL3	Thua Thien - Hue				19					**19**
CL10	Tien Giang					21	2			**23**
CL9	Tra Vinh				407	424	96	15		**941**
TOTAL		**399**	**2,518**	**7,490**	**7,851**	**1,700**	**336**	**39**	**8**	**20,341**

Technical potential capacity per national cluster across wind speed ranges

Table 28: Technical potential wind power capacity per national cluster across wind speed ranges expressed in MW

Cluster ID	Province	4.5-5 m/s	5-5.5 m/s	5.5-6 m/s	6-6.5 m/s	6.5-7 m/s	7-7.5 m/s	7.5-8 m/s	8+ m/s	Total
CL9	Bac Lieu	-	481	887	1,714	161	49	-	-	**3,292**
CL10	Ben Tre	-	-	-	51	448	133	-	-	**632**
CL5	Dak Lak	18	362	2,800	1,617	142	43	15	4	**5,001**
CL6	Dak Lak	14	679	4,638	1,706	32	-	-	-	**7,069**
CL5	Gia Lai	337	2,514	7,078	6,569	757	159	29	-	**17,442**
CL7	Gia Lai	101	636	1,220	865	221	43	-	-	**3,086**
CL2	Ha Tinh	-	7	116	552	81	11	-	-	**767**
CL9	Hau Giang	-	-	1,548	733	-	-	-	-	**2,281**
CL4	Kon Tum	112	687	1,344	707	105	28	14	4	**3,001**
CL8	Lam Dong	388	1,725	1,714	1,859	775	116	13	18	**6,608**
CL3	Quang Binh	-	-	136	319	119	-	-	-	**575**
CL1	Quang Ninh	228	464	554	276	135	11	-	-	**1,668**
CL3	Quang Tri	-	-	333	530	35	-	-	-	**898**
CL9	Soc Trang	-	-	102	4,776	752	124	-	-	**5,754**
CL3	Thua Thien - Hue	-	-	-	58	-	-	-	-	**58**
CL10	Tien Giang	-	-	-	-	62	7	-	-	**68**
CL9	Tra Vinh	-	-	-	1,222	1,271	287	44	-	**2,823**
TOTAL		**1,198**	**7,555**	**22,470**	**23,554**	**5,096**	**1,011**	**115**	**26**	**61,023**

Appendix IV

Technical potential land area per provincial cluster across wind speed ranges

Table 29: Technical potential wind power land area per national cluster across wind speed ranges expressed in km²

Cluster ID	Province	4.5-5 m/s	5-5.5 m/s	5.5-6 m/s	6-6.5 m/s	6.5-7 m/s	7-7.5 m/s	7.5-8 m/s	8+ m/s	Total
PCL1	Binh Thuan					5	200	123	11	**339**
PCL2	Ninh Thuan	1	7	22	81	75	51	28	20	**285**
PCL3	Khanh Hoa	3	3	9	11	15	6	5	4	**56**
PCL4	Khanh Hoa	1	2	4	2	4	1	3	1	**18**
PCL5	Phu Yen	3	22	49	21	7	3			**105**
PCL6	Binh Dinh		1	19	5	2				**27**
PCL7	Quang Ngai	2	3	8	11	1				**25**
PCL_F1	Binh Dinh	6	29	38	33	19	11	1	1	**138**
PCL_F2	Phu Yen	14	37	48	56	32	17	13	3	**220**
PCL_F3	Ninh Thuan	0	0	0	6	5	10	4	15	**40**
TOTAL		30	104	197	226	165	299	177	55	**1253**

Technical potential capacity per provincial cluster across wind speed ranges

Table 30: Technical potential wind power capacity per national cluster across wind speed ranges expressed in MW

Cluster ID	Province	4.5-5 m/s	5-5.5 m/s	5.5-6 m/s	6-6.5 m/s	6.5-7 m/s	7-7.5 m/s	7.5-8 m/s	8+ m/s	Total
PCL1	Binh Thuan	-	-	-	-	15	600	369	33	**1,017**
PCL2	Ninh Thuan	3	21	66	243	225	153	84	60	**855**
PCL3	Khanh Hoa	9	9	27	33	45	18	15	12	**168**
PCL4	Khanh Hoa	3	6	12	6	12	3	9	3	**54**
PCL5	Phu Yen	9	66	147	63	21	9	-	-	**315**
PCL6	Binh Dinh	-	3	57	15	6	-	-	-	**81**
PCL7	Quang Ngai	6	9	24	33	3	-	-	-	**75**
PCL_F1	Binh Dinh	18	87	114	99	57	33	3	3	**414**
PCL_F2	Phu Yen	42	111	144	168	96	51	39	9	**660**
PCL_F3	Ninh Thuan	-	-	-	18	15	30	12	45	**120**
TOTAL		90	312	591	678	495	897	531	165	**3759**

Appendix V

LCOE Base Case calculation for the national clusters

Table 31: LCOE Base Case calculation for the national clusters (USD cents / kWh).
Plant CapEx = 1870 USD/kW; WAC C= 10.8%; O&M costs = 50 USD/kW/year; Plant lifetime = 20 years.
** Based on centroid of core cluster with high wind speeds.*

Cluster ID	Province	LCOE 4,5-5 m/s areas	LCOE 5-5,5 m/s areas	LCOE 5,5-6 m/s areas	LCOE 6-6,5 m/s areas	LCOE 6,5-7 m/s areas	LCOE 7-7,5 m/s areas	LCOE 7,5-8 m/s areas	LCOE 8 m/s and higher areas	Total cluster capacity (MW)	Distance to closest road* (km)	Distance to closest 220kV grid* (km)	Infrastr. on-cost (USD)	CapEx Total (USD)	Infrastr. cost - size range (MW)	Infrastr. cost - size range multiple	Infrastr. on-cost on CapEx (%)
	FLH	***1,399***	***1,822***	***2,245***	***2,667***	***3,090***	***3,513***	***3,936***	***4,359***								
CL9	Bac Lieu	20.3	15.6	12.7	10.6	9.2	8.1	7.2	6.5	3,292	4	3	58,887,500	1,888	600	5	1.0%
CL10	Ben Tre	20.5	15.8	12.8	10.8	9.3	8.2	7.3	6.6	632	6	39	27,054,800	1,913	600	1	2.3%
CL5	Dak Lak	20.3	15.6	12.7	10.7	9.2	8.1	7.2	6.5	5,001	2	5	96,088,000	1,889	600	8	1.0%
CL6	Dak Lak	20.6	15.9	12.9	10.8	9.3	8.2	7.3	6.6	7,069	13	48	401,569,200	1,927	600	12	3.0%
CL5	Gia Lai	20.3	15.6	12.7	10.7	9.2	8.1	7.2	6.5	17,442	3	4	336,115,800	1,889	600	29	1.0%
CL7	Gia Lai	20.5	15.7	12.8	10.7	9.3	8.2	7.3	6.6	3,086	3	33	119,784,500	1,909	600	5	2.1%
CL2	Ha Tinh	20.3	15.6	12.7	10.7	9.2	8.1	7.2	6.5	767	7	11	16,213,000	1,891	600	1	1.1%
CL9	Hau Giang	20.4	15.7	12.7	10.7	9.2	8.1	7.3	6.5	2,281	2	17	68,182,400	1,900	600	4	1.6%
CL4	Kon Tum	20.3	15.6	12.7	10.7	9.2	8.1	7.2	6.5	3,001	1	4	56,388,500	1,889	600	5	1.0%
CL8	Lam Dong	20.3	15.6	12.7	10.7	9.2	8.1	7.2	6.5	6,608	5	1	128,962,900	1,890	600	11	1.0%
CL3	Quang Binh	20.4	15.6	12.7	10.7	9.2	8.1	7.2	6.5	575	1	12	14,517,400	1,895	600	1	1.4%
CL1	Quang Ninh	20.4	15.6	12.7	10.7	9.2	8.1	7.2	6.5	1,668	6	7	42,253,500	1,895	600	3	1.4%
CL3	Quang Tri	20.3	15.6	12.6	10.6	9.2	8.1	7.2	6.5	898	0	14	14,806,800	1,886	600	1	0.9%
CL9	Soc Trang	20.3	15.6	12.7	10.7	9.2	8.1	7.2	6.5	5,754	3	3	114,654,000	1,890	600	10	1.1%
CL3	Thua Thien	20.6	15.8	12.8	10.8	9.3	8.2	7.3	6.6	58	0	16	3,047,800	1,923	100	1	2.8%
CL10	Tien Giang	20.7	15.9	12.9	10.8	9.4	8.2	7.4	6.6	68	-	41	4,167,000	1,931	100	1	3.3%
CL9	Tra Vinh	20.3	15.6	12.7	10.7	9.2	8.1	7.2	6.5	2,823	1	3	53,367,500	1,889	600	5	1.0%

LCOE Low case calculation for the national clusters

Table 32: LCOE Base Case calculation for the national clusters (USD cents / kWh).
Plant CapEx = 1500 USD/kW; WACC = 7%; O&M costs = 45 USD/kW/year; Plant lifetime = 22 years.
** Based on centroid of core cluster with high wind speeds.*

Cluster ID	Province	LCOE 4,5-5 m/s areas	LCOE 5-5,5 m/s areas	LCOE 5,5-6 m/s areas	LCOE 6-6,5 m/s areas	LCOE 6,5-7 m/s areas	LCOE 7-7,5 m/s areas	LCOE 7,5-8 m/s areas	LCOE 8 m/s and higher areas	Total cluster capacity (MW)	Distance to closest road* (km)	Distance to closest 220kV grid* (km)	Infrastr. on-cost (USD)	CapEx Total (USD)	Infrastr. cost - size range (MW)	Infrastr. cost - size range multiple	Infrastr. on-cost on CapEx (%)
	FLH	***1,399***	***1,822***	***2,245***	***2,667***	***3,090***	***3,513***	***3,936***	***4,359***								
CL9	Bac Lieu	13.0	10.0	8.1	6.8	5.9	5.2	4.6	4.2	3,292	4	3	58,887,500	1,518	600	5	1%
CL10	Ben Tre	13.2	10.1	8.2	6.9	6.0	5.3	4.7	4.2	632	6	39	27,054,800	1,543	600	1	3%
CL5	Dak Lak	13.0	10.0	8.1	6.8	5.9	5.2	4.6	4.2	5,001	2	5	96,088,000	1,519	600	8	1%
CL6	Dak Lak	13.3	10.2	8.3	7.0	6.0	5.3	4.7	4.3	7,069	13	48	401,569,200	1,557	600	12	4%
CL5	Gia Lai	13.0	10.0	8.1	6.8	5.9	5.2	4.6	4.2	17,442	3	4	336,115,800	1,519	600	29	1%
CL7	Gia Lai	13.2	10.1	8.2	6.9	6.0	5.2	4.7	4.2	3,086	3	33	119,784,500	1,539	600	5	3%
CL2	Ha Tinh	13.0	10.0	8.1	6.8	5.9	5.2	4.6	4.2	767	7	11	16,213,000	1,521	600	1	1%
CL9	Hau Giang	13.1	10.1	8.2	6.9	5.9	5.2	4.7	4.2	2,281	2	17	68,182,400	1,530	600	4	2%
CL4	Kon Tum	13.0	10.0	8.1	6.8	5.9	5.2	4.6	4.2	3,001	1	4	56,388,500	1,519	600	5	1%
CL8	Lam Dong	13.0	10.0	8.1	6.8	5.9	5.2	4.6	4.2	6,608	5	1	128,962,900	1,520	600	11	1%
CL3	Quang Binh	13.1	10.0	8.1	6.9	5.9	5.2	4.6	4.2	575	1	12	14,517,400	1,525	600	1	2%
CL1	Quang Ninh	13.1	10.0	8.1	6.9	5.9	5.2	4.6	4.2	1,668	6	7	42,253,500	1,525	600	3	2%
CL3	Quang Tri	13.0	10.0	8.1	6.8	5.9	5.2	4.6	4.2	898	0	14	14,806,800	1,516	600	1	1%
CL9	Soc Trang	13.0	10.0	8.1	6.8	5.9	5.2	4.6	4.2	5,754	3	3	114,654,000	1,520	600	10	1%
CL3	Thua Thien	13.3	10.2	8.3	6.9	6.0	5.3	4.7	4.3	58	0	16	3,047,800	1,553	100	1	4%
CL10	Tien Giang	13.3	10.2	8.3	7.0	6.0	5.3	4.7	4.3	68	-	41	4,167,000	1,561	100	1	4%
CL9	Tra Vinh	13.0	10.0	8.1	6.8	5.9	5.2	4.6	4.2	2,823	1	3	53,367,500	1,519	600	5	1%

Appendix VI

LCOE Base Case calculation for the provincial clusters

Table 33: LCOE Base Case calculation for the provincial clusters (USD cents / kWh).
Plant CapEx = 1870 USD/kW; WACC= 10.8%; O&M costs = 50 USD/kW/year; Plant lifetime = 20 years.
** Based on centroid of core cluster with high wind speeds.*
*** Distance to 110kV grid point used (due to the size of the project suitable for the connection)*

Cluster ID	Province	LCOE 4,5-5 m/s areas	LCOE 5-5,5 m/s areas	LCOE 5,5-6 m/s areas	LCOE 6-6,5 m/s areas	LCOE 6,5-7 m/s areas	LCOE 7-7,5 m/s areas	LCOE 7,5-8 m/s areas	LCOE 8 m/s and higher areas	Total cluster capacity (MW)	Distance to closest road* (km)	Distance to closest 220kV grid* (km)	Infrastr. on-cost (USD)	CapEx Total (USD/ kW)	Infrastr. cost - size range (MW)	Infrastr. cost - size range multiple	Infrastr. on-cost on CapEx (%)
	FLH	***1,399***	***1,822***	***2,245***	***2,667***	***3,090***	***3,513***	***3,936***	***4,359***								
PCL_F1	Binh Dinh	20.61	15.82	12.84	10.81	9.33	8.21	7.32	6.61	414	10	26	21,805,200	1,923	450	1	2.8%
PCL_F2	Phu Yen	20.47	15.72	12.76	10.74	9.27	8.15	7.28	6.57	660	7	32	24,774,200	1,908	600	1	2.0%
PCL_F3	Ninh Thuan	20.75	15.94	12.94	10.88	9.40	8.26	7.38	6.66	120	9	23	8,304,100	1,939	150	1	3.7%
PCL1	Binh Thuan	20.40	15.66	12.71	10.70	9.23	8.12	7.25	6.55	1,017	4	11	29,633,200	1,899	600	2	1.6%
PCL2	Ninh Thuan	20.34	15.62	12.68	10.67	9.21	8.10	7.23	6.53	855	7	18	19,026,100	1,892	600	1	1.2%
PCL3	Khanh Hoa	20.66	15.87	12.88	10.84	9.35	8.23	7.34	6.63	168	0	8	9,893,800	1,929	300	1	3.1%
PCL4	Khanh Hoa	20.78	15.96	12.95	10.90	9.41	8.28	7.39	6.67	54	4	4	3,921,900	1,943	100	1	3.9%
PCL5	Phu Yen	20.65	15.86	12.87	10.83	9.35	8.22	7.34	6.63	315	6	21	18,224,450	1,928	450	1	3.1%
PCL6	Binh Dinh	20.47	15.72	12.76	10.74	9.27	8.15	7.28	6.57	81	1	15	3,044,600	1,908	100	1	2.0%
PCL7	Quang Ngai	20.59	15.81	12.83	10.80	9.32	8.20	7.32	6.61	75	4	4	3,760,000	1,920	100	1	2.7%

LCOE Low case calculation for the provincial clusters

Table 34: LCOE Base Case calculation for the provincial clusters (USD cents / kWh).
Plant CapEx = 1500 USD/kW; WACC = 7%; O&M costs = 45 USD/kW/year; Plant lifetime = 22 years.
** Based on centroid of core cluster with high wind speeds.*
*** Distance to 110kV grid point used (due to the size of the project suitable for the connection)*

Cluster ID	Province	LCOE 4,5-5 m/s areas	LCOE 5-5,5 m/s areas	LCOE 5,5-6 m/s areas	LCOE 6-6,5 m/s areas	LCOE 6,5-7 m/s areas	LCOE 7-7,5 m/s areas	LCOE 7,5-8 m/s areas	LCOE 8 m/s and higher areas	Total cluster capacity (MW)	Distance to closest road* (km)	Distance to closest 220kV grid* (km)	Infrastr. on-cost (USD)	CapEx Total (USD/ kW)	Infrastr. cost - size range (MW)	Infrastr. cost - size range multiple	Infrastr. on-cost on CapEx (%)
	FLH	***1,399***	***1,822***	***2,245***	***2,667***	***3,090***	***3,513***	***3,936***	***4,359***								
PCL_F1	Binh Dinh	13.25	10.18	8.26	6.95	6.00	5.28	4.71	4.25	414	10	26	21,805,200	1,553	450	1	3.5%
PCL_F2	Phu Yen	13.15	10.10	8.20	6.90	5.95	5.24	4.68	4.22	660	7	32	24,774,200	1,538	600	1	2.5%
PCL_F3	Ninh Thuan	13.36	10.26	8.33	7.01	6.05	5.32	4.75	4.29	120	9	23**	8,304,100	1,569	150	1	4.6%
PCL1	Binh Thuan	13.10	10.06	8.16	6.87	5.93	5.22	4.66	4.20	1,017	4	11	29,633,200	1,529	600	2	1.9%
PCL2	Ninh Thuan	13.05	10.02	8.14	6.85	5.91	5.20	4.64	4.19	855	7	18	19,026,100	1,522	600	1	1.5%
PCL3	Khanh Hoa	13.29	10.21	8.28	6.97	6.02	5.29	4.72	4.27	168	0	8	9,893,800	1,559	300	1	3.9%
PCL4	Khanh Hoa	13.38	10.27	8.34	7.02	6.06	5.33	4.76	4.29	54	4	4**	3,921,900	1,573	100	1	4.8%
PCL5	Phu Yen	13.28	10.20	8.28	6.97	6.01	5.29	4.72	4.26	315	6	21	18,224,450	1,558	450	1	3.9%
PCL6	Binh Dinh	13.15	10.10	8.20	6.90	5.95	5.24	4.68	4.22	81	1	15**	3,044,600	1,538	100	1	2.5%
PCL7	Quang Ngai	13.23	10.16	8.25	6.94	5.99	5.27	4.70	4.25	75	4	4**	3,760,000	1,550	100	1	3.3%

Appendix VII

Provincial technical potential land area across wind speed ranges

Table 35: Provincial technical potential land area across wind speed ranges expressed in km²

Annual average wind speed range	Binh Dinh	Binh Thuan	Khanh Hoa	Ninh Thuan	Phu Yen	Quang Ngai
4.5-5 m/s	53	32	41	5	35	151
5-5.5 m/s	154	175	82	11	163	119
5.5-6 m/s	201	446	61	45	228	61
6-6.5 m/s	121	193	42	152	143	37
6.5-7 m/s	52	227	32	111	62	7
7-7.5 m/s	28	329	20	88	24	2
7.5-8 m/s	5	162	20	44	15	0
8+ m/s	3	47	10	53	3	0
Total	**616**	**1,610**	**308**	**509**	**673**	**378**

Provincial technical potential capacity across wind speed ranges

Table 36: Provincial technical potential wind power capacity across wind speed ranges expressed in MW

Annual average wind speed range	Binh Dinh	Binh Thuan	Khanh Hoa	Ninh Thuan	Phu Yen	Quang Ngai
4.5-5 m/s	159	96	124	15	104	452
5-5.5 m/s	461	524	245	34	490	358
5.5-6 m/s	602	1,337	183	135	683	184
6-6.5 m/s	364	580	127	455	429	110
6.5-7 m/s	156	680	95	333	187	21
7-7.5 m/s	83	986	60	263	71	5
7.5-8 m/s	14	487	60	131	45	0
8+ m/s	8	140	29	160	10	1
Total	**1,847**	**4,829**	**923**	**1,527**	**2,018**	**1,133**

Appendix VIII

Biomass resource technical potential per region in 2014, 2020 and 2030

Table 37: Biomass resource technical potential per region in 2014. Unit: millions of tons. Source: (GIZ, 2017)

No	Biomass	Red River Delta	Northern midlands and mountainous	North and South-Central Coast	Central High-lands	South -east	Mekong River Delta	Total
1	**Energy wood**	**1.4**	**4.9**	**5.6**	**2.8**	**1.9**	**2.4**	**19.0**
1.1	From Forest	0.5	3.2	3.2	1.2	0.4	0.2	8.7
	Natural Forest	0.1	1.3	1.3	0.8	0.1	0.0	3.5
	Plantation Forest	0.4	1.9	1.9	0.4	0.3	0.2	5.2
1.2	Perennial plants	0.0	0.2	0.2	0.6	0.4	0.8	2.2
	Industrial Plants	0.0	0.1	0.2	0.5	0.4	0.6	1.8
	Fruit Plants	0.0	0.1	0.1	0.0	0.0	0.1	0.3
1.3	Others	0.8	1.6	2.1	1.0	1.1	1.4	8.1
	Dispersal Plants	0.8	1.2	1.8	0.9	1.1	1.4	7.2
	bare land and hills	0.0	0.4	0.3	0.1	0.0	0.0	0.9
2	**Wood residues**	**0.1**	**0.4**	**1.0**	**0.1**	**0.3**	**0.2**	**2.1**
2.1	from forest exploitation	0.0	0.1	0.2	0.0	0.0	0.0	0.5
2.2	Timber processing	0.1	0.2	0.7	0.1	0.3	0.2	1.7
3	**Agricultural residues**	**6.0**	**6.9**	**9.9**	**5.4**	**3.2**	**21.4**	**52.9**
	Rice husk	1.1	0.6	1.2	0.2	0.2	4.3	7.6
	Rice straw	4.1	2.0	4.2	0.7	0.8	15.1	27.0
	Bagasse	0.0	0.5	1.8	0.9	0.6	1.3	5.1
	Others	0.8	3.8	2.7	3.6	1.6	0.7	13.2
	Total	**7.5**	**12.2**	**16.5**	**8.3**	**5.4**	**24.1**	**74.1**

Table 38: Biomass resource technical potential per region in 2020. Unit: millions of tons. Source: (GIZ, 2017)

No	Biomass	Red River Delta	Northern midlands and mountainous	North and South-Central Coast	Central High-lands	South -east	Mekong River Delta	Total
1	**Energy wood**	**1.6**	**6.0**	**6.7**	**3.2**	**2.2**	**2.8**	**22.4**
1.1	From Forest	0.6	4.1	4.1	1.5	0.6	0.3	11.3
	Natural Forest	0.1	1.7	1.7	1.0	0.1	0.0	4.6
	Plantation Forest	0.5	2.4	2.5	0.5	0.4	0.3	6.7
1.2	Perennial plants	0.0	0.2	0.3	0.5	0.5	0.9	2.4
	Industrial Plants	0.0	0.1	0.2	0.5	0.4	0.7	2.0
	Fruit Plants	0.0	0.1	0.1	0.0	0.1	0.2	0.4
1.3	Others	0.9	1.7	2.3	1.1	1.2	1.6	8.7
	Dispersal Plants	0.9	1.3	2.0	1.0	1.2	1.6	7.9
	bare land and hills	0.0	0.4	0.3	0.1	0.0	0.0	0.9
2	**Wood residues**	**0.2**	**0.5**	**1.4**	**0.2**	**0.5**	**0.4**	**3.2**
2.1	from forest exploitation	0.0	0.2	0.3	0.0	0.0	0.1	0.6
2.2	Timber processing	0.1	0.3	1.2	0.2	0.5	0.3	2.6
3	**Agricultural residues**	**7.3**	**10.6**	**11.5**	**5.0**	**5.8**	**22.2**	**62.3**
	Rice husk	1.3	0.7	1.3	0.3	0.2	4.1	7.9
	Rice straw	4.5	2.6	4.5	0.9	0.8	14.6	28.0
	Bagasse	0.1	0.7	2.2	0.6	1.3	1.8	6.6
	Others	1.4	6.6	3.5	3.2	3.4	1.6	19.8
	Total	**9.0**	**17.1**	**19.6**	**8.4**	**8.5**	**25.3**	**88.0**

Table 39: Biomass resource technical potential per region in 2030. Unit: millions of tons. Source: (GIZ, 2017)

No	Biomass	Red River Delta	Northern midlands and mountainous	North and South-Central Coast	Central High-lands	South -east	Mekong River Delta	Total
1	**Energy wood**	**1.9**	**7.4**	**8.2**	**3.8**	**2.6**	**3.3**	**27.2**
1.1	From Forest	0.8	5.3	5.3	2.0	0.7	0.4	14.4
	Natural Forest	0.1	2.2	2.1	1.3	0.1	0.0	5.9
	Plantation Forest	0.7	3.1	3.2	0.6	0.6	0.4	8.5
1.2	Perennial plants	0.1	0.3	0.3	0.6	0.6	1.0	2.8
	Industrial Plants	0.0	0.1	0.2	0.6	0.5	0.8	2.2
	Fruit Plants	0.1	0.1	0.1	0.0	0.1	0.2	0.6
1.3	Others	1.0	1.9	2.6	1.3	1.3	1.8	10.0
	Dispersal Plants	1.0	1.5	2.3	1.2	1.3	1.8	9.1
	bare land and hills	0.0	0.4	0.3	0.1	0.0	0.0	0.8
2	**Wood residues**	**0.2**	**0.6**	**1.6**	**0.2**	**0.5**	**0.4**	**3.5**
2.1	from forest exploitation	0.1	0.2	0.4	0.0	0.0	0.1	0.8
2.2	Timber processing	0.1	0.4	1.2	0.2	0.5	0.3	2.7
3	**Agricultural residues**	**7.6**	**11.9**	**12.5**	**5.7**	**6.6**	**22.8**	**67.0**
	Rice husk	1.3	0.8	1.3	0.3	0.2	4.2	8.0
	Rice straw	4.5	2.7	4.5	0.9	0.8	14.8	28.3
	Bagasse	0.1	0.7	2.4	0.6	1.5	1.9	7.2
	Others	1.7	7.8	4.2	3.9	4.0	1.9	23.4
	Total	**9.7**	**20.0**	**22.2**	**9.7**	**9.7**	**26.5**	**97.7**

Appendix IX

Wind power annual production potential estimates

Table 40: Estimated annual wind power production potential (for a 'normal' wind year) based on the national technical potential scenarios. Production estimates based on 200 W/m2 wind turbine technology with 100m hub height (please see section Annual Energy Production estimation) at 0.1m/s mean annual wind speed steps

	Production (GWh)			
Wind speed range	***North***	***Central***	***South***	***TOTAL***
National technical potential (NTP)				
4.5 - 5.0 m/s	16,663	14,743	12,668	**44,074**
5.0 - 5.5 m/s	16,183	55,079	29,956	**101,218**
5.5 - 6.0 m/s	6,189	96,732	40,625	**143,546**
6.0 - 6.5 m/s	2,180	61,264	26,119	**89,562**
6.5 - 7.0 m/s	934	22,608	8,622	**32,163**
7.0 - 7.5 m/s	107	13,652	2,239	**15,999**
7.5 - 8.0 m/s	22	6,261	224	**6,508**
Over 8.0 m/s	10	3,481	5	**3,495**
TOTAL	**42,289**	**273,819**	**120,457**	**436,565**
NTP 20km infrastructure proximity				
4.5 - 5.0 m/s	7,996	9,501	7,533	**25,030**
5.0 - 5.5 m/s	4,980	35,841	15,340	**56,161**
5.5 - 6.0 m/s	2,554	68,026	34,537	**105,116**
6.0 - 6.5 m/s	1,134	45,005	23,463	**69,602**
6.5 - 7.0 m/s	395	20,251	5,249	**25,895**
7.0 - 7.5 m/s	55	12,645	1,398	**14,098**
7.5 - 8.0 m/s	4	6,066	208	**6,279**
Over 8.0 m/s	2	3,361	5	**3,367**
TOTAL	**17,120**	**200,696**	**87,733**	**305,549**
NTP 10km infrastructure proximity				
4.5 - 5.0 m/s	4,510	4,841	4,034	**13,384**
5.0 - 5.5 m/s	3,077	18,694	7,163	**28,934**
5.5 - 6.0 m/s	1,691	35,557	18,178	**55,426**
6.0 - 6.5 m/s	804	23,641	14,427	**38,873**
6.5 - 7.0 m/s	142	12,845	2,632	**15,619**
7.0 - 7.5 m/s	1	9,281	362	**9,644**
7.5 - 8.0 m/s	3	3,988	119	**4,110**
Over 8.0 m/s	0	1,774	5	**1,779**
TOTAL	**10,228**	**110,622**	**46,918**	**167,768**
NTP No croplands				
4.5 - 5.0 m/s	10,706	9,910	4,213	**24,829**
5.0 - 5.5 m/s	10,568	31,473	7,448	**49,489**
5.5 - 6.0 m/s	4,198	42,960	3,497	**50,655**
6.0 - 6.5 m/s	1,306	22,997	949	**25,252**

6.5 - 7.0 m/s	575	7,738	208	**8,521**
7.0 - 7.5 m/s	89	3,151	35	**3,275**
7.5 - 8.0 m/s	14	1,670	35	**1,718**
Over 8.0 m/s	9	1,457	5	**1,471**
TOTAL	**27,466**	**121,354**	**16,390**	**165,210**
NTP No croplands 20km infrastructure proximity				
4.5 - 5.0 m/s	5,379	6,315	2,702	**14,397**
5.0 - 5.5 m/s	3,388	19,088	4,966	**27,442**
5.5 - 6.0 m/s	1,679	27,537	2,166	**31,382**
6.0 - 6.5 m/s	564	17,131	877	**18,572**
6.5 - 7.0 m/s	265	6,277	78	**6,620**
7.0 - 7.5 m/s	51	2,568	28	**2,647**
7.5 - 8.0 m/s	1	1,517	33	**1,552**
Over 8.0 m/s	1	1,349	5	**1,354**
TOTAL	**11,329**	**81,781**	**10,855**	**103,965**
NTP No croplands 10km infrastructure proximity				
4.5 - 5.0 m/s	3,083	3 113	1 505	**7,701**
5.0 - 5.5 m/s	1,953	9 319	2 198	**13,470**
5.5 - 6.0 m/s	1,033	13 696	950	**15,679**
6.0 - 6.5 m/s	319	8 398	512	**9,229**
6.5 - 7.0 m/s	72	3 065	14	**3,152**
7.0 - 7.5 m/s	1	1 224	25	**1,250**
7.5 - 8.0 m/s	0	746	21	**767**
Over 8.0 m/s	0	672	5	**677**
TOTAL	**6,462**	**40 233**	**5 230**	**51,924**

Appendix X

NTP and the projections of PDP 7 revised

Table 41: Projections of PDP 7 revised for 2020, 2025 and 2030 vis-à-vis the NTP estimates for wind, solar PV biomass in MW, estimated total possible power generation based on NTP in TWh, and the respective shares of national power production.
** Share calculation based on projected national power demand for 2020 of PDP 7 revised*

	NTP 2020	PDP 7 rev. 2020	PDP 7 rev. 2025	PDP 7 rev. 2030
Generation (TWh)				
National power demand		265	400	570
Wind	**437**	2	4	12
Wind (No croplands 10km infrastructure proximity)	**52**	2	4	12
Solar PV	**436**	1	6	19
Biomass	**86**	3	5	12
Capacity (MW)				
Wind	**214,686**	800	2,000	6,000
Wind (No croplands 10km infrastructure proximity)	**27,141**	800	2,000	6,000
Solar PV	**339,628**	850	4,000	12,000
Biomass	**12,236**	(not defined)	(not defined)	(not defined)
Share of national power production (%)				
Wind	**165% ***	0.8%	1.0%	2.1%
Wind (No croplands 10km infrastructure proximity)	**20%***	0.8%	1.0%	2.1%
Solar PV	**165% ***	0.5%	1.6%	3.3%
Biomass	**32% ***	1.0%	1.2%	2.1%

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