TECHNO-ECONOMIC AND INSTITUTIONAL ASSESSMENT OF WIND ENERGY IN INDONESIA

A spatial evaluation of wind energy potential and its pertinent institutions

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Josef Sergio Simanjuntak

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Executive Summary

Indonesia is facing a challenge in fulfilling its future energy demand. A combination of consistently high economic growth and a fast-growing population is expected to significantly increase the level of demand in the coming years. In designing a future-proof energy system, the system's impact on climate change must also be taken into account. Given the low level of renewable energy (RE) integration into the current energy system and the climate agreements in place, Indonesia needs to accelerate the deployment of RE technology. One of the RE alternatives being considered to advance the integration is wind energy.

Wind energy is severely underutilized in Indonesia: as of 2019, only 154.3 MW wind power plant capacity is installed[1], although the potential of wind energy is listed as 60.6 GW[2]. Accordingly, the national government (hereinafter referred to as *the Government*) aims to increase the installed capacity by approximately twelvefold within the next five years. To reach this goal, it is crucial to have a comprehensive study on the spatially-distributed technical and economic wind energy potential which covers both onshore and offshore territories of Indonesia. Furthermore, the study should be supported with insights from the institutional perspective, by critically reflecting on the rules and regulations surrounding wind energy development. To the author's knowledge, such study is not available in the existing literature. Consequently, this research's objective is to determine economic potential of offshore and onshore wind energy in Indonesia and to formulate recommendations for institutional changes in order to proliferate wind energy development.

The main research question of this study is:
What is the economic potential of wind energy across Indonesia and within its provinces, and how can its development be promoted given the prevailing institutions?

Answering the research question entails two types of analysis: techno-economic analysis and institutional analysis. Techno-economic analysis is performed to determine the technical and economic wind energy potential. A GIS-based modelling approach is adopted to spatially compute these potentials. A set of onshore (50 MW) and offshore (400 MW) wind power plants are modelled at eligible sites within the national borders. The plants are then connected to the nearest demand center. By utilizing openly-available wind resource data, the average power output of each plant can be estimated. Subsequently, inserting wind farm investment costs into the model enable the computation of levelized cost of energy (LCOE) and economic average power output, i.e. total average power output of wind farms having LCOE lower than or equal to the maximum allowable electricity purchase price.

Based on the analysis, onshore and offshore wind technical potential in Indonesia amounts to 17.6 – 30.9 GW and 470.6 – 595.6 GW, respectively. Hence, the total technical potential is 488.2 – 626.5 GW. In terms of the annual energy production, this potential is as large as 15 – 19 times the nation's electricity demand in 2019, or 1.9 – 2.5 times the projected demand in 2050. Moreover, the potential's spatial distribution suggests wind energy potential being more prevalent in the eastern part of Indonesia compared to the western part. On the other hand, LCOE of onshore and offshore wind energy can be as low as 6.1 and 13.4 USD ct/kWh, respectively. However, only up to 8.0% and 1.4% of the onshore and offshore wind technical potential, respectively, is economically feasible under the current regulations. The economically feasible wind farm sites are

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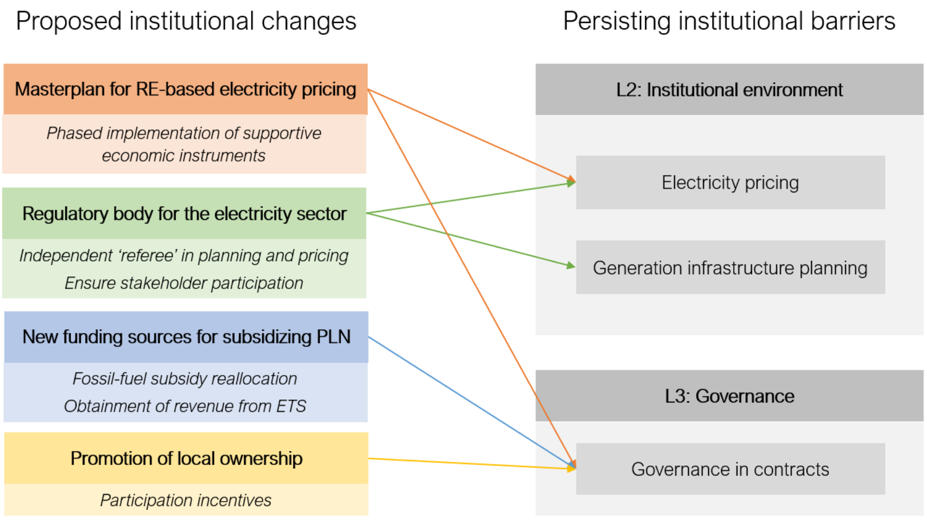
[1] Directorate General of Electricity MEMR. (2020). STATISTIK KETENAGALISTRIKAN 2019. Sekretariat Jenderal Ketenagalistrikan (Ministry of Energy and Mineral Resources).

[2] Suharyati, Pambudi, S. H., Wibowo, J. L., & Pratiwi, N. I. (2019). Indonesia Energy Outlook 2019 (S. Abdurrahman, M. Pertiwi, & Walujanto (Eds.)). National Energy Council.

predominantly located in Nusa Tenggara Barat, Nusa Tenggara Timur, Sulawesi Selatan, Maluku, and Papua. Additionally, exclusion of sites at areas highly prone to earthquake and landslide curtails the economic potential by up to 31% and 8%, respectively.

The techno-economic analysis is followed by an institutional analysis with a goal of identifying institutional barriers hampering wind energy development. Williamson's four layers of institutions framework is employed to guide the analysis. Of the framework's four layers, this study focuses on *institutional environment* (L2) and *governance* (L3). Institutional components being scrutinized include *electricity pricing* (L2), *governance in generation infrastructure planning* (L2), *property rights allocation* (L2), and *governance in contracts* (L3). In parallel, the relevant actors are scrutinized to reveal their interests, objectives, and relational dependencies.

A wide range of institutional barriers are pinpointed based on a desk study. Barriers related to electricity pricing include regulatory uncertainty and a low purchase price of RE-based electricity. Furthermore, the barrier in infrastructure planning (L2) is the low amount of additional wind farm capacity being planned by PLN, the monopolist in electricity transmission and distribution. Moreover, major changes to the plans are made annually, which adds institutional uncertainty for investors. Analyzing the regional-level plans of provinces with promising economic potential reveals a minimum level of wind energy development being planned in the coming years. Issues on property rights allocation (L2), i.e. ownership transfer and foreign ownership restrictions on wind energy projects, have been addressed in recently enacted laws. Lastly, barriers in contracting (L3) encompass prolonged negotiations between PLN and IPPs, poor law and contract enforcement, insufficient coordination and leadership in the multi-layered governance, and limited project funding available.



As shown in the figure above, three institutional recommendations are derived based on the identified barriers. First, the Government shall create an electricity pricing masterplan, which entails a phased implementation of supportive economic policy instruments. A consecutive implementation of FiT and competitive bidding using a regional approach is recommended to entice wind energy investments. Second, project funding should be provided by sustaining the Government's subsidy to PLN and promoting local participation and ownership in the projects. The subsidy can be sourced from a reallocation of fossil-fuel subsidy and revenues of ETS. Third, this study recommends the formation of an independent regulator dedicated to the electricity sector. The regulator is authorized to ensure sufficient stakeholder involvement and monitor the actors' activities in electricity pricing, infrastructure planning, and contracting.

In conclusion, significant changes to the institutional setting must be made to enlarge the economic potential of wind energy and in turn, proliferate wind energy development. Looking at the recent progress in policymaking, however, it seems that Indonesia is on the right track to support RE utilization. Furthermore, this study's results indicate two research avenues that can be pursued. The first one is to improve the methodology and input data of this research in order to gain more accurate and deeper results and insights. Meanwhile, the second avenue builds upon the results of this research. For instance, a similar study shall be employed at the regional level, particularly, at provinces with promising economic potential of wind energy. Another alternative is to conduct a detailed institutional design and to formulate regional- and national-level roadmap for wind energy development based on the identified potentials.

List of Abbreviations

ADB	Asian Development Bank
AEAI	*Asosiasi Energi Angin Indonesia* (Indonesian Wind Energy Association)
AEP	Annual Energy Production
APO	Average Power Output
Bappenas	*Badan Perencanaan Pembangunan Nasional* (The Ministry of National Development Planning)
BOO	Build, Operate, and Own
BOOT	Build, Operate, Own, and Transfer
BPP	*Biaya Pokok Penyediaan Pembangkitan* (Cost of power generation for electricity provision by PLN)
CAPEX	Capital Expenditure (USD (2020)/kW)
CF	Capacity Factor
CRF	Capital Recovery Factor
DECOM	Decommissioning Cost
DGE	Directorate General of Electricity of MEMR
DGNREEC	Directorate General of New Renewable Energy and Energy Conservation of MEMR
DPR	*Dewan Perwakilan Rakyat* (The Parliament or House of Representatives)
EEZ	Economic Exclusive Zone
ETS	Emission Trading System
FiT	Feed-in Tariff
GIS	Geographical Information System
GR	Government Regulation
GWA	Global Wind Atlas
IESR	Institute of Essential Services Reform
IISD	International Institute for Sustainable Development
INA	Indonesia Investment Authority
IPP	Independent Power Producer
IUPTL	*Izin Usaha Penyediaan Tenaga Listrik* (Electricity Supply Business License)
IUPTLS	*Izin Usaha Penyediaan Tenaga Listrik untuk kepentingan Sendiri* (Business License for Electricity Supply for Self-Interest)

IUPTLU	*Izin Usaha Penyediaan Tenaga Listrik untuk kepentingan Umum* (Business License for Electricity Supply for the Public)
LCOE	Levelized Cost of Electricity or Levelized Cost of Energy (USD ct (2020)/kWh)
MD	Ministerial Decree
MEMR	Ministry of Energy and Mineral Resources
MMAF	Ministry of Marine Affairs and Fisheries
MoEMR	Minister of Energy and Mineral Resources
MR	Ministerial Regulation
NRE	New and Renewable Energy
OPEX	Operational Expenditure (USD (2020)/kW)
PLN	*PT. Perusahaan Listrik Negara (Persero)* (State Electricity Company)
PPA	Power Purchase Agreement
PR	Presidential Regulation
RE	Renewable Energy
RPS	Renewable Portfolio Standards
RTRWD	*Rencana Tata Ruang Wilayah Daerah* (Regional Spatial Plan)
RTRWN	*Rencana Tata Ruang Wilayah Nasional* (National Spatial Plan)
RUED	*Rencana Umum Energi Daerah* (General Plan for Regional Energy)
RUEN	*Rencana Umum Energi Nasional* (General Plan for National Energy)
RUKD	*Rencana Umum Ketenagalistrikan Daerah* (General Plan for Regional Electricity)
RUKN	*Rencana Umum Ketenagalistrikan Nasional* (General Plan for National Electricity)
RUPTL	*Rencana Usaha Penyediaan Tenaga Listrik* (Electricity Supply Business Plan)
WACC	Weighted Average Cost of Capital
WEP	Wind Energy Potential
WLIF	Williamson’s four layers of institutions framework
WPP	Wind Power Plant

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Chapter 1. Introduction

1.1. Challenges in meeting future energy demand

Indonesia has an ambitious economic vision for 2045. Based on a consistent economic growth and poverty rate reduction prior to the COVID-19 pandemic (The World Bank, 2020b), Bappenas (2019) projected Indonesia to become a high-income economy with the fifth-largest GDP in 2045. Furthermore, the Indonesian population is projected to rise to 318.9 million in 2045 (BPS RI, 2018). Higher living standards, coupled with a fast-growing population, pose a serious challenge in meeting future energy demand (OECD & IEA, 2011): the national energy consumption is expected to triple in 2030 from its level in 2010 (Erdiwansyah et al., 2019). Therefore, this challenge calls for a future-proof energy system.

Designing the system must also consider its impact on climate change. As of 2018, more than half of the electricity produced in Indonesia was derived from fossil-fuel combustion (Suharyati et al., 2019). With a multilateral climate agreement in place, the Government of Indonesia has stipulated the General Plan of National Energy, which mandates an increase of renewable energy (RE) contribution to 23% of the primary energy mix by 2025 (PR 22/2017, 2017). Consequently, Indonesia's future energy system shall be developed with sufficient RE integration.

A description of recent RE advancements in Indonesia is presented in the next section to provide a context of its present state.

1.2. Recent progression of renewable energy in Indonesia

Indonesia boasts plentiful resources of energy, including geothermal, biomass, coal, and natural gas. However, the country is experiencing an energy and power crisis (Maulidia, Dargusch, Ashworth, & Ardiansyah, 2019), making the country susceptible to issues associated with future energy demand fulfillment. The crisis translates to poor distribution and provision of electricity. Not only does ~5% of the Indonesian population is unconnected to the grid, but also a sustainable, inexpensive, and stable electricity supply is either inaccessible or restrictively accessible to most of the population residing outside Java and Bali Island (Maulidia, Dargusch, Ashworth, & Ardiansyah, 2019).

In recent years, the Government had implemented ambitious electricity infrastructure development programs to increase the *electrification ratio*[3] and thereby to enhance electricity access for the population. One of the programs is the *35 GW Electricity Development Program*, a megaproject initiated in 2015 with a goal of reaching 97% electrification ratio in 2019 (MEMR, 2015). One year later, the Government ratified the Paris Agreement through Law 16/2016 (2016). The agreement stipulates 29% greenhouse gas (GHG) emission decrease by 2030. According to the law, new renewable energy (NRE) development shall be a priority in the future energy system.

As the monopolist in electricity transmission and distribution, state-owned company PLN is given the responsibility of constructing 71% of the total 35 GW additional capacity (MEMR Ministerial Decree (MD) 39/2019, 2019). PLN partly relies on private parties (Independent Power Producers or IPPs) in constructing new power plants due to budget limitations. However, the megaproject was hampered by issues such as delays

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[3] Electrification ratio is defined as the ratio between households having access to electricity and all households in Indonesia.

facing IPPs in obtaining financial closure, government guarantees, and land acquisition (MEMR MD 39/2019, 2019). Furthermore, the COVID-19 pandemic exacerbates the situation: PLN renegotiated with IPPs to postpone the commercial operations date of upcoming power plants because of the reduced electricity consumption by businesses and industries (Sukmawijaya, 2021). Looking at the 2019 share of RE in the primary energy supply mix of 9.2% (MEMR, 2020), achieving the targeted RE contribution in 2025 may thus seem overly ambitious. Nonetheless, the Government strives to meet the target by drafting a Presidential Regulation (PR) on RE pricing and a bill to ease RE business licensing, which are aimed at enticing investors in clean energy projects (Dewanto & Haryati, 2020; Mulyana, 2021).

Among various RE alternatives, wind energy has emerged as one of the means to achieve the aforementioned targets. The National Energy Council (NEC; 2021) lists four advantages of wind power generation over other technologies. First, the generation process does not emit local pollution and GHG. Second, the associated costs are relatively predictable and steady since the generation does not require fuel and entail low operating costs. Third, wind energy technology is modular: stranded costs caused by overbuilds can be averted because the capacity can be gradually expanded to meet future demands. Fourth, the technology can be implemented with shorter lead times compared to its competitors. In comparison to other RE alternatives such as solar, wind energy can be harvested at any time of the day. Moreover, wind turbines occupy merely a small fraction of the available land. This creates opportunities for co-location of wind power generation and other activities: the turbine can be installed on productive lands, such as farms and ranches (U.S. Department of Energy EERE, n.d.-a). Lastly, wind energy can be harnessed at offshore locations, away from places of settlement and human activities.

Despite the advantages, wind energy has not historically been a major contributor to energy in Indonesia (PwC, 2018). Martosaputro & Murti (2014) summarize the implementation of wind energy technology up to 2014. Before 2014, small wind turbines of up to 100 kW were applied at a research scale either in stand-alone or hybrid systems at isolated areas or islands. These islands include Java, Madura, Sulawesi, and Nusa Tenggara. Furthermore, the largest wind farm at that time (735 kW) was located in Nusa Penida, Bali. From 2015 to 2017, the installed wind generation capacity stagnated at 1.5 MW (DGE MEMR, 2020). In 2018, Indonesia's first large-scale wind farm (75 MW) was commissioned in Sidrap, Sulawesi Selatan. It was then followed by the commissioning of Tolo-1 wind farm (72 MW) in Jeneponto, Sulawesi Selatan (NEC, 2017). The installed capacity was 154.3 MW by 2019 (DGE MEMR, 2020) and no capacity addition occurred in 2020 (Meilanova, 2021a). In summary, large-scale wind power generation in Indonesia has only started to take place in recent years.

Future implementation of wind power technology, which is referred to as *wind energy development* in this study, is anticipated although in general, wind resources in Indonesia are relatively scarce: attractive resources are only present at certain locations in the vast Indonesian archipelago (NEC, 2017). Wind energy is expected to play a considerable role in the future energy system: the Government targets 1.8 GW and 28 GW of wind-generating capacity by 2025 and 2050, respectively (PR 22/2017, 2017). Achieving the target requires a capacity expansion by roughly 12 times within the next five years.

With the targets in place, it is pivotal to identify suitable locations for wind power generation by studying the spatial characteristic of wind resources. Moreover, an appropriate selection of wind turbine is important to optimize energy harvesting in areas of low wind speed. Lastly, it is imperative to consider where electricity demand centers are located: higher electricity transmission cost from wind farms to the demand centers may detract from their economic feasibility. For these reasons, wind energy potential assessment from the technical and economic perspective is essential to pinpoint promising sites for wind energy development.

1.3. Problem statement and research objectives

Section 1.2 implies a substantial gap between the current level of RE contribution in the energy mix and its target for 2025. Additionally, a gap exists in the utilization of wind energy: the currently installed wind farm capacity is much less than the potential of wind energy according to the Ministry of Energy and Mineral Resources (MEMR), i.e. 60.6 GW (Suharyati et al., 2019). It is noteworthy that the figure was calculated without considering the spatial distribution of electricity demand and economic feasibility of the envisioned wind power generation (PwC, 2018). The underwhelming utilization of wind energy implies the presence of barriers to be surmounted before wind energy development can take place. Thus, a two-part assessment is necessary to understand these barriers and in turn, devise recommendations to accelerate wind energy development.

The first part of the assessment is to evaluate the technical and economic wind energy potential (WEP). Technical potential pertains to the contribution of RE technologies assuming their future implementation, whereas economic potential includes economic calculations and their attractiveness to the society (Blok & Nieuwlaar, 2017). To the author's knowledge, there is no study that comprehensively characterizes these potentials, both at onshore and offshore areas, at the national level in Indonesia (see Chapter 2). Gaining insights on these spatially-characterized potentials act as the starting point in understanding the barriers.

The second part entails an assessment of RE institutions in Indonesia, especially those related to wind energy. There are two reasons for integrating the institutional analysis with WEP analysis in this study. First, institutions play an important role in sociotechnical systems in which wind energy technology is implemented. To attain the desired goal – i.e. the targeted RE contribution in the energy mix – these complex systems mandate an interconnection between technical and social elements. The evolution of these systems becomes a convoluted process: technological innovations need novel regulations and introduce distinct arrangement of organizations, whereas institutions constrain and direct technological advancements (Ghorbani et al., 2010). Second, institutions can heavily influence the progression of wind energy development. Bernard et al. (2011) highlight the importance of long-term institutional certainty to wind energy development: although the United States has the comparative advantage in terms of wind resources, the absence of a stable means of compensation for IPPs (e.g. through feed-in tariff or FiT) in the country resulted in a state of wind energy development that lags behind Germany and Spain, which both applied FiT (Bernard et al., 2011).

Institutions conjointly shape wind energy development through legislations and governance. Attaining the RE targets mandates a transparent set of regulations and policies to facilitate energy sector reform and make RE competitive with fossil-fuel energy (Maulidia, Dargusch, Ashworth, & Ardiansyah, 2019). An institutional assessment would therefore complement the techno-economic analysis in interpreting the relationship between the potentials and the institutions, and subsequently shed some light into possible institutional changes in order to advance wind energy development. The linkage between the potentials and the institutions is also unavailable in the literature (see Chapter 2).

Based on the above, the overarching objective of this research is to determine economic potential of offshore and onshore wind energy in Indonesia and devise recommendations for institutional alterations to support wind energy development. The objective is operationalized into four sub-objectives: (i) to identify the technical potential and economic potential, (ii) investigate the current institutional setting, (iii) analyze the institutional barriers hampering the potentials' realization, and (iv) devise recommendations for institutional changes.

1.4. Research questions

The objectives are encapsulated into the main research question underlying this study, namely:

What is the economic potential of wind energy across Indonesia and within its provinces, and how can its development be promoted given the prevailing institutions?

In turn, three sub-questions are formulated to answer the main research question (see Table 1).

Table 1. A list of sub-questions underlying this study

Code	*Sub-question*
SQ1	**What is the technical and economic potential of onshore and offshore wind energy in Indonesia?** *SQ1 corresponds to the first sub-objective and demands a quantitative determination of the technical and economic potential. Answering this sub-question involves a techno-economic analysis that identifies locations suitable for wind energy development and aggregates the potentials at the national level.*
SQ2	**Considering the current institutional setting, what are the institutional barriers hampering Indonesia's wind energy development?** *SQ2 is related to the second and third sub-objective. This sub-question is answered by means of an assessment of relevant institutions. The assessment results in an identification of institutional barriers which establishes a linkage between possible WEP realization and the prevailing institutions.*
SQ3	**How can the institutional setting be improved to proliferate wind energy development in Indonesia?** *SQ3 corresponds to the fourth sub-objective. Furthermore, SQ3 is aimed at deriving institutional recommendations for improving the current institutions based on the identified barriers.*

1.5. Research approach

This research combines an analysis of quantitative and qualitative information, and involves a mixed-methods approach (Creswell & Clark, 2018; Johannesson & Perjons, 2014) to meet the sub-objectives. The approach allows for the use of a wider range of data collection tools from quantitative and qualitative research. Therefore, new findings, which go beyond those of each research type, can be derived.

The first sub-objective pertains to identifying technical and economic WEP. Because field measurements are not possible within this research, a quantitative modelling approach is chosen with the purpose of prediction: quantitative value-estimation of variables of a system (Kelly et al., 2013), i.e. the WEP indicators. Wind power plants (WPP) are modelled at eligible onshore and offshore locations within Indonesia's borders. These farms are then connected to electricity demand centers by onshore and/or submarine transmission lines. Hence, locations with promising WEP can be pinpointed based on the adopted assumptions. This approach was adapted and refined to suit the case of wind energy from an Ocean Thermal Energy Conversion (OTEC) economic potential study (Cahyaningwidi, 2018; Langer et al., 2021). In summary, technical and economic WEP calculation is conducted by a techno-economic analysis, which constitutes Part I of this research.

The second and third sub-objective involves a qualitative approach by means of an institutional analysis. A qualitative approach is suitable since the diagnosis involves scrutinizing document-based textual data (Johannesson & Perjons, 2014). Williamson's four layers of institutions framework (WLIF) is used to structure the analysis: WLIF serves as a diagnostic tool to analyze existing institutions related to wind energy development, and to identify the barriers that inhibit the development. A stakeholder analysis is also performed to understand the interests, objectives, and relational dependencies of relevant actors.

Results from the techno-economic analysis and the institutional analysis serve as an input for creating institutional recommendations. These recommendations are aimed at improving the institutional setting surrounding wind energy development. The formulation is done qualitatively to meet the fourth sub-objective.

1.6. Alignment to Complex Systems Engineering and Management

This study addresses a complex system that fits the criteria of a Complex Systems Engineering and Management master thesis. The study's engineering component is the energy system: a complex sociotechnical system, in which multiple actors with varying interests are present, surrounding a technology implementation. In this case, technological components include WPPs and their supporting infrastructure. Additionally, technical issues related to the wind farms' design and operation are considered when calculating the technical and economic WEP. A systematic and scientific approach is adopted by means of a spatial energy system modelling: WPPs are modelled at eligible locations given the location-specific wind resources and infrastructure costs. Such an approach is also signified by the use of WLIF to structure the institutional analysis. Finally, the social context is deliberated through an evaluation of existing institutions and their alignment to the possible exploitation of WEP in Indonesia. For these reasons, this study embodies a Complex Systems Engineering and Management thesis.

1.7. Thesis outline

This report is divided into three parts. The first part is the techno-economic analysis on onshore and offshore wind in Indonesia. Part I encompasses Chapter 2 to Chapter 5. In Chapter 2, the knowledge gap being addressed by this study is presented through a literature review. Subsequently, Chapter 3 explains the theoretical background for the techno-economic analysis, including working principles of wind power generation and the associated costs. Methodology of the analysis is then elaborated in Chapter 4. In turn, Chapter 5 concludes Part I with the analysis' results.

Part II entails an institutional analysis of prevailing institutions surrounding wind energy development in Indonesia. The analysis consists of institutional assessment and institutional recommendations. Theoretical background and methodology of the analysis are elaborated in Chapter 6. Subsequently, Chapter 7 describes the results of Part II.

Part III covers the discussion, conclusion, and recommendations of this research. Discussion of results and methodology of Part I and Part II is provided in Chapter 8. This chapter also includes a reflection on scientific relevance, societal relevance, and limitations of this study. In turn, the research conclusion is presented along with recommendations for future studies in Chapter 9. Chapter 10 lists the references used by this study. A summary of the report's outline can be found in Figure 1.

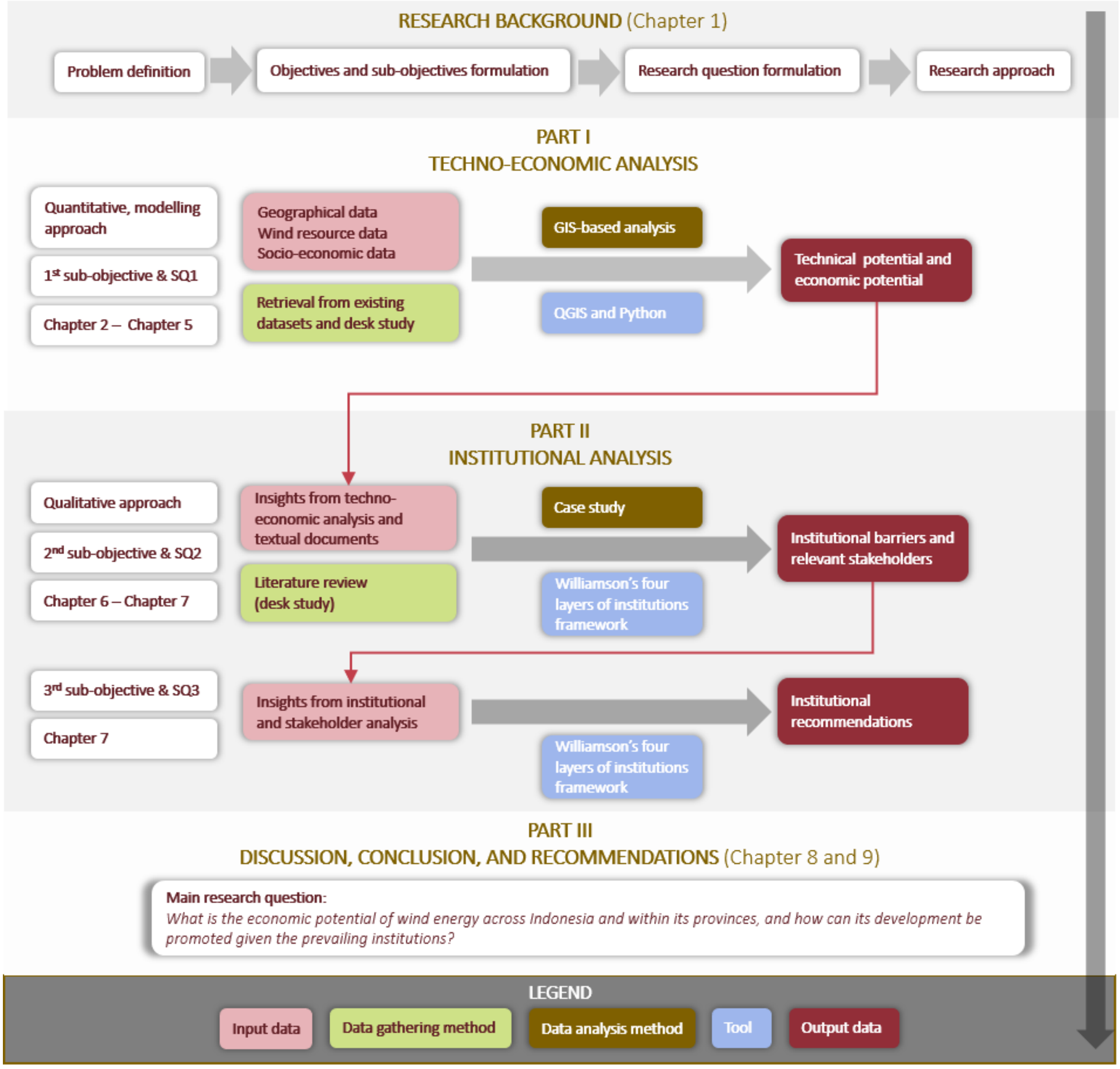

Figure 1. Research flow diagram underlying this study

PART I:
TECHNO-ECONOMIC ANALYSIS

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Chapter 2. Literature Review

This chapter presents the knowledge gap being addressed in this study as derived from a literature review on technical and economic potential studies on wind energy in Indonesia. This chapter is organized as follows. Section 2.1 introduces the definition of potentials. Subsequently, Section 2.2 and 2.3 presents the literature review methodology and findings, respectively.

2.1. Understanding 'potential' as a concept

WEP assessment requires a segregation of the different types of potential. Blok & Nieuwlaar (2017) define six types of 'potential' based on scoping and constraints being applied. The three types considered here are theoretical, technical, and economic potential. Theoretical potential looks at physical limitations in determining RE generation quantity based on the available flow of natural energy. As a subset of theoretical potential, technical potential takes into account technological constraints stemming from the energy-harvesting devices. Lastly, economic potential pertains to economically attractive portion of the technical potential (Blok & Nieuwlaar, 2017).

There are multiple indicators to describe each WEP type (see Table 2). First, theoretical potential is described by wind power density: the available energy for conversion to electricity by a wind turbine at the location (Mostafaeipour et al., 2011). This indicator can be displayed in its averaged form, namely, average wind power density (WPD). Second, technical potential is characterized by annual energy production (AEP; Chauhan & Saini, 2016), average power output (APO), and capacity factor (CF; Ohunakin & Akinnawonu, 2012). AEP is the sum of energy produced by a wind turbine or a WPP throughout one year. Notably, AEP highly depends on the wind turbine technology, i.e. the turbine's efficiency in converting wind energy into electricity. Moreover, APO is calculated by dividing AEP by the number of hours in a year. Meanwhile, CF is the ratio of APO to the turbine's (or the power plant's) rated capacity.

Table 2. Formula for average power output (APO), capacity factor (CF), and levelized cost of energy (LCOE)

Indicator	*Formula*	*Variable definitions*
Average power output (APO; GW)	$APO = \frac{AEP}{8760\ hours/year}$	AEP: annual energy production (GWh/year);
Capacity factor (%)	$CF = \frac{APO}{P_R}$	APO: average power output; P_R : rated power of turbine
Levelized cost of energy (LCOE; $/kWh)	$LCOE = \frac{CRF \times CAPEX + OPEX}{E_t}$	CRF: capital recovery factor; $CAPEX$: capital expenses; $OPEX$: operational expenses; E_t: the electricity produced at year t

Third, economic potential can be expressed by LCOE, net present value, and internal rate of return. However, only LCOE is considered in this study because this indicator will later be compared with electricity tariffs (see Chapter 4). LCOE signifies the minimum electricity selling price from a power plant to guarantee the investment being paid-off (Visser & Held, 2014). Through CRF, LCOE calculation includes payments made to the providers of capital (Bosch et al., 2019). The reviewed literature is scrutinized with respect to these indicators.

2.2. Literature search methodology

A review on scientific journal articles and conference papers which were written in English and published up to December 2020 were conducted to identify knowledge gaps in the field of wind energy development. Table 3 presents search terms, databases, and number of publications used in the literature search. To narrow down the search results, studies on multi-criteria WPP siting are excluded. Furthermore, conference papers are included due to the limited amount of journal articles available in this field. These papers are subjected to a close examination of their methods and assumptions. Several NGO reports, which were derived by forward- and backward-snowballing on the scientific publications and subsequently on the reports are also reviewed. Only reports specifically scrutinizing Indonesia's WEP assessment are selected, including those being conducted at the regional and supranational level.

Table 3. A summary of academic literature search methodology and its results

Search code	*Database*	*Search query*	*Number of publications*	
			Before selection	*After selection*
ST1	Scopus	TITLE-ABS-KEY((renewable OR wind) AND (energy) AND (resource OR practicable OR theor* OR techn* OR econom*) AND (potential) AND (Indonesia OR Bali OR Kalimantan))	354	9
ST2	Scopus	TITLE-ABS-KEY ("wind energy" AND Indonesia)	88	7
ST3	Scopus	TITLE-ABS-KEY (wind AND potential AND Indonesia)	195	1
ST4	Indonesia OneSearch	"wind", "energy", and "potential"	154	1
Snowballing				6
NGO reports				4
			Total	28

2.3. Literature review findings

The reviewed publications are listed in Table 24 and Table 25 of Appendix A. Scrutinizing their attributes leads to four observations. First, there is no study that comprehensively assess WEP in Indonesia at the national-level. Most publications adopt a regional scope at onshore locations and investigate WEP at only a few points within a small area. For instance, Ismail et al. (2014) and Hiendro et al. (2013) studied the WEP in Purworejo and Temajuk Village, respectively. On the other hand, some researchers broaden the regional scope by applying a more comprehensive spatial analysis. For example, Mahmuddin (2015) evaluates technical WEP at offshore areas near Sulawesi and Maluku Islands. The areas of assessment are represented by point-grids using Geographical Information System (GIS). Instead of a fixed, conventional WPP, however, a mobile floating structure is modelled to harvest wind energy. Another example is the GIS-based technical potential assessment by Sah & Wijayatunga (2017) on onshore locations in Bali Island. Additionally, existing literature predominantly analyze wind sites in Java Island, e.g. Yogyakarta (Tjahjana et al., 2016), Jember (Hardianto et al., 2017), Semarang (Premono et al., 2017), and Malang (Hidayat et al., 2020). While there are global and supranational WEP evaluations (Bosch et al., 2019; Deng et al., 2015; Lee et al., 2019), they either do not apply comprehensive site selection criteria (e.g. residential and forest area) or exclude a large portion of the Indonesian territory because of a CF restrictions. Furthermore, studies on onshore wind energy are found to be more prevalent than its offshore counterpart, even though offshore wind can enhance WEP at areas with small onshore WEP such as Indonesia (Gernaat et al., 2014). In conclusion, a comprehensive WEP assessment at the national scale that applies detailed site-selection criteria and addresses both onshore and offshore WEP is not yet available in the literature.

Second, there is a divergence in terms of wind speed data source: the data stems from either actual measurement (by researchers or governmental bodies), literature, or satellite data. Some papers even do not explicate their data sources, despite the significant influence of wind speed on WEP assessment. There is also a variety of measurement tool standards being employed. For instance, some studies obtain the data from multiple weather stations, which presumably use standardized anemometers (Bestari & Arifin, 2019; Satwika et al., 2019; Tjahjana et al., 2018). Nonetheless, it is not clear whether these anemometers are research-grade devices. Moreover, one study uses wind speed data from a regular, handheld digital anemometer (Hardianto et al., 2017). Other studies do not clearly specify the measurement tools (Daratha et al., 2019; Ismail et al., 2014, 2015; Putro et al., 2019; Tjahjana et al., 2016). Differences in wind speed measurement periods are also observed. These periods are either in the order of days (Putro et al., 2019), months (Bestari & Arifin, 2019; Daratha et al., 2019; Hardianto et al., 2017), or years (Ismail et al., 2014, 2015; Satwika et al., 2019; Tjahjana et al., 2016, 2018). In summary, this observation shows the disparity of reporting standards and the procedure of wind speed measurement.

Third, most studies compute theoretical potential, while there are only a few studies diving into the technical and economic potential. Building upon the first two potentials, economic potential is arguably an important indicator of wind energy development feasibility given the considered physical, technological, and economic constraints. However, only a few publications address economic WEP. Furthermore, none of the studies incorporates the impact of natural disaster proneness on the potentials to portray a more ‘realistic’ WEP. Coupled with the first observation, this finding indicates a necessity for an extensive techno-economic analysis to support wind energy development in Indonesia.

Fourth, only three studies draw attention to the institutional setting. Firstly, Martosaputro & Murti (2014) discuss existing laws on energy and electricity that foster RE utilization including wind energy. They also noted that MEMR regulation on RE-based electricity pricing does not make RE competitive compared to fossil fuels, and hence, leaving prospective IPPs discouraged. Secondly, KPMG et al. (2019) incorporate maximum levels of electricity pricing allowed by MEMR regulation in assessing the economic potential of a wind farm in Lombok. Failure in establishing a Power Purchase Agreement (PPA) between PLN and the project developer due to grid stability concerns is highlighted as a risk that shall be mitigated. Thirdly, Kusumo et al. (2018) also refer to such risk for IPPs as no legislation obligates PLN to sign the PPA. In gauging the competitiveness of wind-based electricity at selected islands, the authors compare wind farms’ LCOE and a proposed FiT to PLN’s average cost of electricity generation. In conclusion, further WEP studies that also consider existing institutions are needed to better understand the prospects of wind power generation.

This chapter presents multiple knowledge gaps present in the body of literature of Indonesia’s wind energy potential. It is evident that there is a lack of a comprehensive techno-economic analysis of WEP in Indonesia that also considers the current RE institutions. Therefore, this study aims to address the knowledge gap as inferred by the first, third, and fourth observation. Subsequently, the study intends to propose institutional recommendations to support wind energy development in Indonesia. The next chapter presents the theoretical background of the techno-economic analysis.

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Chapter 3. Techno-Economic Analysis: Theoretical Background

This chapter introduces some concepts related to the techno-economic analysis of wind energy based on a literature review on scientific publications. Section 3.1 presents an overview of wind energy technology. Subsequently, Section 3.2 explains wind turbines classification based on the wind class at site. Possible sources of energy loss in a WPP operation are addressed in Section 3.3. Section 3.4 and Section 3.5 elaborate upon onshore and offshore wind turbine implementation, and WPP site selection, respectively. Lastly, Section 3.6 discusses the cost components entailed in a WPP investment.

3.1. Overview of wind energy technology

Generation of electrical energy from the kinetic energy of wind occurs in a wind turbine, which predominantly takes form in horizontal-axis turbines (Ackermann, 2012). As shown in Figure 2, these devices comprise of two parts: nacelle and tower. The former part sits on top of the latter and houses the rotor, gearbox, and generator. Most state-of-the-art wind turbines operate based upon aerodynamic lift that arises when incoming wind interacts with wind turbine blades.

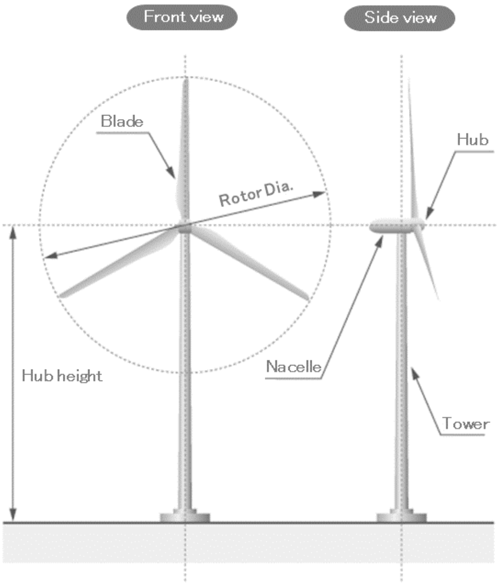

Figure 2. A schematic representation of a wind turbine (Venti Japan, n.d.)

The amount of energy generated by wind turbines depends on the aerodynamic power, i.e., the amount of power that can be derived from incoming wind. Aerodynamic power (P; see Equation 1) is directly proportional to air density (ρ), rotor sweep area (A), wind speed (U), and aerodynamic efficiency (C_p). This relationship indicates the importance of wind turbine selection based on the turbine's wind class, and deployment and arrangement of the turbines in areas with suitable wind resources.

Equation 1. Aerodynamic power formula

$$P = \frac{1}{2}\,\rho\,A\,U^3\,C_p$$

An important wind turbine characteristic is the *power curve* (see Figure 3). The curve expresses the relationship between incoming wind speed and the turbine's power output. Three wind speeds that characterize wind turbines are *cut-in*, *rated*, and *cut-out* wind speed. *Cut-in* wind speed is the minimum wind speed required for the turbine to operate and generate power. Between *rated* wind speed and *cut-out* wind speed, wind turbine produces power at its rated capacity, i.e. the maximum generated power according to the turbine's design. Finally, the turbine's operation is suspended at wind speeds equal to or larger than *cut-out* wind speed (e.g. during a storm) to avoid excessive mechanical stresses that may damage the turbine (Ackermann, 2012; Ea Energy Analyses et al., 2017).

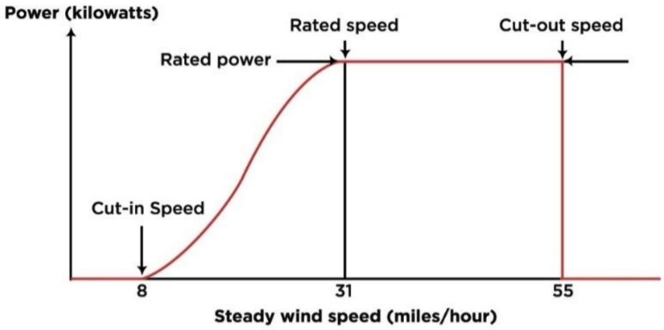

Figure 3. A typical wind turbine power curve showing cut-in, rated, and cut-out wind speed (U.S. DoE EERE, n.d.)

3.2. Classification of wind turbines

Technology selection based on wind class can crucially affect the economic WEP as indicated by the levelized cost of energy (LCOE; Noonan et al., 2018). Consequently, wind turbines are typically designed for specific wind sites to optimize power-generating performance and ensure reliability in withstanding weather conditions that the turbines may endure throughout their lifetime (LM Wind Power, n.d.). Based on these designs, wind turbines are classified into four classes according to IEC 61400-1 (see Table 4). These classes are differentiated based on turbulence and wind speed parameters (Ea Energy Analyses et al., 2017). According to Ea Energy Analyses et al. (2017), Class III wind turbines are generally appropriate for wind power generation in Indonesia. Turbines of this class are suitable for power generation at low wind conditions: these wind turbines are equipped with larger rotors to maximize the energy harvested on-site (Renewables First, 2015).

Table 4. Wind turbine classification according to IEC 61400-1; adapted from (LM Wind Power, n.d.)

	IEC Wind Class			
	I (High wind)	II (Medium wind)	III (Low wind)	IV (Very low wind)
Reference wind speed (m/s)	50	42.5	37.5	30
Annual average wind speed (max; m/s)	10	8.5	7.5	6
Fifty-year return gust (m/s)	70	59.5	52.5	42
One-year return gust (m/s)	52.5	44.6	39.4	31.5

3.3. Sources of energy loss in wind power plants

Installing wind turbines in an array entails several sources of energy loss. Ackermann (2012) categorizes these losses into three groups. The first source is wake effect, which occurs when wind turbines shield each other from incoming wind. A turbine located behind another in the downwind direction will be subjected to lower wind speed and hence, produce less power. In practice, this loss ranges from 5 to 15% of a WPP's AEP (Ackermann, 2012). To minimize the loss, wind turbines are arranged in such a way that inter-wind turbine and inter-row spacing are optimized (Schallenberg-Rodríguez & Pino, 2014). These spacings are function of rotor diameter (*D*) and inversely proportional to the extent to which wake effect occurs. In this study, the loss is included in *array efficiency*, which depicts aggregate WPP efficiency (Schallenberg-Rodríguez & Pino, 2014). For instance, Schallenberg-Rodriguez (2013) models a WPP with nullified theoretical wake effect loss by setting wind turbines 12D and 4D apart in downwind and crosswind direction, respectively. Meanwhile, Bosch (2018) fits a modified Langmuir model on Gustavson's (1979) empirically-derived array efficiencies: the efficiencies of a 10 x 10 WPP (i.e. a WPP consisting 10 rows of turbines, with 10 turbines per row) and a 5 x 5 WPP with 10D-distance between the turbines are found to be 95% and 88.55%, respectively.

The second source of loss is electrical instruments, i.e. cable interconnections and WPP collector systems. Their properties and configuration determine the amount of loss. There are two types of transmission cables: high voltage alternating current (HVAC) and high voltage direct current (HVDC). Compared to HVAC, HVDC offers lower cable losses at transmission distances above 50 km (Apostolaki-Iosifidou et al., 2019). However, HVDC is only cost-competitive starting at roughly 56-km transmission distance; below this threshold, HVAC is the preferred, cheaper option (Bosch et al., 2019). Cost difference between the two cable types arises from the need for terminal stations in an HVDC system for AC-DC electricity conversion and vice versa (Nagababu, Kachhwaha, & Savsani, 2017). Typically, electricity *transmission loss* through the cables is assumed to be 2 – 5% of WPPs' AEP (Ackermann, 2012; Bosch et al., 2019; Noonan et al., 2018).

The third source is WPP unavailability due to scheduled maintenance on or improper performance of wind turbines, cable interconnections, and unit transformers. Availability of wind turbines assumed in other studies ranges from 95 to 98% (Ackermann, 2012; Bosch et al., 2019; KPMG et al., 2019; Lee et al., 2019). In this study, losses due to unavailability are referred to as *operational efficiency*: the ratio of wind turbine actual operation time to its possible operation time (Deng et al., 2015).

3.4. Onshore and offshore application of wind turbines

Wind turbines can be installed at onshore and offshore locations. Sánchez et al. (2019) epitomize the advantages and disadvantages of offshore WPP relative to its onshore counterpart. The advantages include (a) higher wind resource at sea, (b) less visual and acoustic nuisance that allows for larger and more efficient turbine geometries, (c) larger job creation throughout the WPP's construction, installation, and maintenance, (d) more stable power generation, and (e) environmental spaciousness. Nonetheless, offshore WPP involves harsher environmental conditions to withstand, more expensive and complex wind resource assessment, and larger investment and operational costs.

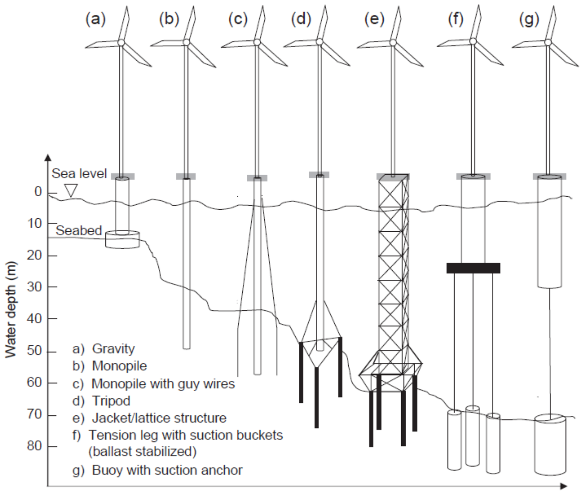

Figure 4. Types of offshore wind turbine foundations (O'Kelly & Arshad, 2016)

An important distinction between onshore and offshore WPP pertains to the wind turbine's foundation. Foundations serve to sufficiently support wind turbines against external loads and establish a solid and reliable base (Sánchez et al., 2019). Offshore wind turbine foundation can be classified into several types (see Figure 4): gravity-based structure, monopile, tripod, jacket, and floating structure (Sánchez et al., 2019). The first four types are categorized into fixed foundations. In turn, the fifth type encompasses tension leg platforms (TLB), semi-submersibles, and single point anchor reservoir (SPAR or buoy with suction anchor; Wu et al., 2019). Offshore project developers refer to seabed depth as the main determinant when selecting the suitable foundation type. Table 5 summarizes the water depth ranges for each foundation typology found in the literature.

Table 5. Selection of offshore wind turbine foundation based on water depth as gathered from the literature

Foundation type	*Depth (m)*			
	Arapogianni et al. (2013)	*Nagababu, Kachhwaha, Naidu, et al. (2017)*	*Bosch et al. (2019)*	*Sánchez et al. (2019)*
Gravity-based structure	-	0 – 30	30 – 50	0 – 20
Monopile	0 – 30	0 – 30	0 – 40	0 – 30
Jacket	25 – 50	30 – 50	30 – 50	5 – 50
Tripod	25 – 50	30 – 50	30 – 50	25 – 50
Tension leg platforms and semi-submersible	> 50	50 – 120	> 50	> 50
SPAR	> 120	> 120	> 50	> 50

3.5. Site selection of wind power plants

WPP developers are increasingly facing a challenge in searching for sites with promising technical and economic WEP (Grassi et al., 2012). Section 3.1 to 3.4 already imply some site selection constraints of WPP, e.g. wind speed and seabed depth. There are additional constraints originating from WPPs' environmental impacts. A major positive impact is the non-GHG emitting power generation. Nevertheless, Aydin et al. (2010) list the negative environmental impacts as noise and visual nuisance, bird collisions, safety concerns, and electromagnetic interference. Due to these adverse impacts, a number of site selection criteria are adopted to promote environmental gains and mitigate siting conflicts (Sliz-Szkliniarz & Vogt, 2011).

Generation of noise from a WPP may be deemed unacceptable by the community living nearby. Moreover, despite some people being receptive to WPPs because of the clean energy image, others may deem WPPs as an aesthetic nuisance (Aydin et al., 2010). This phenomenon results in Not-In-My-Back-Yard (NIMBY) attitude of the surrounding community (Nagababu, Kachhwaha, Naidu, et al., 2017). Therefore, WPP must be located at a certain distance away, or buffered, from populated areas to remedy these noise and visual concerns. To prevent bird collisions, WPP should not be sited at conservation areas. Furthermore, a buffer between WPPs and airports is required for safety reasons. Finally, electromagnetic scattering of waves from navigation and telecommunication signals is mainly solved by state-of-the-art cable and wave transmission technologies (Aydin et al., 2010).

There is a wide range of site selection criteria for WPP available in the literature. They are employed to identify *eligible areas*, i.e., sites that are technically feasible for wind energy development (Grassi et al., 2012). Based on a literature review on techno-economic WEP and site selection studies, commonly-used criteria are classified into three groups: *general*, *offshore*, and *onshore*. These groups are further divided into subgroups, which contain the site selection criteria. The inclusion threshold or buffer values used in the studies for each criterion are shown in Table 6 (*general*), Table 7 (*offshore*), and Table 8 (*onshore*).

In the general criteria*, minimum average wind speed* is applied at certain hub heights because a lower wind speed corresponds to a higher LCOE (Schallenberg-Rodríguez & Montesdeoca, 2018). Meanwhile, *water use*, one of the offshore criteria, pertains to parts of the water being used for human-related activities or infrastructures. *Seabed depth* restriction depends on the applicability of turbine foundation: some studies set the limit to 1,000 m because current technologies are only applicable up to 800 m depth (Bosch et al., 2019). In addition, WPP distance from shore is either constrained by territorial waters, wind speed data availability, or Economic Exclusive Zone (EEZ).

Onshore areas of high altitude are excluded due to two economic reasons (Schallenberg-Rodríguez & Pino, 2014). First, installing wind turbines in such areas are more expensive compared to lower altitude areas. Second, the decline in air density at higher altitudes may result in lower aerodynamic power (see Equation 1), although this effect may be counteracted by higher wind speeds. On the other hand, there are three reasons to avoid highly-sloped areas (Grassi et al., 2012). Firstly, safety concerns arise when operating cranes for wind turbine installation and boring machines for foundation construction in these areas. Secondly, transportation of equipment to these sites is challenging. Finally, equipment transfers entail an expensive cost of building access road with sufficient dimensions.

Buffers on *transport infrastructure* are commonly applied for safety of operation and activities within the infrastructure. Moreover, *land use* may either be mutually exclusive or compatible: for example, a stretch of agricultural land can simultaneously be utilized for electricity generation (Sliz-Szkliniarz & Vogt, 2011). If land use is mutually exclusive, a buffer exclusion area is typically adopted.

Table 6. General wind power plant site selection criteria and their threshold or buffer values used in the literature (SG: subgroup)

SG	*Criteria*	*Inclusion threshold*	*Buffer (m)*	*Area of application*	*Reference*	*Remarks*
Conservation zones	Protected areas	-	300	Iowa, USA	Grassi et al. (2012)	
		-	1,000	Kozani, Greece	Latinopoulos & Kechagia (2015)	
	Parks and protected landscapes	-	200 – 500	Kujawsko-Pomorskie, Poland	Sliz-Szkliniarz & Vogt (2011)	Buffer depends on landscape type
		-	1,000	Canary Islands, Spain	Schallenberg-Rodríguez & Pino (2014)	
	Forest	-	300	Iowa, USA	Grassi et al. (2012)	
Wind speed	Minimum wind speed (onshore)	> 4.8 m/s	-	Canary Islands, Spain	Schallenberg-Rodríguez & Pino (2014)	Onshore, at 78 m hub height
		> 6 m/s	-	Global	Deng et al. (2015)	Onshore, at 90 m hub height
		> 4.5 m/s	-	Kozani, Greece	Latinopoulos & Kechagia (2015)	Onshore
		> 3.65 m/s	-	Bali, Indonesia	Sah & Wijayatunga (2017)	Onshore, at 50 m height
		> 5 m/s	-	Northwestern Iran	Bina et al. (2018)	Onshore
	Minimum wind speed (offshore)	> 8 m/s	-	Global	Deng et al. (2015)	Offshore, at 90 m hub height
		> 6 – 6.5 m/s	-	Canary Islands, Spain	Schallenberg-Rodríguez & Montesdeoca (2018)	Offshore, at 80 m height
		> 7 m/s	-	Brazil, India, Morocco, Philippines, South Africa, Sri Lanka, Turkey, and Vietnam	ESMAP (2019)	Offshore

Table 7. Offshore wind power plant site selection criteria and their threshold or buffer values used in the literature (SG: subgroup)

SG	*Criteria*	*Inclusion threshold*	*Buffer (m)*	*Area of application*	*Reference*
Water use	Fishing grounds, shipping routes, and military areas	-	500	Canary Islands, Spain	Schallenberg-Rodríguez & Montesdeoca (2018)
	Submarine cable	-	1,000	Global	Bosch et al. (2019)
Boundary	Seabed depth	≤ 50 m	-	India	Nagababu, Kachhwaha, & Savsani (2017)
		≤ 500 m	-	Canary Islands, Spain	Schallenberg-Rodríguez & Montesdeoca (2018)
		≤ 1,000 m	-	Global Brazil, India, Morocco, Philippines, South Africa, Sri Lanka, Turkey, and Vietnam	Deng et al. (2015) Bosch et al. (2019) ESMAP (2019)
	Distance from shore	≤ ~19 km	-	Canary Islands, Spain	Schallenberg-Rodríguez & Montesdeoca (2018)
		≤ 200 km	-	Global Brazil, India, Morocco, Philippines, South Africa, Sri Lanka, Turkey, and Vietnam	Deng et al. (2015) ESMAP (2019)
		≤ 370 km	-	India Global	Nagababu, Kachhwaha, & Savsani (2017) Bosch et al. (2019)

Table 8. Onshore wind power plant site selection criteria and their threshold or buffer values used in the literature (SG: subgroup)

SG	Criteria	Inclusion threshold	Buffer (m)	Area of application	Reference	Remarks
Geography	Elevation	≤ 2,000 m	-	Kujawsko-Pomorskie, Poland Northwestern Iran Global	Sliz-Szkliniarz & Vogt (2011) Deng et al. (2015) Bina et al. (2018)	
	Slope	≤ ~47%	-	Kujawsko-Pomorskie, Poland	Sliz-Szkliniarz & Vogt (2011)	25^0 threshold
		≤ 100%	-	Canary Islands, Spain	Schallenberg-Rodríguez & Pino (2014)	45^0 threshold
		≤ 25%	-	Kozani, Greece	Latinopoulos & Kechagia (2015)	
		≤ 30%	-	Bali, Indonesia	Sah & Wijayatunga (2017)	
		≤ ~27%	-	Northwestern Iran Global	Deng et al. (2015) Bina et al. (2018)	15^0 threshold
		≤ 20%	-	Iowa, USA ASEAN region	Grassi et al. (2012) Lee et al. (2019)	
Transport infrastructure	Airports	-	2,000	Iowa, USA	Grassi et al. (2012)	
		-	3,000	Kozani, Greece Kujawsko-Pomorskie, Poland	Latinopoulos & Kechagia (2015) Sliz-Szkliniarz & Vogt (2011)	
		-	300	Northwestern Iran	Bina et al. (2018)	
	Roads	-	100	Kujawsko-Pomorskie, Poland	Sliz-Szkliniarz & Vogt (2011)	
			60 (240)	Iowa, USA	Grassi et al. (2012)	Minor (major) road
		-	120	Canary Islands, Spain	Schallenberg-Rodríguez & Pino (2014)	
		-	150	Kozani, Greece	Latinopoulos & Kechagia (2015)	
			5,000*	Bali, Indonesia	Sah & Wijayatunga (2017)	*within 5,000 m distance from road for accessibility
		-	500	Northwestern Iran	Bina et al. (2018)	
	Railways	-	100	Kujawsko-Pomorskie, Poland	Sliz-Szkliniarz & Vogt (2011)	
		-	150	Iowa, USA	Grassi et al. (2012)	
		-	300	Northwestern Iran	Bina et al. (2018)	
Land use	Settlements and farms	-	240	Iowa, USA	Grassi et al. (2012)	
	Residential	-	500	Kujawsko-Pomorskie, Poland	Sliz-Szkliniarz & Vogt (2011)	
			250	Canary Islands, Spain	Schallenberg-Rodríguez & Pino (2014)	
		-	500 – 1,500	Kozani, Greece	Latinopoulos & Kechagia (2015)	
	Industry and commercial	-	250	Kujawsko-Pomorskie, Poland	Sliz-Szkliniarz & Vogt (2011)	
	Water bodies	-	200 – 250	Kujawsko-Pomorskie, Poland	Sliz-Szkliniarz & Vogt (2011)	
		-	240	Iowa, USA	Grassi et al. (2012)	
		-	1,000	Northwestern Iran	Bina et al. (2018)	
	Waterways (rivers)	-	500	Northwestern Iran	Bina et al. (2018)	

3.6. Cost components of wind power plants

Constructing and operating WPPs entail capital-intensive investments which are fed into the economic WEP evaluation. Wind energy development economics is typified by high capital costs and low operating costs (Nagababu, Kachhwaha, & Savsani, 2017). Furthermore, these costs can have a fixed and a variable component which is independent and dependent of WPP location, respectively (Nagababu, Kachhwaha, & Savsani, 2017). Based on a literature review, studies generally segregate the costs into three groups: capital cost (CAPEX), operating and maintenance costs (OPEX), and decommissioning cost (DECOM). Figure 5 exemplifies a detailed breakdown of cost components for each group throughout the lifespan of a WPP (Bosch et al., 2019).

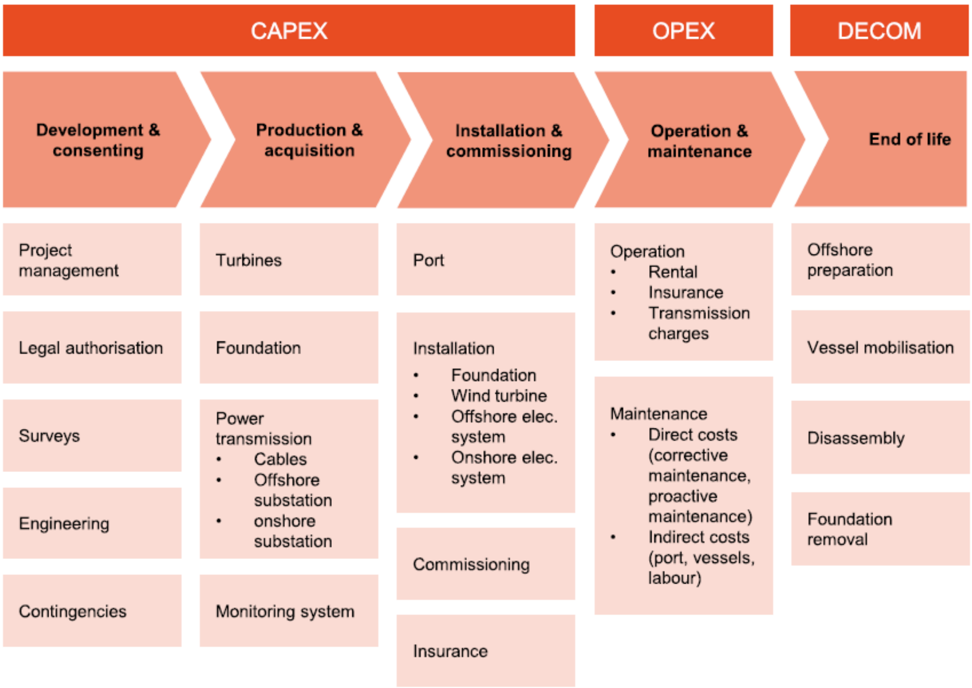

Figure 5. A decomposition of a wind power plant's life cycle costs (Bosch et al., 2019)

In the next subsections, each group and its entailed cost components are discussed. It is important to note that the values serve as estimates, since they are gathered from academic literature instead of from equipment manufacturers.

3.6.1. Capital expenses (CAPEX)

CAPEX concerns a one-time investment cost that occurs at the beginning of the project. CAPEX of offshore WPP is usually larger than its onshore counterpart since the former WPP requires submarine transmission cables, a more sophisticated foundation, and a complex tower erection process (Nagababu, Kachhwaha, & Savsani, 2017). A range of representative CAPEX for onshore and offshore WPP are shown in Figure 6 and Figure 7, respectively. It is important to note the different regions to which the costs apply. Moreover, the listed values are converted to USD (2020) from their original currency and year. If a study does not specify the currency year, then the year of publication is assumed to be the currency year. The conversion is based on inflation and currency exchange data from Inflation Tool (2021) and Eurostat (2021), respectively.

Although not shown in Figure 6 and Figure 7, CAPEX of WPP projects worldwide has decreased over time due to technological learning. According to IRENA (2019), the global average of total onshore WPP installation cost has declined from 1,913 USD/kW in 2010 to 1,497 USD/kW in 2018. Over the same period, the global average of total offshore WPP installation cost decreased from 4,572 USD/kW to 4,353 USD/kW. Nevertheless, there still exists a considerable discrepancy of CAPEX among different countries/regions. For example, China's average onshore WPP CAPEX (1,055 USD/kW) is less than half of that of *Other Asia* (2,368 USD/kW) in 2019 (IRENA, 2019). Consequently, the economic WEP analysis in this study utilizes Indonesia-specific CAPEX whenever possible.

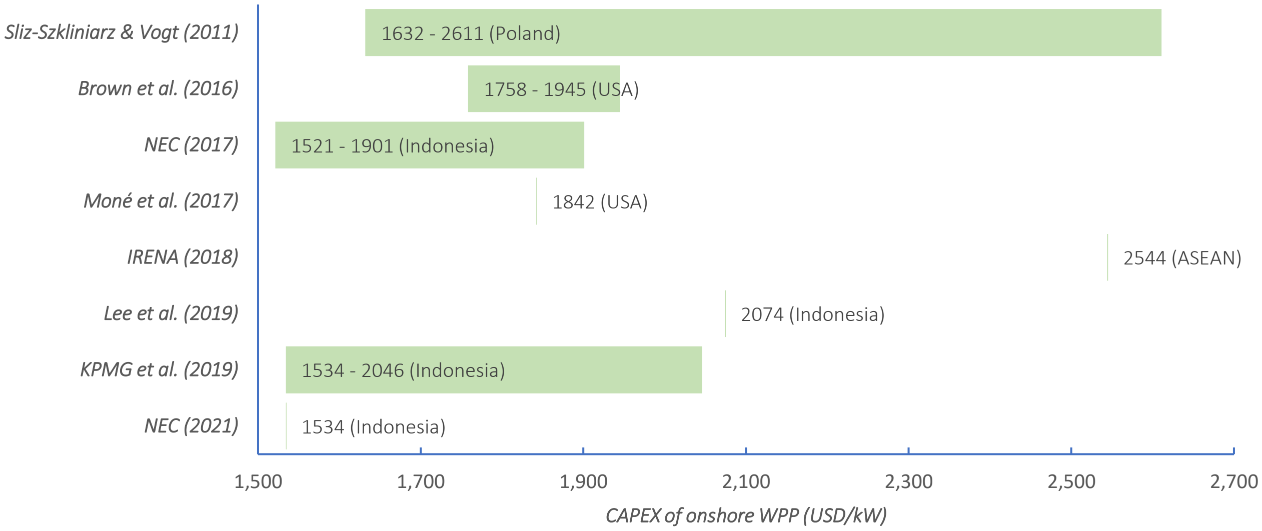

Figure 6. CAPEX of onshore wind power plants in economic WEP studies (A. Brown et al., 2016; IRENA, 2018; KPMG et al., 2019; Moné et al., 2017; NEC, 2017, 2021b; Sliz-Szkliniarz & Vogt, 2011); the underlying data can be found in Table 26 of Appendix B.

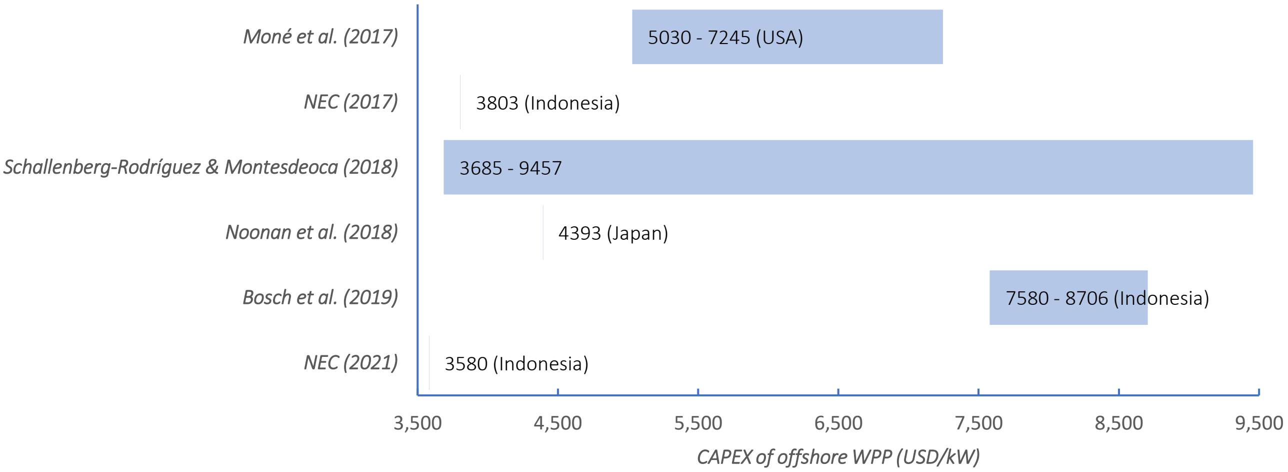

Figure 7. CAPEX of offshore wind power plants in economic WEP studies (Bosch et al., 2019; Moné et al., 2017; NEC, 2017, 2021b; Noonan et al., 2018; Schallenberg-Rodríguez & Montesdeoca, 2018); the underlying data can be found in Table 27 of Appendix B.

CAPEX can be segregated into four parts: turbine cost, foundation cost, installation cost, and transmission cost. For onshore WPPs, turbine cost ranges from 75% to 85% of CAPEX (Sliz-Szkliniarz & Vogt, 2011) depending on wind turbine specification and WPP total capacity. This cost can also be presented as a function of wind turbine rated power (Ali & Jang, 2019; Nagababu, Kachhwaha, & Savsani, 2017). Foundation cost depends on soil structure and water depth: WPPs located at deeper offshore sites entail larger foundation costs (Grassi et al., 2012) due to the foundation type being employed. Notably, foundation cost can be expressed as a function of water depth (Bosch et al., 2019; Nagababu, Kachhwaha, & Savsani, 2017).

Installation cost pertains to wind turbine erection and foundation setting. Thus, installation cost depends on the selected foundation type. Lastly, transmission cost – also known as electrical cost – is largely determined by the cable type (HVDC or HVAC). This cost usually amounts to 2 – 15% of onshore WPP CAPEX (ACE, 2019; Grassi et al., 2012; Sliz-Szkliniarz & Vogt, 2011) depending on site and cable characteristics. Alternatively, the cost can be described by linear equations (Bosch et al., 2019).

In general, total CAPEX for offshore WPP is more expensive than its onshore counterpart because of the necessary additional corrosion protection on its components to withstand harsh environmental conditions, and the costly offshore foundation (NEC, 2021). Additionally, offshore tower and foundation costs can be higher than 2.5 times of its onshore counterpart (Feltes et al., 2012).

3.6.2. Operating and maintenance expenditure (OPEX)

There is a range of OPEX estimates found in the literature. The reviewed studies express OPEX either in nominal value (Brown et al., 2016; Lee et al., 2019; Moné et al., 2017; NEC, 2017; Sliz-Szkliniarz et al., 2019), as a percentage of other costs (see Table 9), or as a linear function (Bosch et al., 2019). Additionally, some studies decompose OPEX into fixed and variable annual expenses (Lee et al., 2019; NEC, 2017; Noonan et al., 2018). The former expense is directly proportional to WPP capacity and can include tools and spare parts, labor, and insurance. Meanwhile, the latter expense is a function of the amount of energy being produced per year (Lee et al., 2019). For offshore WPPs, OPEX also depends on transportation cost, port cost, and site conditions (Bosch et al., 2019). Consequently, OPEX of offshore WPPs is usually 5 – 10 times more expensive than OPEX of onshore WPPs (Nagababu, Kachhwaha, & Savsani, 2017).

Table 9. OPEX values of wind power plants as percentage of other costs as gathered from the literature

Author	*Application*	*OPEX (Annual)*	*Country of application*
Sliz-Szkliniarz & Vogt (2011)	Onshore	3% of CAPEX	Poland
Grassi et al. (2012)	Onshore	4-7% of annual revenues	USA
Bina et al. (2018)	Onshore	2% of CAPEX	Iran
KPMG et al. (2019)	Onshore	4% of CAPEX	Indonesia
Ali & Jang (2019)	Onshore	5% of wind turbine cost	South Korea
Schallenberg-Rodríguez & Pino (2014)	Offshore	2 – 3% of CAPEX	Spain
Schallenberg-Rodríguez & Montesdeoca (2018)	Offshore	2 – 3% of CAPEX	Spain

3.6.3. Decommissioning cost (DECOM)

DECOM is the expenses made in returning the WPP site into its initial state (Bosch et al., 2019). As reviewed by Bosch et al. (2019), DECOM of 1.2 – 2.5% of total project investment is used as an estimate in the literature. On the other hand, KPMG et al. (2019) and Schallenberg-Rodríguez & Montesdeoca (2018) set DECOM cost to zero: revenues received from the sale of steel scrap and secondhand wind turbines are assumed to compensate the expenses endured when uninstalling and removing WPP equipment.

In this chapter, theoretical background for the techno-economic analysis is presented. The information within this chapter will be used to arrive at key modelling decisions, such as in designing the WPPs and determining investment cost assumptions, in Chapter 4.

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Chapter 4. Techno-Economic Analysis: Methodology

Answering SQ1 calls for a techno-economic analysis. According to Blok & Nieuwlaar (2017), the analysis consists of three steps: (1) regional resource availability assessment, (2) sites identification based on economic criteria and physical restrictions, and (3) potential calculation. In this study, the first step is to acquire and prepare wind speed data as the model's input. The second step comprises an application of site selection constraints and a definition of economic parameters. Finally, the previous steps' results are aggregated to calculate technical and economic WEP in the last step.

The following sub-sections provide a description of activities within each techno-economic analysis step: Section 4.1, Section 4.2, and Section 4.3 consecutively describe the first, second, and third step. In general, these activities include input data gathering, preparation, and processing.

A GIS-based approach is adopted to complete the techno-economic analysis. GIS entails hardware, software, and procedures to manage, handle, and generate geospatial data (Arán Carrión et al., 2008; Carton & Ache, 2017; Villacreses et al., 2017). A key feature of GIS is its ability to include, overlay, and analyze numerous data layers which depict regional characteristics in a cost-effective manner (Atici et al., 2015; Sliz-Szkliniarz & Vogt, 2011). Consequently, an integrated evaluation of technical and economic WEP can be performed based on multifaceted and sometimes paradoxical spatial, technical, and economic criteria (Schallenberg-Rodríguez & Montesdeoca, 2018; Sliz-Szkliniarz & Vogt, 2011). In addition, GIS is capable of spatially visualizing relationships among locations on wind resources, constraints, and costs (Nagababu, Kachhwaha, Naidu, et al., 2017). Additionally, GIS facilitates the most detailed potential analysis (Blok & Nieuwlaar, 2017), which is useful for a thorough WEP evaluation. Due to the possibly high cost of GIS data (Meaden & Chi, 1996), this research only use openly-accessible data. Moreover, GIS-related processes are performed in QGIS, an open-source software, with complementary Python programming to perform computations.

4.1. Regional resource availability assessment

This step begins with wind resource data collection from *Renewables.ninja*[4] and the Global Wind Atlas (GWA; DTU Wind Energy et al., n.d.). *Renewables.ninja* provides geospatial *hourly wind speed* data from NASA's MERRA-2[5] reanalysis (Molod et al., 2015; Staffell & Pfenninger, 2016). 'Reanalysis' refers to the product of simulating global weather system based on historic observations over a period of time and space (Staffell & Pfenninger, 2016) in order to cover where no observation is taken. In turn, the platform's *Virtual Wind Farm* model interpolates the wind speeds geographically, before extrapolating them to the desired hub heights based on a logarithmic wind profile (Staffell & Pfenninger, 2016).

A drawback of using MERRA-2 reanalysis from *Renewables.ninja* is the relatively coarse spatial resolution of 0.5° x 0.625° – which corresponds to approximately 50 km at the equator – compared to the area of WPP site in this research (see Subsection 4.2.2). Using the approach of Bosch (2018), the MERRA-2 data is therefore

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[4] Renewables.ninja is a platform to simulate the performance of wind and solar power plants at any location on earth (Pfenninger & Staffell, n.d.).

[5] MERRA-2 stands for Modern-Era Retrospective Analysis for Research and Applications-2.

bias-corrected: *hourly wind speed* values of MERRA-2 are scaled using the *mean wind speed* values of GWA. This bias-correction procedure constitutes the data pre-processing activity of this step.

GWA is selected as the reference in bias-correction because it provides high-resolution *mean wind speed* data, which was obtained by DTU Wind Energy et al. (n.d.) in two processes: mesoscale and microscale modelling. The former process entails the processing of large-scale wind climate data (approximately 30 km grid-spacing) from ECMWF's[6] ERA5 dataset over a simulation period of 2008-2017. The output is a medium-scale wind climate data with 3 km grid-spacing. Subsequently, the medium-scale data is subjected to generalization and further modelling in the latter process. At this microscale level (approximately 0.25 km grid-spacing), GWA incorporates local topographical features such as roughness, roughness change, and orography (Bosch, 2018). Therefore, the final result of GWA modelling is a *mean wind speed* map with approximately 0.25 km resolution.

As mentioned above, the bias-correction involves scaling *hourly wind speed* data using "time-invariant linear scale factors" (Bosch, 2018, p. 69). For instance, if the *mean wind speed* derived from GWA at a certain location is 10% higher than the corresponding average of *hourly wind speed* data of MERRA-2, then each *hourly wind speed* data of MERRA-2 is increased by 10%. Accordingly, the bias-correction procedure retains the seasonal, temporal, and diurnal properties of the MERRA-2 data (Bosch, 2018).

Due to resource limitations, a set of 54 reference *mean wind speed* values of GWA and their corresponding locations/coordinates is employed in the scaling process. These reference data are derived in five steps and summarized in Figure 8. First, the Indonesian territory is divided into 9 wind speed regions (see Figure 9). *Mean wind speed* raster data from GWA is then clipped according to these 9 regions. In turn, each raster clipping is divided into two area classifications: onshore and offshore. Hence, the second step results in 18 raster clippings. Third, *mean wind speed* data-points in each raster clipping are demarcated into three speed levels: high (> 7.5m/s), medium (6 – 7.5 m/s), and low (4 – 6 m/s). This results in 54 groups of data-points. Fourth, data-points within each group are averaged. Consequently, this step results in a total of 54 data-point averages. Fifth, each data-point average is matched with a *representative location*, i.e. a corresponding data-point having an identical *mean wind speed* value, region, area classification, and speed level. The *mean wind speeds* and coordinates of these 54 *representative locations* are used as the reference data.

The reference coordinates, i.e. coordinates of the *representative locations*, are the locations at which *hourly wind speed* profile of MERRA-2 in 2019 are collected from *Renewables.ninja*. Finally, these *hourly wind speed* profiles are bias-corrected using the reference *mean wind speed* values. This process generates 54 bias-corrected *hourly wind speed* profiles that represent wind speed variation at each WPP site within the model.

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[6] ECMWF is the abbreviation of the European Centre for Medium-Range Weather Forecasts.

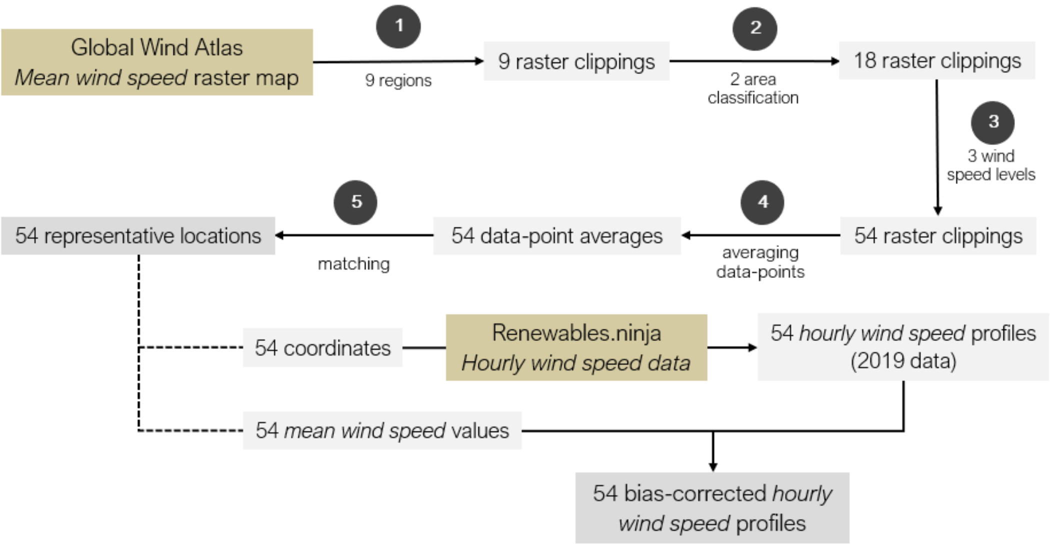

Figure 8. A schematic representation of the procedure to obtain representative wind profiles

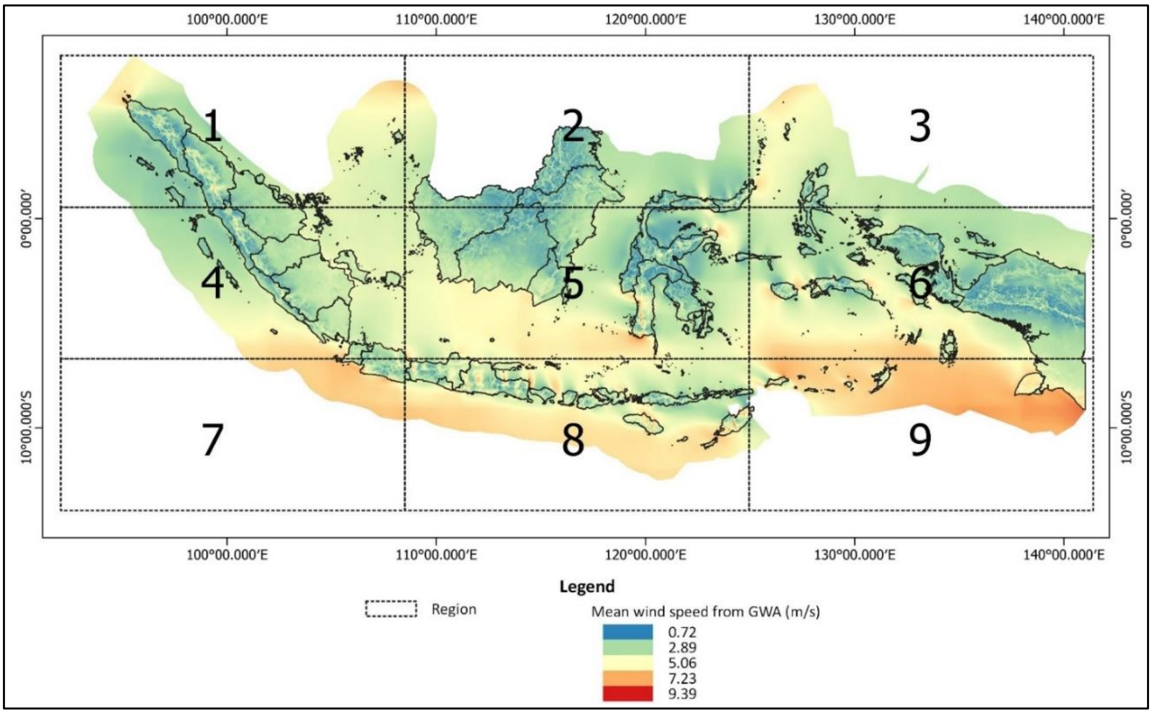

Figure 9. Division of Indonesia into 9 wind speed regions with the region number marked inside each box

4.2. Site selection of wind power plants

Site selection of WPP begins with the design (Subsection 4.2.1) and plotting of WPP (Subsection 4.2.2) in the model. In turn, the plotted WPPs are filtered based on some site selection criteria (Subsection 4.2.3).

4.2.1. Wind power plant design

Selecting a wind turbine based on the wind resource at site is pivotal to obtain an economically favorable WPP. A summary of wind turbine and WPP characteristics being modelled in this study is shown in Table 10. Three criteria are employed to motivate the turbine selection. The first one is turbine class: the class should be in accordance with the wind resource class at site (see Section 3.2). The second criterion is market availability, which is signified by either the turbine's listing on the manufacturers' website or the turbine's deployment in recently commissioned WPPs. The final constraint is the availability of verified turbine power curves with fine speed increments (e.g. 0.01 m/s). Considering these criteria, Vestas V110 2000 and Siemens SWT 4.0 130 are selected as the onshore and offshore wind turbine being modelled, respectively. These turbines are assumed to have a constant 100-m hub height. Additionally, the corresponding single-turbine power curves are sourced from *Renewables.ninja*.

Table 10. Selected wind turbines for onshore and offshore WPP and their attributes

Application	*Wind turbine*	*Rated power (MW)*	*Rotor diameter (m)*	*Turbine class*	*Array size (WPP capacity)*	*Turbine (capacity) density*	*Array efficiency*	*Turbine specification reference*
Onshore	Vestas V110 2000	2	110	III	5 x 5 (50 MW)	0.83 turbine/km^2 (1.65 MW /km^2)	95%	(Vestas Wind Systems, n.d.)
Offshore	Siemens SWT 4.0 130	4	130	I	10 x 10 (400 MW)	0.59 turbine/km^2 (2.37 MW /km^2)	88.55%	(Shanghai Electric, n.d.)

The next step is to define the turbine arrangement within a WPP. Among the different arrangements presented in Section 3.3, this research utilizes 10D-spacing in crosswind and downwind directions for both onshore and offshore WPPs. Furthermore, the onshore WPP array size is set to 5 x 5, resulting in a single-WPP capacity of 50 MW. Such capacity is chosen to mimic the capacities of existing utility-scale onshore WPPs in Indonesia. Accordingly, the array efficiency for onshore WPP is 95% (Bosch, 2018). On the other hand, the array size of offshore WPP is set to 10 x 10 with a single-WPP capacity of 400 MW, which is comparable to the capacities of modern offshore WPPs. Another reason for adopting the large capacity is to safeguard the plant's economic feasibility: considering the economic aspects, Castro-Santos et al. (2018) finds that a floating offshore WPP – which is included in this research – shall have a capacity of at least 100 MW. Consequently, the offshore WPP array efficiency is 88.55% (Bosch, 2018; Bosch et al., 2019).

It is noteworthy that the aforementioned WPP design implies a fixed capacity for each onshore WPP and offshore WPP being employed in this study. This is due to the available transmission cost functions and the WPP capacities to which they apply (see Subsection 3.6.1 and 4.3.2). Different WPP capacities may entail different cost functions, considering the number of connections needed between the turbines and the possibilities for economies of scale.

In addition to the array efficiency, transmission loss stemming from electrical instruments in a WPP is assumed to be constant at 3% for both HVAC and HVDC cables (Bosch et al., 2019). This value is within the 2-5% range as described in Section 3.3. Finally, this study assumes an operational efficiency of 95% for both onshore and offshore WPP. This figure is within the aforementioned range in Section 3.3. In the onshore case, 95% is selected since the value lies between operational efficiency assumption for a developing country of 90% (Deng et al., 2015) and a figure from the industry of 97% (Bosch, 2018). For simplicity, the operational efficiency of offshore WPP is assumed to be independent of distance from shore.

4.2.2. Wind power plant plotting in QGIS

After determining the characteristics of onshore and offshore WPP, each WPP is represented by its centroid point in QGIS with EPSG 4326 (WGS84) Coordinate Reference System. Figure 10 presents an illustration of the relative positions of the WPP centroids with respect to the WPP site. Spacing between WPP centroid points is calculated by aggregating total inter-turbine spacing in the vertical and horizontal direction. Notably, an extra 5D distance is added to all four edges of the WPP so that the same 10D-spacing is preserved between the turbines of neighboring WPPs.

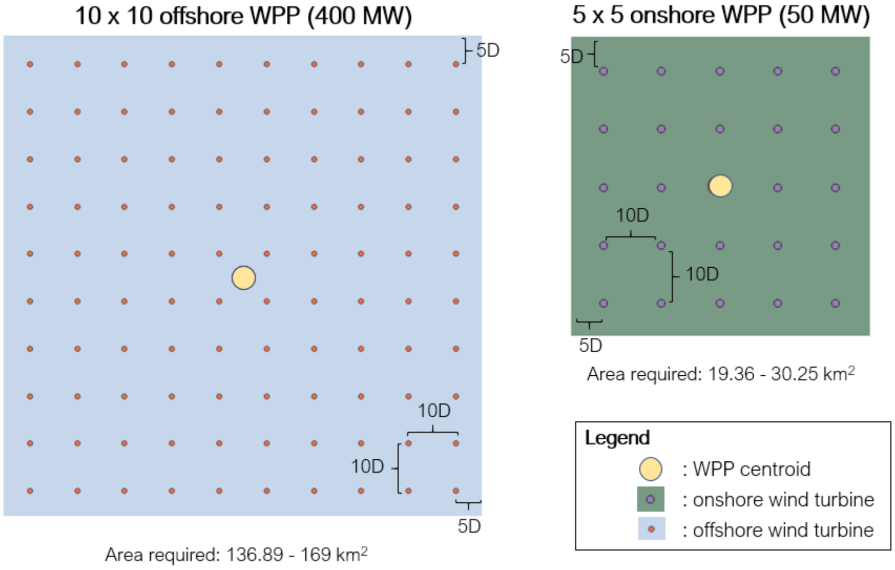

Figure 10. A schematic representation of offshore and onshore WPP arrangement in the model; the area required, which is written at the bottom of each offshore and onshore WPP illustration, ranges from the 'adjusted WPP area' to the ideally required area as calculated based on the displayed inter-turbine distances

	Point-grid	**Square-grid**
Site attribute value (Raster-based)	Point sampling	Areal sampling
Intersection with ineligible areas (Vector-based)	Point removal	Area cropping/reduction

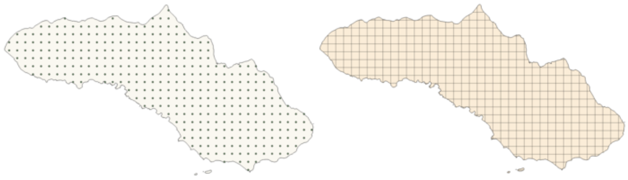

Figure 11. An illustration showing the difference between point-grid and square-grid approach

These centroids are plotted in QGIS using two different approaches: point-grid and square-grid approach (see Figure 11). The point-grid approach is conducted by directly plotting the centroids as point-grid with equal vertical and horizontal distance of 0.496° (~ 5.5 km) and 0.117° (~13 km) for onshore and offshore WPP, respectively. In turn, these points are filtered via a site selection process based on the attributes of each point. Points having attribute values outside the permissible thresholds and/or intersecting with ineligible zones for WPP deployment are removed in the process (see Table 11).

On the other hand, the square-grid approach is done by first applying square-grids with the above-mentioned dimensions for onshore and offshore WPP. Site selection is then performed by contrasting attribute values (e.g. elevation and mean wind speed) contained within each square against the permissible thresholds. The attribute values of each square are represented by their average, or their minimum and maximum. Moreover, areas of each square which intersect with ineligible zones for WPP are cropped. In other words, the intersecting area is removed, while the remaining area within the square is still considered eligible. After the removal process is completed, a square with area less than the *adjusted WPP area* is considered ineligible and thus removed. The *adjusted WPP area* is determined by removing the 5D inter-WPP distance (see Figure 10). The reason for adopting this *adjusted WPP area* concept is the isolated nature (i.e. not adjacent to another eligible site) of some eligible WPP sites. Hence, the 5D inter-WPP distance does not need to be considered. *The adjusted area* is set to 19.36 and 136.89 km^2 for onshore and offshore WPP, respectively. After completing the site selection process, each remaining square is equipped with a centroid to represent the WPP in subsequent potentials calculation.

Both point-grid and square-grid approach are employed to obtain upper and lower estimates of WEP. In the point-grid approach, removal of a point due to its intersection with an ineligible zone may underestimate the eligible area for WPP: the remaining area represented by the point is completely removed from consideration regardless of the remaining area's eligibility. On the other hand, there is also a possibility that the remaining points actually represent an area less than the *adjusted WPP area*. Hence, this causes an overestimation of eligible sites. The square-grid approach alleviates the overestimation and underestimation issue of the point-grid approach through a more precise area subtraction process. Nevertheless, the square-grid approach also entails a possible eligible area underestimation: squares which contain attribute values violating the allowable ranges are completely removed from consideration regardless of the violation's extent. For instance, a 30.25-km^2 square containing only 1 km^2 area with elevation above 2,000 m is completely removed in the site selection process. Considering the characteristics of both approaches, this study uses point-grid and square-grid approach to provide upper-bound and lower-bound WEP estimate, respectively.

4.2.3. Site selection criteria

Most of the site selection criteria and their buffer or threshold values shown in Table 6, Table 7, and Table 8 of Section 3.5 are adopted in this study. Properties and data sources of the adopted criteria are listed in Table 11. Two types of data are utilized for WPP siting, namely, vector and raster data.

After collecting and preparing the data, site selection of onshore and offshore WPP is conducted in two steps (see Figure 11). Firstly, WPP sites are removed based on the attributes derived from the raster datasets. In the point-grid approach, *point sampling* of *mean wind speed*, *elevation*, *ocean floor depth*, and *slope* are employed to capture the attribute values of each site. Hence, this approach assumes the sampled data to fully represent the characteristic of the corresponding WPP site. Afterwards, WPP sites with attribute values exceeding the thresholds (as shown in the *Remarks* column of Table 11) are removed. Site removal based on raster-based attributes is done differently in the square-grid approach: each square is equipped with an aggregated form of attribute values that are contained within the square. Filtering based on *mean wind speed* is conducted by discarding sites that have an average of *mean wind speed* value less than 4 m/s. Furthermore, the minimum and maximum values of *elevation* and *slope* of each square is utilized to remove squares containing *elevation* larger than 2,000 m and/or *slope* greater than 30%.

Table 11. Site selection criteria for WPP siting

Group	*Criteria*	*Buffer (m)*	*Pixel size (for raster)*	*Buffer/threshold value reference*	*GIS data source*	*Remarks*
General	Provincial boundaries	-	-	-	OpenStreetMap data (Ground Zero Communications AB, 2021)	
	Mean wind speed	-	0.0025° (~ 0.28 km)	(MEMR, 2017)	Global Wind Atlas (DTU Wind Energy et al., n.d.)	Areas having mean wind speed < 4 m/s at 100 m hub height are excluded from consideration. This data limits the distance from shore to 200 km for offshore sites.
	Protected areas and forest	300	-	(Grassi et al., 2012) in Table 6	Onshore and offshore: (MoEF, 2017)	Production forest, convertible production forest, and limited production forest are assumed to be eligible for WPP siting.
					Offshore: (Geospatial Information Agency, n.d.-b)	
Offshore	Ocean floor depth	-	0.0083° (~ 0.92 km)	(Bosch et al., 2019; Deng et al., 2015; ESMAP, 2019) in Table 7	GEBCO data (MRC of MMAF, 2013)	Offshore areas with seabed depth > 1,000 m are excluded from consideration.
	Economic Exclusive Zone	-		-	Maritime Boundaries Geodatabase (Flanders Marine Institute, 2019)	
	Artisanal fishing	-	0.93 km	-	(Halpern et al., 2015)	
	Submarine cables	1,000	-	(Bosch et al., 2019) in Table 7	TeleGeography submarine cable map (TeleGeography, 2021)	
Onshore	Elevation	-	0.0083° (~ 0.92 km)	(Bina et al., 2018; Deng et al., 2015; Sliz-Szkliniarz & Vogt, 2011) in Table 6	GTOPO30 digital elevation model (US Geological Survey, 1996)	Onshore areas with elevation > 2,000 m are excluded from consideration.
	Slope	-	-	(Sah & Wijayatunga, 2017) in Table 6	Processed from elevation data	Onshore areas with slope > 30% are excluded from consideration.
	Land use	250	-	(Schallenberg-Rodríguez & Pino, 2014; Sliz-Szkliniarz & Vogt, 2011) in Table 6	OpenStreetMap data (Geofabrik & OpenStreetMap, 2021)	Areas excluded include residential, industrial, commercial, retail, military, cemetery, recreation ground, orchard, vineyard, farmland, and farmyard.
					(Geospatial Information Agency, n.d.-a)	This data encompasses areas of settlement and activity.
					Land cover data (MoEF, 2017)	Only settlement and transmigration area layers of this data are applied for site selection.
	Water bodies and waterways	300	-	Middle value of (Bina et al., 2018; Grassi et al., 2012; Sliz-Szkliniarz & Vogt, 2011) in Table 8	OpenStreetMap data (Geofabrik & OpenStreetMap, 2021)	Waterways include rivers and streams.
	Airports and airfields	3,000	-	(Latinopoulos & Kechagia, 2015; Sliz-Szkliniarz & Vogt, 2011) in Table 8	OpenStreetMap data (Geofabrik & OpenStreetMap, 2021)	
	Roads and railways	150	-	(Grassi et al., 2012; Latinopoulos & Kechagia, 2015) in Table 8	OpenStreetMap data (Geofabrik & OpenStreetMap, 2021)	Categories of roads being considered as ineligible for WPP siting are major roads, minor roads, and highway links.

Secondly, site removal and cropping are performed by intersection with vector datasets such as protected areas and forest. Buffer areas are added to some datasets in this step to ensure there is enough distance between the ineligible zones and the WPP sites. Subsequently, *difference* vector geoprocessing tool is operated in QGIS to remove the intersecting areas. Therefore, the remaining area resulted from this second step is considered eligible for WPP deployment.

4.3. Technical and economic potential calculation

The penultimate step of the techno-economic analysis is divided into three parts: technical potential assessment, economic potential assessment, and effect of natural disaster proneness.

4.3.1. Technical potential assessment

Technical potential assessment starts with the calculation of AEP for each *wind profile*. Power output for each hour is computed by matching the bias-corrected *hourly wind speed* data with the single-turbine power curve. The hourly power output is then aggregated for the whole year to generate a unique AEP value for each *wind profile*. In turn, a Python program matches the AEP values to each eligible WPP site based on the site's wind speed region (as shown in Figure 9) and speed level.

Technical potential indicators in this study include APO, CF, and nominal WPP capacity. APO is calculated by the following formula:

Equation 2. Average power output (APO) formula

$$APO\ [GW] = \frac{AEP\ [GWh]\ \times \eta_{trans} \times \eta_{op} \times \eta_{arr}}{8760}$$

Transmission efficiency (η_{trans}) is equal to 1 – *transmission loss*. Furthermore, η_{op} and η_{arr} represent operational efficiency and array efficiency, respectively. CF of each WPP is derived from the formula listed in Table 2. Finally, nominal WPP capacity is obtained by summing all WPP capacities at the eligible sites.

4.3.2. Economic potential assessment

Connection to demand centers

Connection points, which represent electricity demand centers, are firstly added to QGIS. These points comprise capitals at several layers of government: national capital, provincial capital, regency capital, and Kota (see Figure 42 of Appendix C). The capitals dataset is collected from the Humanitarian Data Exchange platform (UN OCHA, 2016). Existing power substations as mapped in MEMR Geoportal (see Figure 43 of Appendix C) is not used as connection points since the substations are highly concentrated in the western and central part of Indonesia; there are only a few substations in the eastern part. Notably, electricity demand profile at the connection points is out of the scope of this research.

WPPs are connected to their respective demand centers based on shortest distance by using *Distance to nearest hub* tool in QGIS. These connections are established as straight lines at onshore and/or offshore areas. Since it is possible for a line to cross onshore and offshore areas, each line is partitioned into onshore and offshore segments: line segments at onshore areas are considered as land transmission cables, whereas the segments at offshore areas are designated as submarine transmission cables. Land and submarine cable distances are then stored as attributes of each WPP.

Determination of wind power plant costs

Economic potential assessment continues with data gathering of costs. Section 3.6 highlights a range of costs depending on the study's location. Accordingly, the costs assumed in this research are derived from similar techno-economic studies on Indonesia and on neighboring countries. Therefore, the costs can adequately represent the Indonesian context. In case the costs are unavailable in the reviewed literature, they are approximated with some assumptions. This is motivated by the limited experience of wind power generation in Indonesia, which leads to only a small amount of reliable statistical cost data being available (NEC, 2021b). Costs which are calculated based on these approximated values are validated against empirical data. The complete cost assumptions can be found in Table 12. Unless stated otherwise, cost figures presented in this study are inflation-adjusted to USD (2020). An elaboration on how each cost component is derived are presented in the next paragraphs.

Table 12. Cost assumptions being used in this research (x: transmission distance (km); d: depth (m))

Cost component		*Value or function*	
		Onshore WPP	*Offshore WPP*
CAPEX	**Turbine and others** *[USD/kW]*	1,940.30	2,449.50
	Land transmission *[USD/kW/km]*		
	HVAC	$2.72 x + 18.20$	$9.27 x + 61.91$
	HVDC	$0.71 x + 124.23$	$2.40 x + 422.70$
	Submarine transmission *[USD/kW/km]*		
	HVAC	$9.27 x + 61.91$	$9.27 x + 61.91$
	HVDC	$2.40 x + 422.70$	$2.40 x + 422.70$
	Foundation *[USD/kW/m]*	included in *turbine and others cost*	
	Monopile (d < 25 m)	-	$0.22 d^2 + 0.67 d + 448.50$
	Jacket (25 < d < 55 m)	-	$0.12 d^2 + (-2.47) d + 579.59$
	Floating TLB (55 < d ≤ 1,000 m)	-	$0.84 d + 741.91$
OPEX		3% of CAPEX per year	
Decommissioning cost		0	
Project lifetime		20 years	
WACC		10%	

Turbine and others cost

Turbine and others cost for onshore WPP is derived through a few steps. First, the typical onshore WPP CAPEX is assumed to be 2,109 USD/kW (Lee et al., 2019) as shown in Figure 6. *Turbine cost* is calculated by multiplying CAPEX with the share of turbine cost within CAPEX, which generally ranges from 71 to 85% (ACE, 2019; Moné et al., 2017; Sliz-Szkliniarz et al., 2019). This research takes 74.5% as the representative share (ACE, 2019), and thus, the turbine cost amounts to 1,571 USD/kW. Moreover, *others cost* includes other costs than those of turbine and transmission: foundation, project development, plant commissioning, engineering management, access-to-site, and installation and assembly cost. Computing *others cost* requires demarcation of transmission cost from CAPEX. The share of transmission cost in CAPEX can range from 2 to 15% (Grassi et al., 2012; Lee et al., 2019; Moné et al., 2017; Sliz-Szkliniarz et al., 2019). Setting the transmission cost share to 8%

(Grassi et al., 2012) leaves *others cost* share to be 17.5% or equivalent to 369 USD/kW. Finally, adding *turbine cost* and *others cost* results in a *turbine and others cost* of 1,940 USD/kW.

For offshore WPPs, *turbine and others cost* are determined differently. Because the corresponding cost assumptions are not available for Indonesia and ASEAN, the assumed *turbine cost* in Japan of 1,856 USD/kW is employed in this study (Noonan et al., 2018). This figure is consistent with the assertion of Feltes et al. (2012): offshore *turbine cost* is typically 20% more expensive compared to the onshore counterpart. Furthermore, the *others cost* encompasses costs other than those of transmission, foundation, and turbine. *Others cost* is approximated to be 34.67% of *turbine cost* (Noonan et al., 2018). In total, the offshore *turbine and others cost* amounts to 2,449 USD/kW.

Transmission cost

Transmission cost is set as a function of transmission distance and WPP capacity. HVAC cables are used for transmission distances up to 56 km, while HVDC is opted for greater distances (see Section 3.6.1). For offshore WPP, the cost function is taken from Bosch et al. (2019) for 500 – 1,000 MW offshore WPPs. The function covers the required cable, switchgear, substation, and transformer costs (Bosch et al., 2019). Importantly, the land and submarine *transmission cost* for offshore WPP are conservatively assumed to be equal.

On the other hand, *transmission cost* of onshore WPP is distinguished for land and submarine transmission in order to accurately calculate the economic potential of WPPs at 'power islands'. Exemplified in Figure 12, a 'power island' is defined as an island that contains suitable areas for WPP; however, the island does not have any *connection point*. Hence, the electricity generated by the WPP must be transmitted through a combination of submarine and land cables. Submarine *transmission cost* of onshore WPP follows the corresponding cost function of offshore WPP. Land *transmission cost*, however, is based on an approximation since a distance-dependent cost function is not available in the reviewed literature. According to the study of Moné et al. (2017), land *transmission cost* is roughly equivalent to 37.5% and 21.3% of a typical fixed offshore WPP and floating offshore WPP transmission cost, respectively. The average of the two percentages (29.4%) is multiplied by the submarine *transmission cost* functions to arrive at the approximated land *transmission cost*.

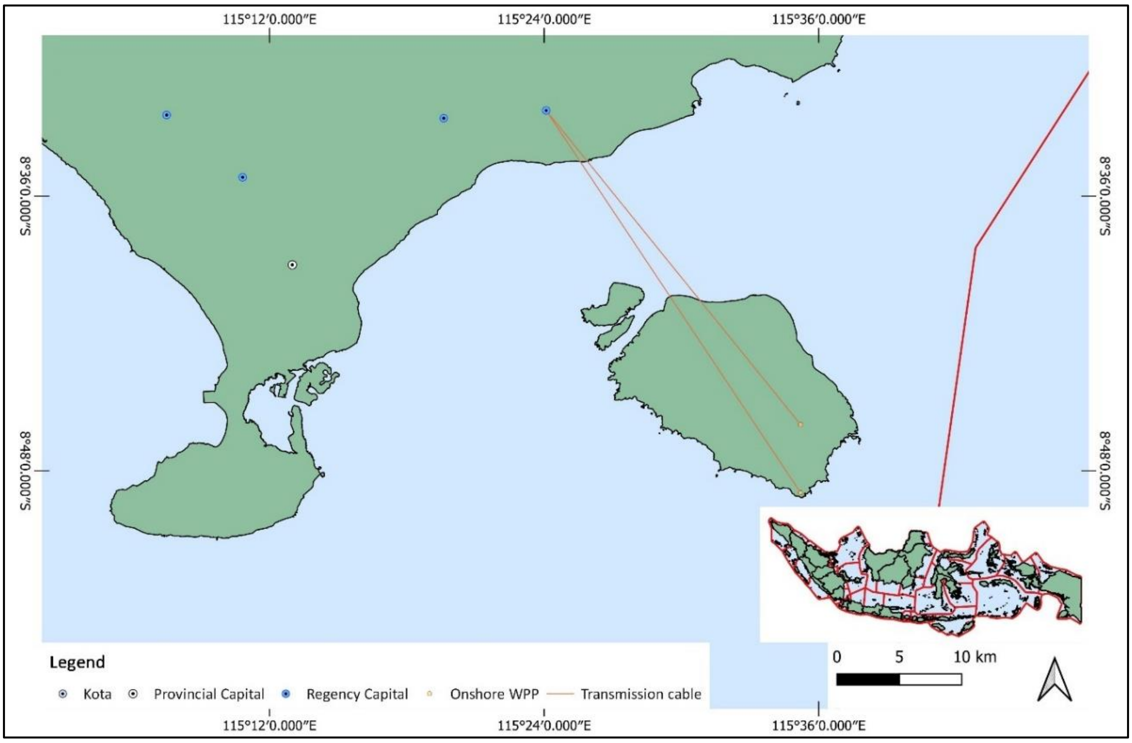

Figure 12. An example of a 'power island'

Foundation cost

As previously described, *foundation cost* of onshore WPPs is already included in *turbine and other costs*. For offshore WPP, however, *foundation cost* is categorized based on three foundation types (see Section 3.4) as derived from Bosch et al. (2019). As shown in Table 12, these types encompass monopile, jacket, and floating TLB. Moreover, the water depths to which each foundation type applies is determined by aggregating the corresponding values used in other studies (see Table 5). Finally, total onshore and offshore CAPEX assumed in this study is theoretically validated by a comparison with CAPEX values from other studies and empirical project data (see Section 5.6).

Other cost parameters

OPEX, decommissioning cost, project lifetime, and weighted average cost of capital (WACC) are assumed to be equal for both onshore and offshore WPP. OPEX is assumed to be 3% of CAPEX (Sliz-Szkliniarz & Vogt, 2011), which roughly corresponds to the median of the ranges found in literature (see Table 9). Moreover, decommissioning cost is set to zero (KPMG et al., 2019; Schallenberg-Rodríguez & Montesdeoca, 2018) for the reason explained in Subsection 3.6.3. WACC, or the effective discount rate, is assumed to be 10% (Langer et al., 2021). A detailed derivation such WACC figure can also be found in KPMG et al. (2019). Cost calculation of each WPP is followed by LCOE computation (see Table 2 for the formula). Both processes are performed using a Python program. CRF, one of the variables of LCOE, is described by Equation 3. In the equation, *n* represents the project lifetime.

Equation 3. The formula for Capital Recovery Factor (CRF)

$$CRF = \frac{WACC}{1 - (WACC + 1)^{-n}}$$

Economic potential indicators

The product of economic potential assessment is geospatial LCOE data of onshore and offshore WPP. The data is theoretically validated in Section 5.7 by comparing the computed LCOE values with those of similar studies on ASEAN countries (ACE, 2019; Lee et al., 2019) and estimates provided by IESR[7] (2019). Another product of the assessment is the aggregate APO of WPPs having LCOE lower than or equal to the *maximum allowable electricity purchase price* or *PPA tariff* (Langer et al., 2021). This aggregated APO will be referred to as *economic APO* from here onwards. Economic APO is complemented by nominal economic WPP capacity, namely, the aggregate of capacities of economically viable WPPs. A complete description of the current electricity pricing scheme in Indonesia will be described in the institutional analysis (see Chapter 7). The techno-economic analysis model, however, does not fully follow the prevailing pricing regulation because in some cases, the maximum allowable PPA tariff is determined by negotiation between the independent power producer (IPP) and PLN. Since PLN wishes to prevent the increase of national-average BPP[8], the model assumes the following conditions:

- If regional BPP > national-average BPP: the maximum allowable PPA tariff is 85% of the regional BPP
- If regional BPP ≤ national-average BPP: the maximum allowable PPA tariff is 100% of the regional BPP

In this study, sensitivity analysis is performed in two ways. Firstly, the effect of varying parameters that determine LCOE (e.g. CAPEX and OPEX) by +/- 20% with respect to average LCOE is quantified. Secondly, the analysis is performed on the national economic APO by applying a range of hypothetical FiT and WACC.

4.3.3. Effect of natural disaster proneness

Indonesia is located at the junction of three major tectonic plates, i.e., Indo-Australia, Eurasia, and Pacific plate. As a result of tectonic activities, a volcanic arc is formed through the major islands of Indonesia. The arc is part of the *Ring of Fire* (NBDM, 2016). As a result, Indonesia is prone to geological natural disasters such as earthquake, tsunami, volcano, and landslide. It is therefore important to consider the impact of natural disaster proneness on the calculated potentials. The impact is quantified by categorizing the onshore WPP sites into four types of disaster-prone zones. A map of earthquake-prone zones is gathered from Infrastructure GIS of the Ministry of Public Works and Public Housing (n.d.). Furthermore, the map for land slide-, tsunami-, and volcano-prone zones are sourced from MEMR Geoportal (MEMR, n.d.).

Zonal classification of disaster-proneness is defined in MEMR MD 11/2016 (2016) on the determination of geological natural disaster-prone zones. Earthquake-prone zone and landslide susceptibility zone are each comprised of four zonal categories: high, medium, low, and very low. Since the map for these two disasters covers all of Indonesia's islands, onshore WPPs are subjected to *Join attributes by location* tool of QGIS to obtain their corresponding zonal categories. Meanwhile, volcano-prone areas are classified based on three levels: high (KRB III), medium (KRB II), and low (KRB I). There are three types of volcanoes: type A, type B, and type C. Type A and type B volcano have a history of eruption after and before 1600, respectively. On the contrary, type C volcano does not have any history of eruption (MAGMA Indonesia, 2020). Tsunami-prone areas are also classified into three levels: high, medium, and low. Since the maps of volcano- and tsunami-prone zones only cover a few regions with relatively small area, a 0.025° (~2.75 km or half of the onshore WPP dimension) buffer is applied to onshore WPPs. Subsequently, these buffered areas are intersected with volcano- and tsunami-proneness layers in QGIS. If a WPP site intersects with two levels of zoning, then the

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[7] IESR stands for Institute for Essential Services Reform, an Indonesian think-tank focusing on energy and the environment.

[8] BPP is the abbreviation of *Biaya Pokok Penyediaan Pembangkitan*, i.e. the cost of electricity provision by PLN which includes power generation and excludes transmission.

higher proneness level is considered. Lastly, the technical and economic WEP are classified according to the levels of proneness with respect to each natural disaster type.

This chapter has presented the methodology of the techno-economic analysis of this research. The methodology is divided into three steps, which are aimed at the assessment of technical and economic WEP. In the next chapter, the results of the analysis are presented.

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Chapter 5. Techno-Economic Analysis: Results

This chapter starts with site selection results in Section 5.1. Subsequently, Section 5.2 and 5.3 display technical and economic WEP modelling results, respectively. Finally, this chapter is concluded by presenting the impact of natural disaster proneness and sensitivity analysis in Section 5.4 and 5.5, respectively.

5.1. Site selection outcome

WPP site selection results are summarized in Figure 13. Onshore WPP sites are firstly narrowed-down based on *mean wind speed* criterion. A majority of these sites (54,781 sites for point-grid approach and 60,546 sites for square-grid approach) are removed from further consideration in this step due to having *mean wind speeds* less than 4 m/s. Among the initial number of sites, 1,403 and 2,384 sites are excluded due to high *elevation* in the point-grid and square-grid approach, respectively. Meanwhile, the number of sites exceeding *slope* threshold amounts to 291 (point-grid) and 2,211 (square-grid) sites. Other important exclusion criteria include *land use and protected areas*, which highly affect WPP siting in densely-populated islands such as Java. Onshore site filtering process results in 3,487 and 2,037 onshore WPP sites for point-grid (upper-bound) and square-grid approach (lower-bound), respectively.

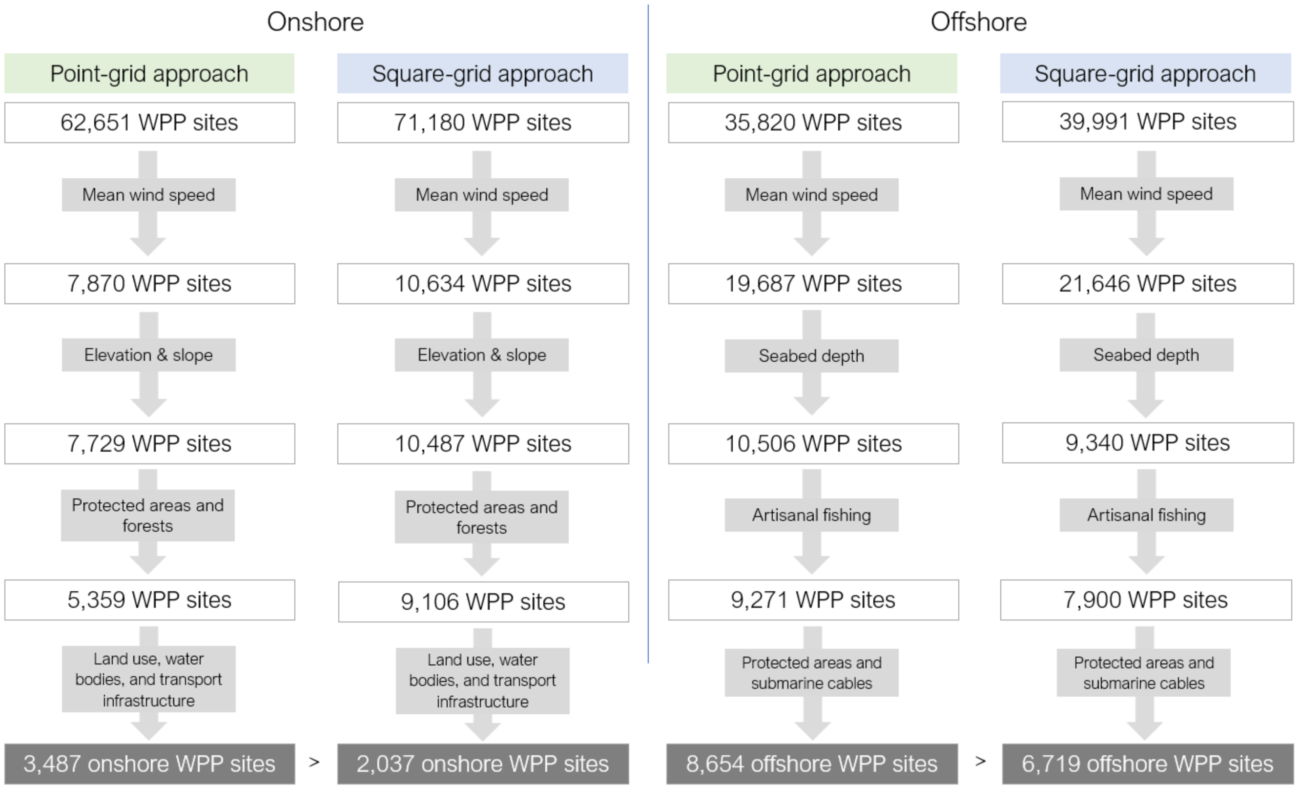

Figure 13. A summary of onshore and offshore WPP site selection result using the point-grid and square-grid approach

Offshore site filtering is largely affected by *mean wind speed* and *seabed depth* criteria. As will be shown in Section 5.3, these sites are largely concentrated in Java Sea and Arafura Sea. The main determinant for this spatial distribution is *seabed depth* (see Figure 14): most areas in Celebes Sea, Banda Sea, and the Indian Ocean are unsuitable for offshore WPP due to seabed depths larger than 1,000 m. Consequently, a total of 20,377 and 23,516 sites are deemed ineligible based on this criterion for point-grid and square-grid approach, respectively. This means numerous sites with relatively high mean wind speeds located in the Indian Ocean and Banda Sea are excluded. Moreover, areas such as Makassar Strait and the northern part of Banda Sea are ineligible for WPP based on *mean wind speed* and *seabed depth* thresholds. Based on the initial number of sites, the point-grid and square-grid site selection results in 16,133 and 18,345 sites having *mean wind speed* less than 4 m/s. Additionally, excluding artisanal fishing areas also results in an appreciable reduction of eligible WPP sites. This may have a considerable impact in the WEP calculation, particularly with respect to the economic potential: WPP sites situated at the fishing areas are quite near to shore, and hence, these sites can have lower transmission costs. Overall, applying site selection criteria to offshore sites produces 8,654 and 6,719 offshore WPP sites for point-grid (upper-bound) and square-grid approach (lower-bound), respectively.

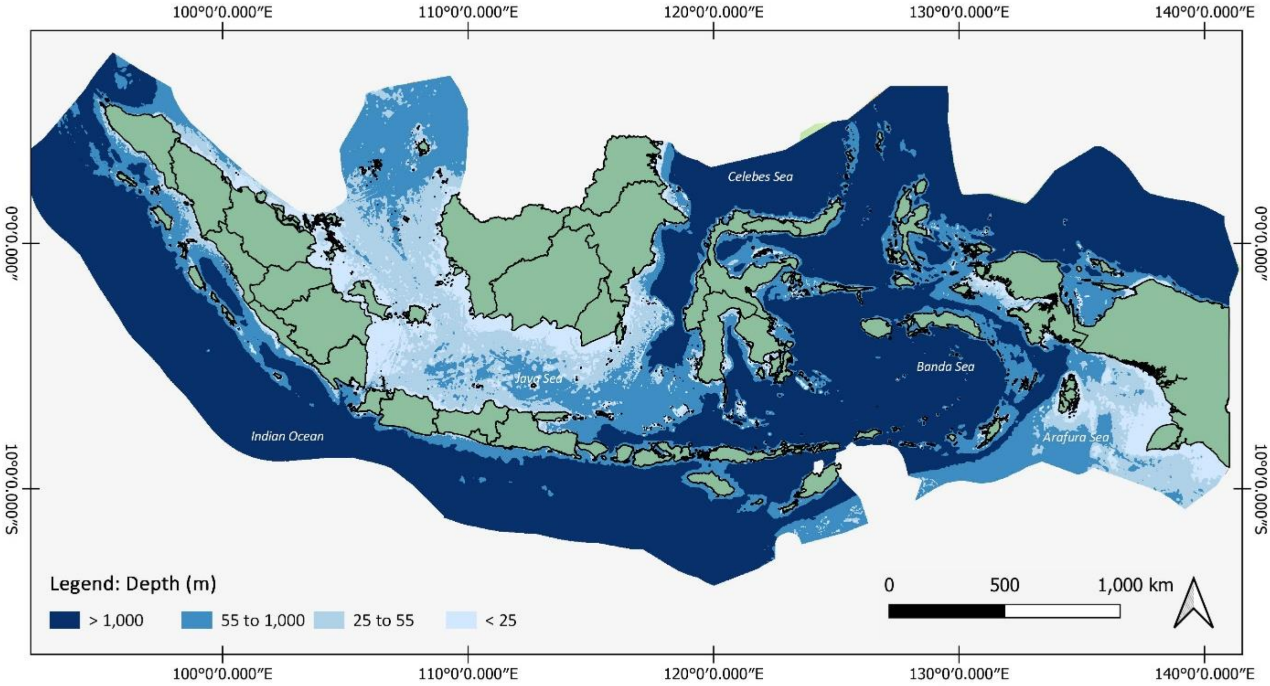

Figure 14. A map of seabed depth within Indonesia's EEZ showing the large amount of area being ineligible for offshore WPP; depth symbol categorization is based upon the range of offshore WPP foundation application

5.2. Technical potential of wind energy

In this section, technical potential of wind energy is firstly described by APO. The national APO of the modelled onshore and offshore WPP using point-grid and square-grid approach is shown in Figure 15. The point-grid approach provides an upper estimate to the national APO of onshore WPP (30.9 GW), whereas the square-grid approach provides the lower estimate (17.6 GW). Meanwhile, the nominal onshore WPP capacity is 174.4 GW and 101.9 GW respectively for point-grid and square-grid approach.

For the offshore WPP, the national APO amounts to 595.6 and 470.6 GW for point-grid and square-grid approach, respectively. This corresponds to a nominal offshore WPP capacity of 3,461.6 GW (point-grid) and 2,687.6 GW (square-grid). Therefore, the total technical WEP ranges from 488.2 to 626.5 GW, whereas the total nominal WPP capacity is 2,789.5 – 3,636 GW. These figures correspond to an AEP of 4.3 to 5.5 million GWh, which is roughly equivalent to 15 – 19 times the national electricity consumption in 2019 (DGE MEMR, 2020), or 1.9 – 2.5 times the consumption in 2050 according to the Business-as-Usual scenario of NEC (Suharyati et al., 2019).

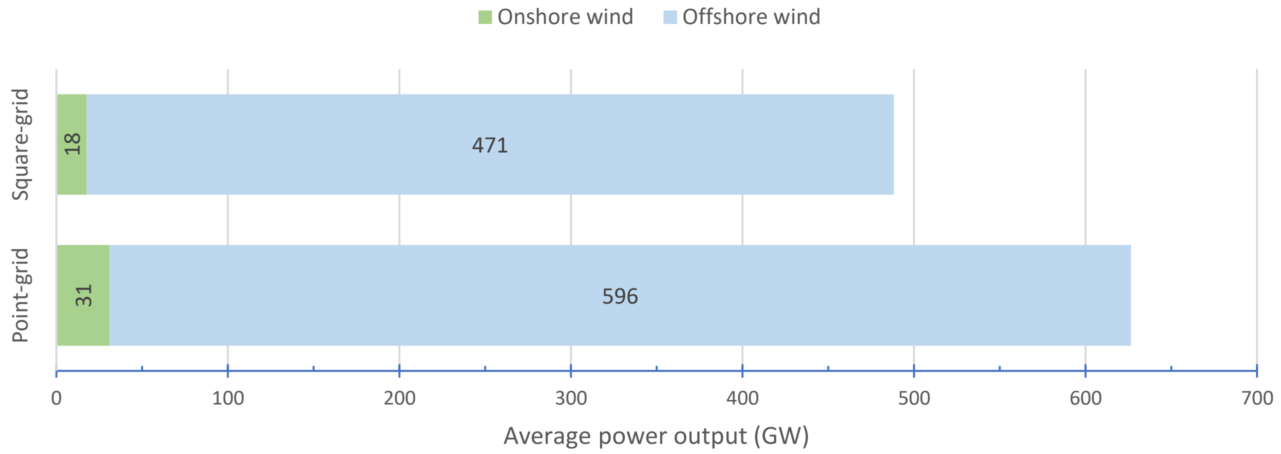

Figure 15. Average power output of the onshore and offshore WPP stemming from point-grid and square-grid approach; figures in the bar chart are rounded to the nearest integer

Besides nationwide APO, another notable aspect of the technical potential is its spatial distribution. Appendix D presents APO of each province for point-grid and square-grid approach. For onshore wind, Papua has the largest APO (5.1 – 5.5 GW), followed by Maluku (2.9 – 4.3 GW), Nusa Tenggara Timur (1.8 – 3.4 GW), and Sulawesi Selatan (1.3 – 2.3 GW). Additionally, Maluku has the biggest offshore wind APO (107.0 – 134.7 GW). It is subsequently trailed by Papua (97.6 – 108.4 GW), Kepulauan Riau (71.0 – 87.9 GW), and Jawa Timur (33.0 – 41.9 GW). This observation is explained by the concentration of WPP sites in Java Sea and Arafura Sea. Overall, such spatial distribution suggests wind power generation being more favorable in the eastern part than in the western part of Indonesia.

Table 13. Statistics of capacity factor (CF) generated by the model for offshore and onshore WPP

Application	*Approach*	*Capacity factor (%)*			
		Min	*Max*	*Average*	*Median*
Onshore	Point-grid	12.93	56.56	17.74	17.81
	Square-grid	12.93	40.01	17.32	17.81
Offshore	Point-grid	11.90	40.96	17.18	14.04
	Square-grid	11.90	40.96	17.51	14.04

The next description of technical potential is CF. Table 13 presents the statistics of capacity factor calculated for onshore and offshore WPP based on the two approaches. It is important to note that energy losses are factored into the CF computation. Moreover, validation of CF by direct comparison against corresponding values from similar studies is not performed because CF largely depends on the assumed wind farm capacities. An interesting insight from Table 13 is that there is relative agreement between CF figures derived by point-grid and square-grid approach. In addition, onshore WPPs with the largest CF are located in Nusa Tenggara Timur and Jawa Tengah if the square-grid approach is adopted. The point-grid approach situates onshore WPP having the largest CF in Sulawesi Selatan. Meanwhile, Papua hosts offshore WPPs with the largest CF in both approaches.

5.3. Economic potential of wind energy

This section is divided into two subsections: onshore and offshore wind economic potential. In each subsection, the economic potential is sequentially characterized by LCOE, economic APO, and nominal economic WPP capacity.

5.3.1. Onshore wind economic potential

The range of LCOE from the modelled 50-MW onshore WPP is shown in Figure 16. According to the point-grid approach, onshore wind LCOE can reach as low as 6.1 USD ct/kWh. Meanwhile, the square-grid approach assigns a larger minimum LCOE value of 8.7 USD ct/kWh.

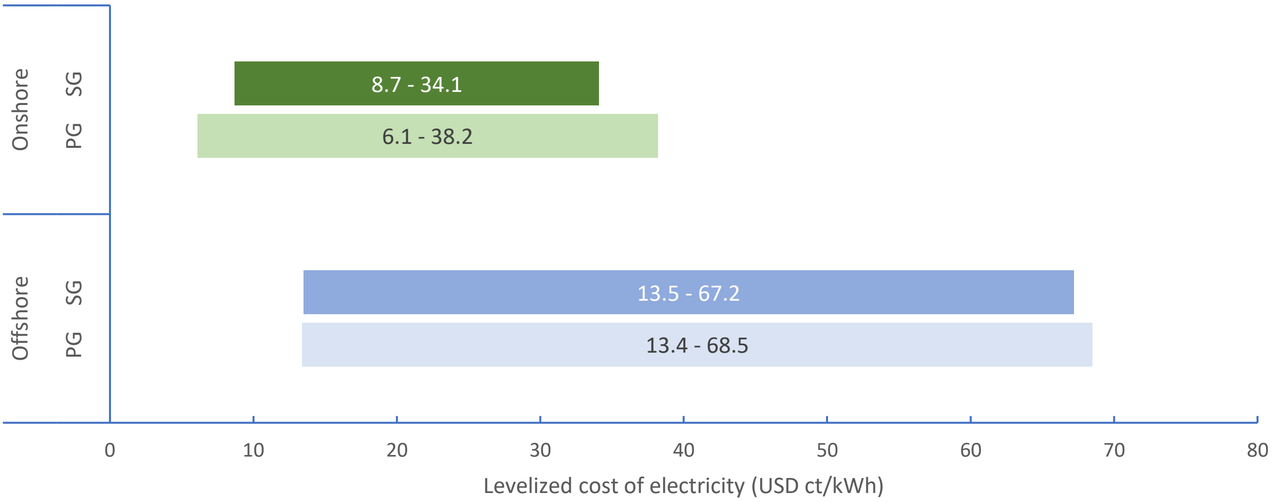

Figure 16. LCOE range of onshore and offshore WPP (PG: point-grid approach; SG: square-grid approach)

Figure 17 and Figure 18 depict the spatial distribution of onshore WPP sites in Indonesia as derived from the point-grid and square-grid approach, respectively. These figures show that a majority of onshore WPP sites in Sumatera Island has LCOE > 25 USD ct/kWh. Banda Aceh, Takengon (Aceh), Padang Sidempuan, and Gunung Tua (Sumatera Utara) are the only connection points in Sumatera which are connected to WPP sites having LCOE < 10 USD ct/kWh. On the contrary, there are more sites in Java Island with LCOE < 10 USD ct/kWh. Examples of connection points to these sites include Slawi (Jawa Tengah), Ponorogo (Jawa Timur), and Kuningan (Jawa Barat). In Kalimantan and Bali Island, however, there is no site with LCOE of this category.

More sites with low LCOE are located in the eastern part of Indonesia. Most of these sites are connected to capitals in Nusa Tenggara Timur (e.g. Oelmasi, Waingapu, and Atambua) and Sulawesi Selatan (e.g. Pare-Pare, Sidenreng, and Pangkajene). Furthermore, the square-grid approach also pinpoints additional sites with low LCOE connected to, among others, Tiakur (Maluku), Limboto (Gorontalo), Taliwang (Nusa Tenggara Barat), Merauke (Papua), and Luwuk (Sulawesi Tengah).

Point-grid and square-grid approach produce different onshore WPP sites with the lowest LCOE in the model. The former approach assigns the lowest LCOE to a site in Sidenreng, Sulawesi Selatan, whereas the latter approach designates the lowest LCOE to a site in Oelmasi, Nusa Tenggara Timur. Properties of both sites are summarized in Table 14.

Table 14. A comparison of sites having the lowest LCOE according to point-grid and square-grid approach

Characteristics	*Approach*	
	Point-grid	*Square-grid*
Connection point	Sidenreng, Sulawesi Selatan	Oelmasi, Nusa Tenggara Timur
Mean wind speed *(m/s)*	8.26	6.43
Transmission distance *(km)*	10.65	14.24
Transmission type	HVAC	HVAC
Net annual energy production *(GWh /year)*	248	175
CAPEX *(million USD)*		
Turbine and others cost	97.02	97.02
Transmission cost	5.45	5.94
Total	102.47	102.96
OPEX *(million USD)*	3.07	3.09
LCOE *(USD ct/kWh)*	6.1	8.7

Table 15. Characteristics of the most favorable onshore WPP site according to point-grid and square-grid approach

Characteristics	*Approach*	
	Point-grid	*Square-grid*
Connection point	Tual, Maluku	Waingapu, Nusa Tenggara Timur
Mean wind speed *(m/s)*	8.11	6.44
Transmission distance *(km)*	31.37 (9.93 on land, 21.44 underwater)	15.28
Transmission type	HVAC	HVAC
Net annual energy production *(GWh /year)*	242	175
CAPEX *(million USD)*		
Turbine and others cost	97.02	97.02
Transmission cost	15.29	6.09
Total	112.31	103.10
OPEX *(million USD)*	3.37	3.09
LCOE *(USD ct/kWh)*	6.9	8.7
Maximum allowable PPA tariff *(USD ct/kWh)*	17.8	17.3

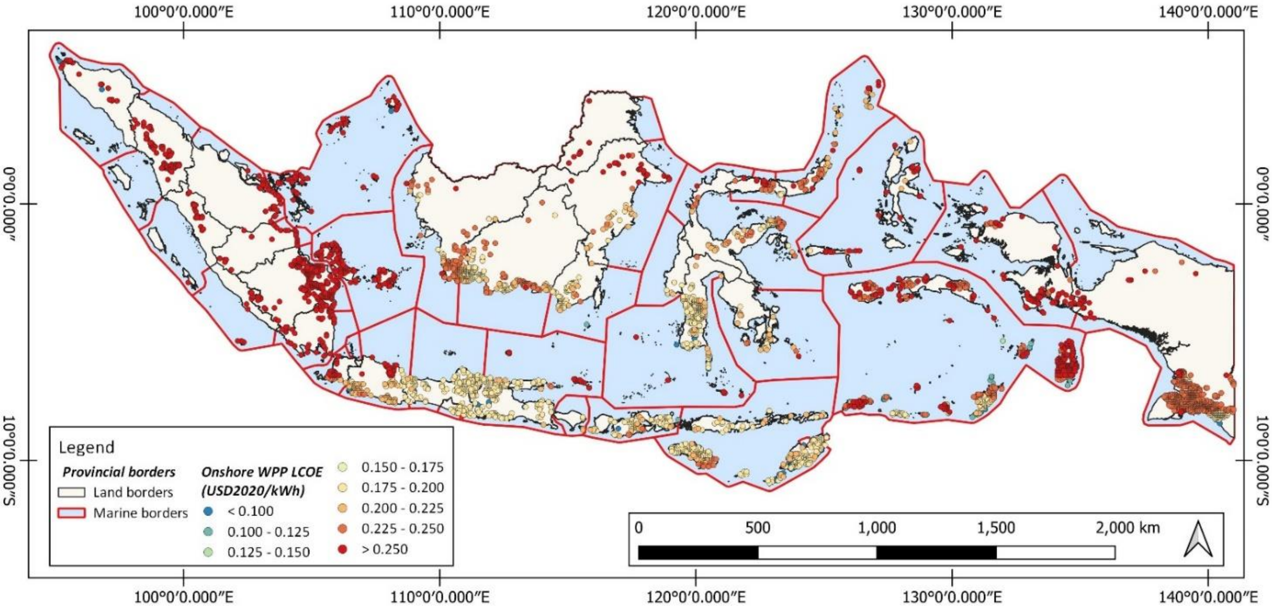

Figure 17. Distribution of onshore WPP sites based on the point-grid approach

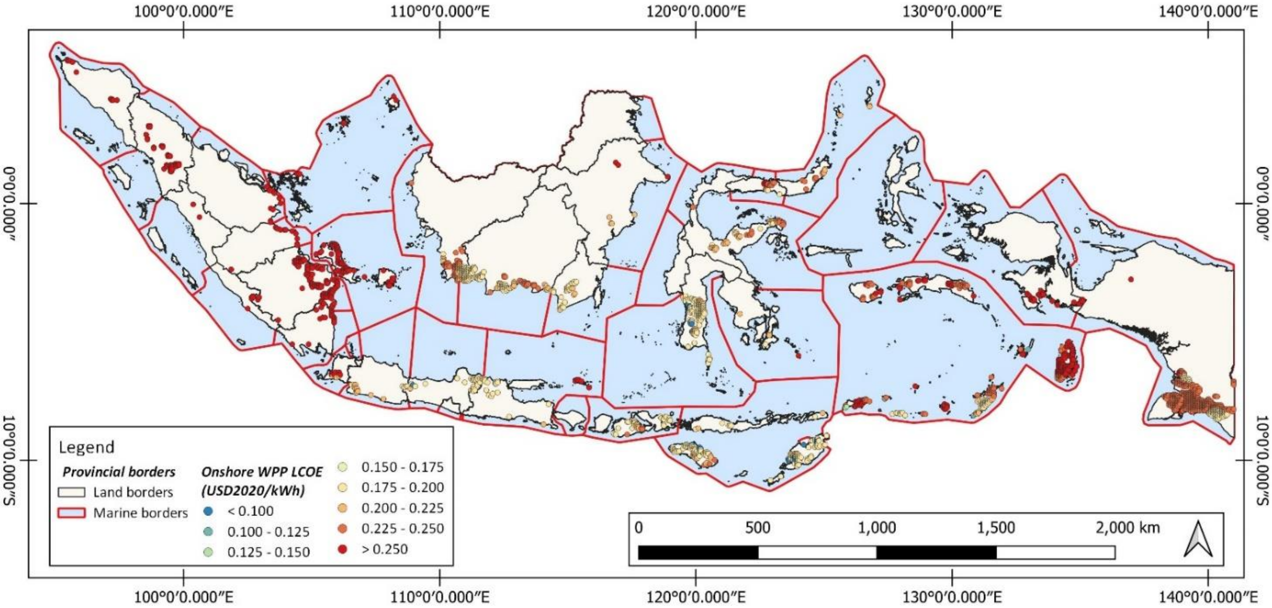

Figure 18. Distribution of onshore WPP sites based on the square-grid approach

Building upon the LCOE figures, economic APO is then determined by contrasting them with the spatially-characterized PPA tariff. Figure 19 and Figure 20 show the spatial distribution of economically feasible onshore WPP sites (i.e. WPP sites with non-zero economic APO) according to the point-grid and square-grid approach, respectively.

National economic APO from onshore sites as derived by the point-grid approach amounts to 2.5 GW (see Appendix D). This value is equivalent to 8.0% of the total onshore wind APO. Almost half of the economic APO is connected to capitals in Nusa Tenggara Timur. In this province, the relatively high BPP allows for PPA tariff of up to 17.8 USD ct/kWh. Furthermore, Maluku becomes the province with the second largest economic APO (0.7 GW). Maluku also has the most favorable site for onshore WPP, namely, the site with the largest difference between maximum allowable PPA tariff and LCOE. Characteristics of this site are displayed in Table 15. Additionally, the corresponding nominal economic onshore WPP capacity of this approach is 6.1 GW.

Table 16. A list of provinces with non-zero economic potential

Provinces	*Economic potential (GW)*		
	Onshore	*Offshore*	*Total*
Aceh	0 – 0.05	0	0 – 0.05
Gorontalo	0 – 0.04	0	0 – 0.04
Kepulauan Riau	0 – 0.02	0	0 – 0.02
Maluku	0.07 – 0.71	0	0.07 – 0.71
Nusa Tenggara Barat	0 – 0.12	0	0 – 0.12
Nusa Tenggara Timur	0.44 – 1.15	0	0.44 – 1.15
Papua	0 – 0.11	5.90 – 8.03	5.90 – 8.14
Sulawesi Selatan	0 – 0.24	0	0 – 0.24
Sulawesi Tengah	0 – 0.04	0	0 – 0.04
Total	**0.51 – 2.48**	**5.90 – 8.03**	**6.41 – 10.51**

Using the square-grid approach leads to a much lower economic APO compared to the point-grid counterpart: the national economic APO of onshore wind becomes merely 0.5 GW (see Appendix D) or 2.9% of the total onshore wind APO. Only two provinces contribute to this figure, i.e. Maluku and Nusa Tenggara Timur. The latter province remains the major contributor to economic APO (0.4 GW). Contrary to the point-grid approach, the most favorable site is instead connected to Waingapu, Nusa Tenggara Timur (see Table 15). Furthermore, this approach results in a nominal economic onshore WPP capacity of 1.3 GW.

A summary of provinces with economic WEP is presented in Table 16. Both approaches concur on the inexistence of economically feasible site within provinces in Java, Kalimantan, and Bali Island. This is due to the islands' low wind resource and/or low BPP, which results in a low maximum allowable PPA tariff. The maximum allowable PPA tariffs are capped at 7.7 USD ct/kWh (Java and Bali Island) and 9.8 USD ct/kWh (Kalimantan Island), making onshore wind energy uncompetitive at these islands.

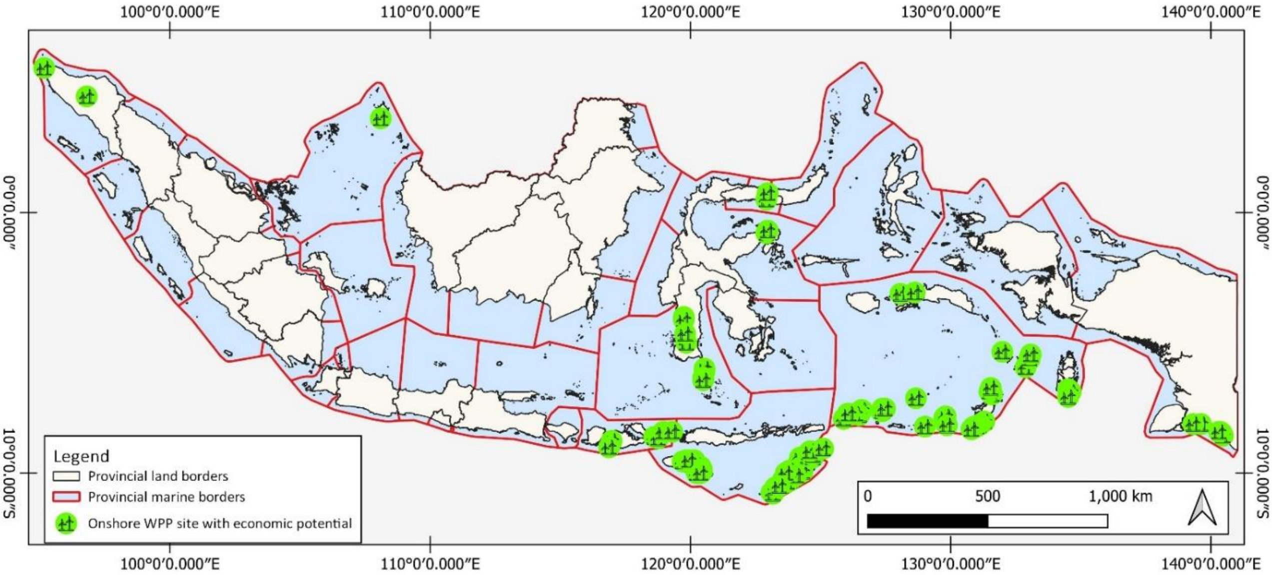

Figure 19. Spatial distribution of economically feasible onshore WPP sites based on the point-grid approach

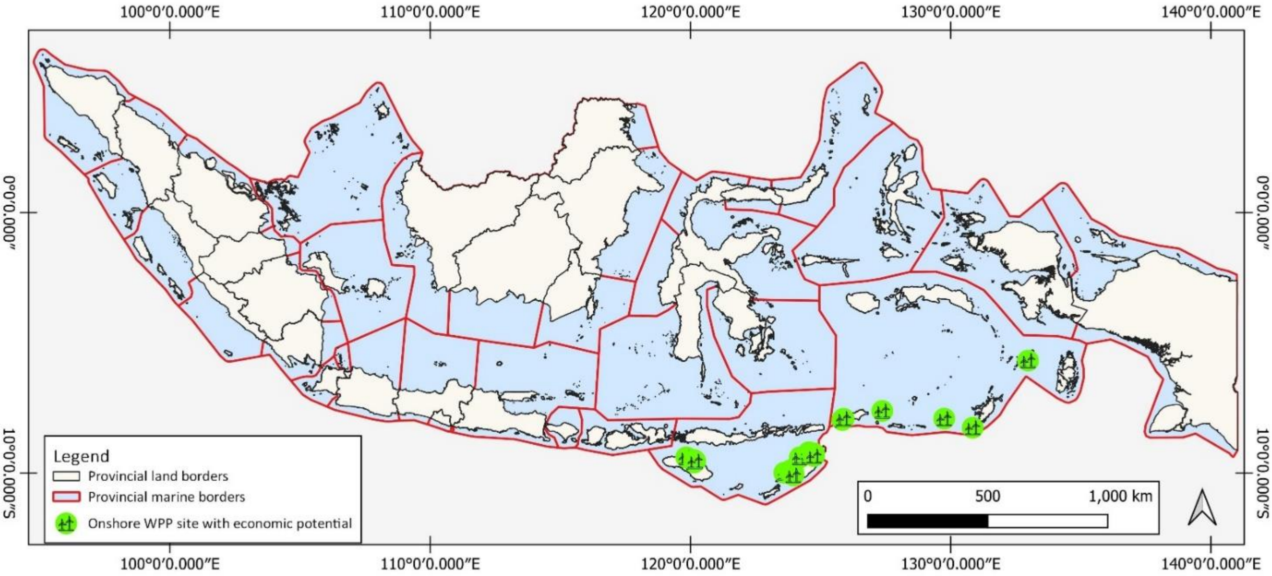

Figure 20. Spatial distribution of economically feasible onshore WPP sites based on the square-grid approach

5.3.2. Offshore wind economic potential

LCOE ranges derived by modelling 400-MW offshore WPP are presented in Figure 16. There is a small difference between the range stemming from both point-grid and square-grid approach. The former approach sets the minimum LCOE at 13.4 USD ct/kWh, whereas the latter generates a minimum LCOE of 13.5 USD ct/kWh.

Spatial distribution of the modelled offshore WPP sites using the point-grid and square-grid approach is presented in Figure 21 and Figure 22, respectively. A common theme implied by the figures is the concentration of sites with LCOE < 20 USD ct/kWh in only a few provinces. According to the point-grid approach, these sites are connected with Merauke (Papua), Saumlaki, Tiakur, Dobo (Maluku), and Cirebon (Jawa Barat). Meanwhile, sites falling into the same category are only connected to Merauke (Papua) based on the square-grid approach. Offshore wind energy is even more expensive on other islands. For instance, the lowest LCOE in Sulawesi Island is 20.3 USD ct/kWh in Bontosunggu, Sulawesi Selatan. Moreover, sites connected to Banda Aceh (Aceh; 22.3 USD ct/kWh) and Ranai (Kepulauan Riau; 27.3 USD ct/kWh) represent the lowest LCOE in Sumatera Island and Riau Islands, respectively. Finally, the minimum LCOE in Bali and Kalimantan Island are greater than 35 USD ct/kWh.

Both square-grid and point-grid approach conclude Merauke (Papua) as the connection point of the offshore site with the smallest LCOE. The characteristics of each site are reported in Table 17.

Table 17. Characteristics of offshore WPP sites having the lowest LCOE

Characteristics	*Approach*	
	Point-grid	*Square-grid*
Connection point	Merauke, Papua	
Mean wind speed *(m/s)*	7.69	7.69
Transmission distance *(km)*	25.90	28.41
Transmission type	HVAC	HVAC
Depth *(m)*	3.87	8.42
Foundation type	Monopile	Monopile
Net annual energy production *(GWh /year)*	1,435	1,435
CAPEX *(million USD)*		
Turbine and others cost	999.80	999.80
Transmission cost	120.79	130.10
Foundation cost	181.75	187.89
Total	1,302.34	1,317.79
OPEX *(million USD)*	39.07	39.53
LCOE *(USD ct/kWh)*	13.4	13.5
Maximum allowable PPA tariff *(USD ct/kWh)*	15.2	

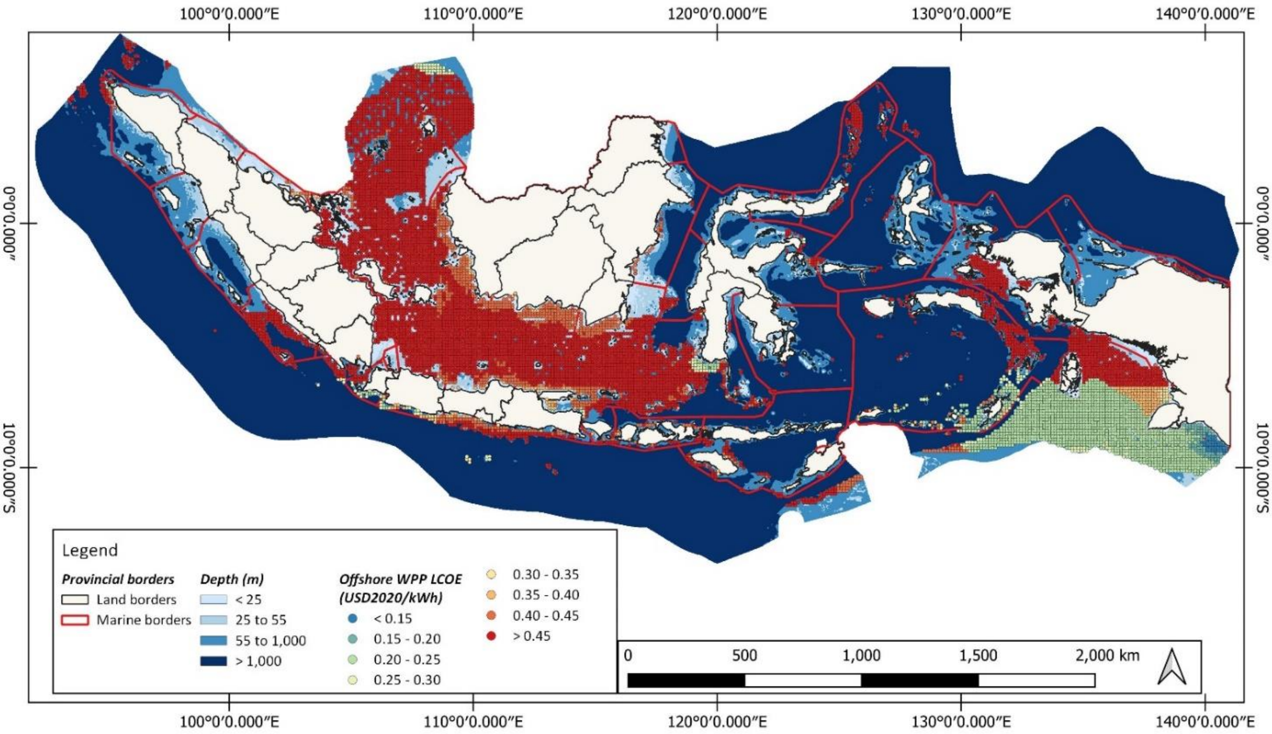

Figure 21. Spatial distribution of the modelled offshore WPP in Indonesia based on the point-grid approach

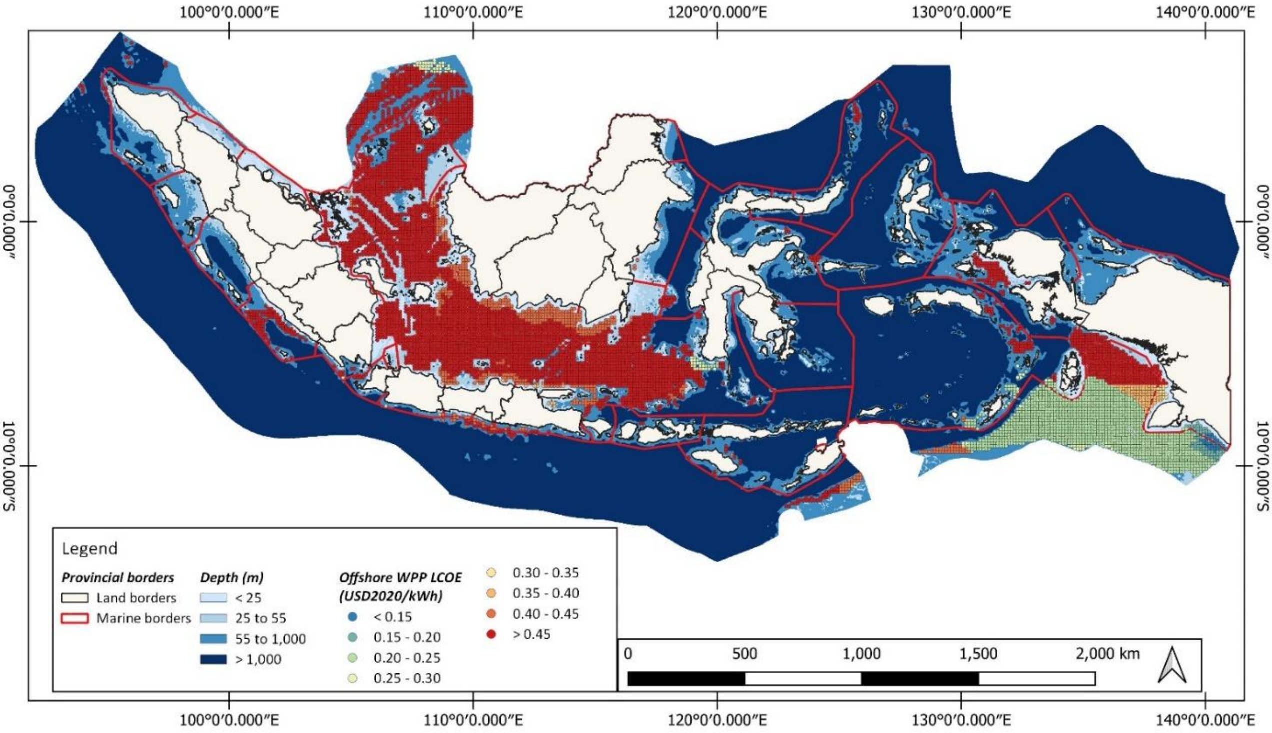

Figure 22. Spatial distribution of the modelled offshore WPP in Indonesia based on the square-grid approach

As listed in Table 16, the national economic APO of offshore WPP is 8.0 and 5.9 GW based on the point-grid and square-grid approach, respectively. In other words, only 1.3 – 1.4% of the total offshore APO is economically feasible under the current regulations. Since most LCOE values are larger than the maximum allowable PPA tariff in respective regions, the economic potential is only present in one province, i.e. Papua. Figure 23 and Figure 24 show the economically feasible WPP sites located near Merauke, Papua. They are all situated in shallow waters with depth less than 25 m and within a distance of roughly 100 km from shore. In addition, the most favorable offshore WPP sites based on the square-grid and point-grid approach coincide with those having the lowest LCOE, as presented in Table 17. Furthermore, the nominal economic WPP capacities for the point-grid and square-grid approach are respectively 19.6 GW and 14.4 GW.

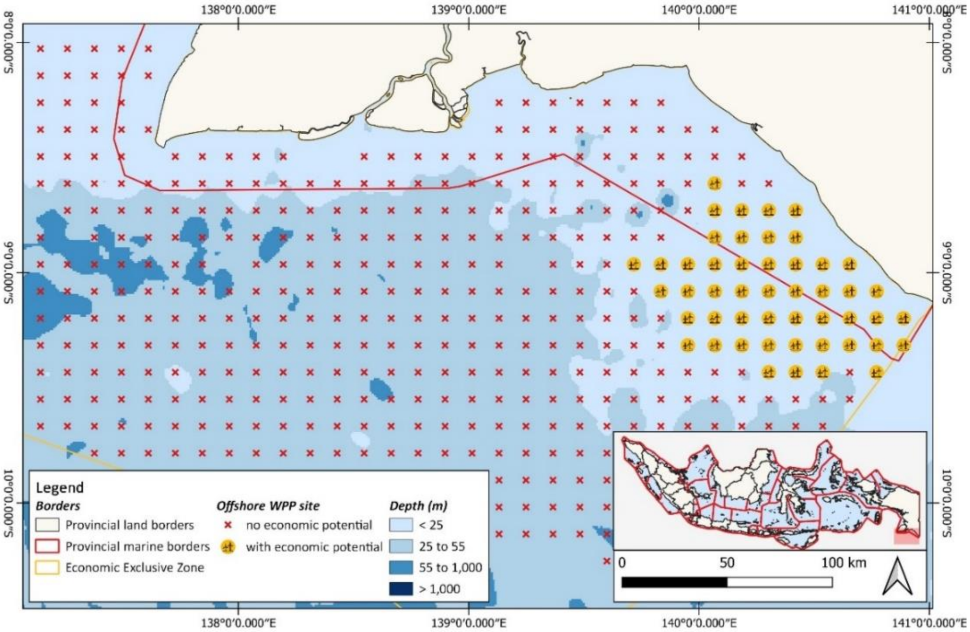

Figure 23. A map showing offshore WPP site with economic potential using the point-grid approach

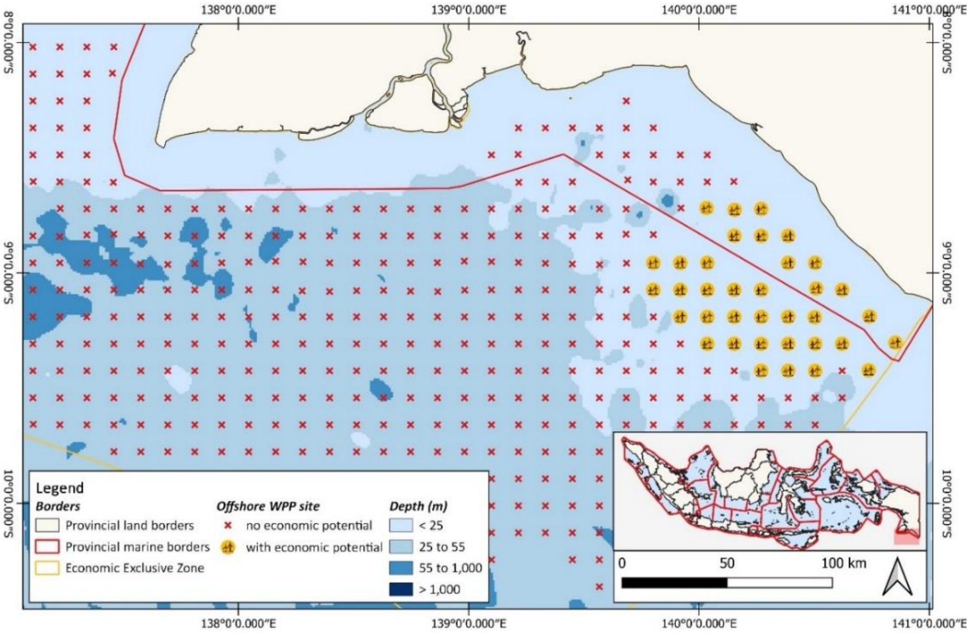

Figure 24. A map showing offshore WPP site with economic potential using the square-grid approach

5.4. Impact of natural disaster proneness

Categorizing the modelled onshore WPP sites based upon natural disaster proneness results in several insights. Figure 25 illustrates the sites' technical and economic potential classification according to earthquake-proneness. Approximately 10 – 16% of the total onshore WPP technical potential is located in areas highly prone to earthquake. Moreover, roughly a quarter of this potential belongs to sites with medium level of earthquake-proneness. Strikingly, up to 31% of the economic potential is contributed by sites at locations of high earthquake-proneness. Waingapu, Oelmasi, Kupang (Nusa Tenggara Timur), and Tual (Maluku) are examples of connection points serving these sites.

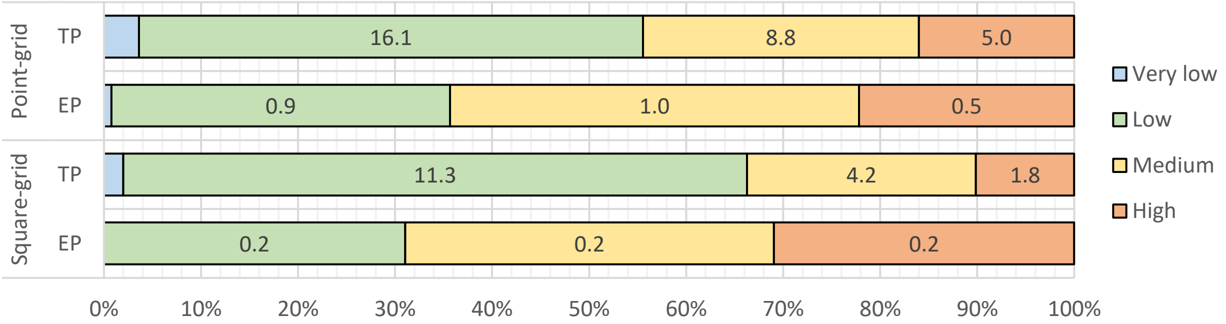

Figure 25. Classification of onshore WPP sites into categories of earthquake-prone zone; labelled numbers within the bar chart represent APO values in GW (TP: technical potential; EP: economic potential)

Figure 26 depicts the share of onshore WPP technical and economic potential in terms of landslide-proneness. Up to 4% of the technical potential is contributed by WPP at locations highly prone to landslide. Meanwhile, as much as 8% of the economic potential belongs to the same category. An example of the connection point to these WPPs is Oelmasi, Nusa Tenggara Timur. Figure 26 also indicates that the economic potential is predominantly provided by sites having medium landslide-proneness.

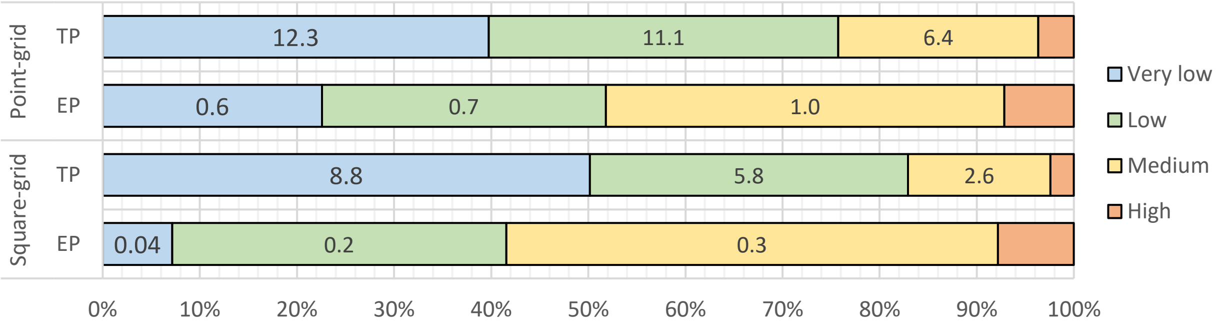

Figure 26. Classification of onshore WPP sites into categories of landslide-prone zone; labelled numbers within the bar chart represent APO values in GW (TP: technical potential; EP: economic potential)

On the other hand, volcano and tsunami proneness zoning affect the potentials in a much lesser extent compared to the aforementioned types of natural disaster. Up to 0.12 and 0.03 GW of the technical and economic potential, respectively, is contributed by sites coinciding with high level of volcano-proneness areas (see Table 30 of Appendix E). Although they represent less than 2% share of the total potentials, it is noteworthy that the intersecting areas are of type A volcano. Furthermore, the fraction of WPP sites (based on APO) located at high-level tsunami proneness is less than 0.2% (see Table 31 of Appendix E). On the other hand, the economic APO is unaffected by tsunami-based zoning. In conclusion, earthquake and landslide are found to be the two most impactful types of natural disaster for onshore WPP technical and economic potential.

5.5. Sensitivity analysis

As specified in Section 4.3, average LCOE and the economic potential (economic APO) are subjected to a sensitivity analysis. The results are presented in the following subsections.

5.5.1. Sensitivity of average LCOE

Sensitivity of average LCOE to changes of its input parameters by +20% and -20% is depicted in Figure 27. The sensitivity derived by point-grid and square-grid approach is almost identical. Moreover, the figure implies the average LCOE being highly sensitive to changes in *mean wind speed*: a 20% decrease of this parameter increases the average LCOE by more than 100% for both onshore and offshore WPP. This is likely due to the cubic relationship between wind speed and aerodynamic power (see Equation 1). On the contrary, a 20% increase of this parameter reduces average LCOE by nearly 40%. The reduction is capped by the rated capacity of wind turbines as depicted by their power curves. Although the average LCOE is very sensitive to *mean wind speed*, it is noteworthy that the model uses a bias-corrected wind speed data based on ten-year wind speeds from GWA (see Subsection 4.1). Consequently, *mean wind speed* fluctuations over the period are taken into account in the model by means of averaging.

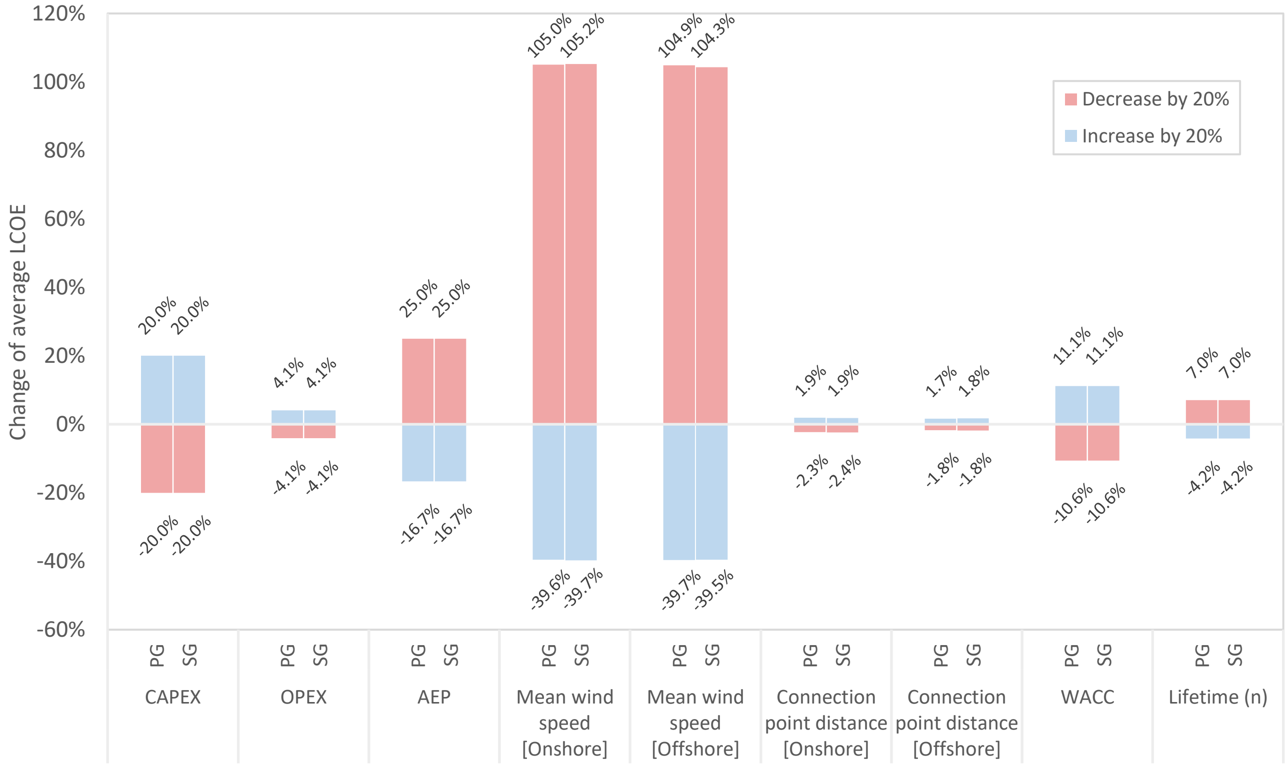

Figure 27. Sensitivity of average LCOE with respect to its input parameters (PG: point-grid approach; SG: square-grid approach)

Figure 27 also indicate the importance of CAPEX, AEP, and WACC in determining the average LCOE of onshore and offshore WPP. Wind energy technology development that enables cost-savings (i.e. lower CAPEX) and more efficient energy conversion by wind turbines (i.e. greater AEP) can lead to a significant decline in average LCOE. In turn, this development may increase the economic potential of wind energy. A reduced cost of capital, such as by the availability of low-interest-rate loans for RE projects, can produce a similar effect. Meanwhile, project lifetime, OPEX, and connection point distance have less powerful influence on the average LCOE compared to the aforementioned input parameters. This result will be further discussed in Chapter 8.

5.5.2. Sensitivity of economic potential

The graph on the left of Figure 28 illustrates the effect of applying a hypothetical national FiT on the economic potential. It can be inferred that offshore WPP economic potential increases to approximately 10 GW at FiT of 16 USD ct/kWh. Furthermore, both offshore and onshore economic potential increases significantly at FiT of 20 USD ct/kWh. These values can serve as reference for future policymaking in wind energy. Moreover, this analysis implies a possibility of increasing the economic potential of onshore and offshore wind energy in Indonesia by means of a FiT. The relevance of this analysis with respect to the institutions will be discussed in Subsection 7.3.1.

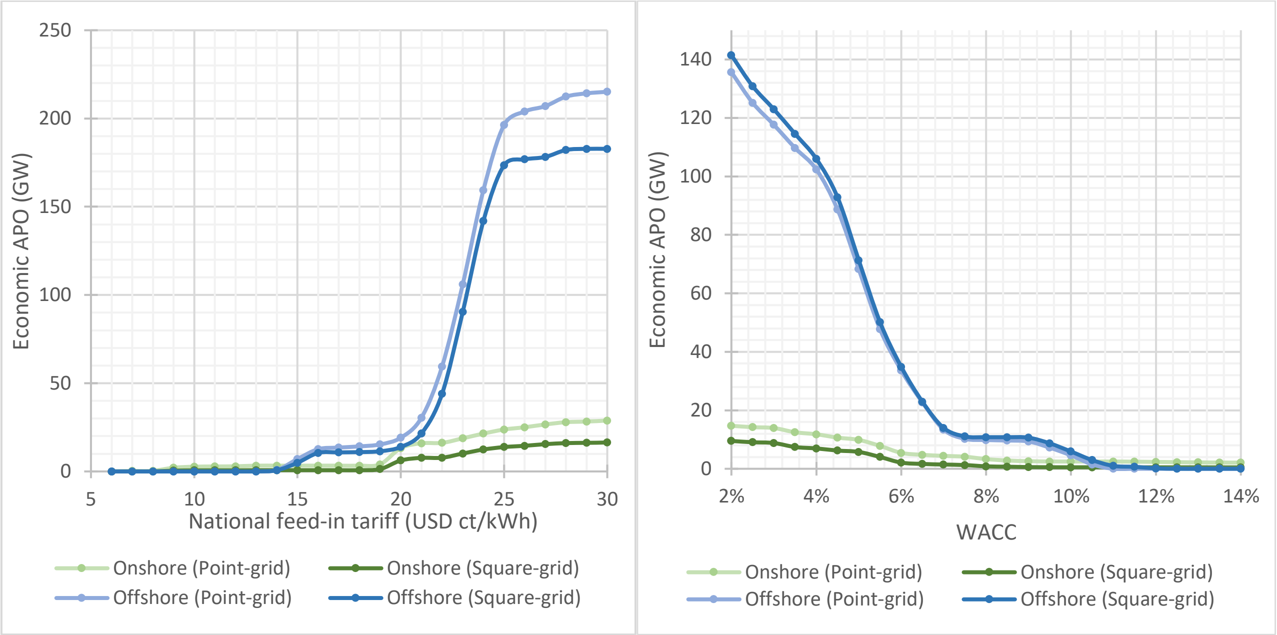

Figure 28. Sensitivity of economic potential (economic APO) with respect to a hypothetical national feed-in tariff (left) and WACC (right)

Sensitivity of economic potential with respect to WACC is presented in the graph on the right of Figure 28. Reducing WACC from 10% (as assumed in the base case of this study) can dramatically increase the national economic potential of offshore WPP. If WPP project funding can be provided at WACC of 8%, the economic potential of offshore WPP rises to roughly 10 GW. Meanwhile, the economic potential of onshore WPP also increases with WACC reduction, albeit at a smaller rate compared to the offshore counterpart. A further discussion on these results, which considers the institutional setting, is presented in Chapter 8.

5.6. Validation of CAPEX assumptions

As explicated in Section 4.3, the WPP model uses cost figures which are derived from the reviewed literature and by approximation. Therefore, it is necessary to validate the aggregation of these cost figures, i.e. CAPEX, which is summarized in Table 18. The validation is divided into two parts, namely, CAPEX of onshore WPP and offshore WPP.

5.6.1. Onshore wind power plant

CAPEX of onshore WPP is validated in two ways. Firstly, CAPEX calculated by the model is compared to the Indonesia-specific figures found in the literature (see Table 26 of Appendix B). Due to the skewed CAPEX distribution, the median provides a better depiction of the central tendency than the average. On one hand, CAPEX median values for onshore WPP of both point-grid and square-grid approaches are higher than the estimate of NEC (2021). In their report, NEC does not provide a detailed breakdown of CAPEX: they only assert equipment (65%) and installation (35%) cost share within CAPEX. Furthermore, NEC only declares that the CAPEX is estimated after considering the estimates of PLN and Vestas in 2017. For these reasons, it is not possible to precisely pinpoint why NEC's estimate is lower compared to that of this research. On the other hand, the median CAPEX values of this study are in line with CAPEX valuations for the Indonesian context (KPMG et al., 2019; Lee et al., 2019). The similarity of this study's CAPEX with Lee et al.'s is understandable since the cost calculation (see Subsection 4.3.2) takes the latter figure as one of the input data. Notably, this may indicate a successful demarcation of CAPEX cost components (i.e. *turbine and others*, *foundation*, and *transmission cost*): the sum of each component is comparable to CAPEX values being assumed in both studies.

Table 18. Statistics of CAPEX values generated by the model for onshore and offshore WPP

Application	*Approach*	*CAPEX (USD/ kW)*			
		Min	*Max*	*Average*	*Median*
Onshore	Point-grid	2,024	3,007	2,268	2,130
	Square-grid	2,029	2,875	2,307	2,152
Offshore	Point-grid	3,065	5,016	4,056	4,028
	Square-grid	3,239	4,923	4,057	4,036

Secondly, the model's CAPEX is contrasted to empirical data derived from established onshore WPPs. ACE (2019) reports a CAPEX range of 1,548 – 2,770 USD/kW for onshore WPPs in Thailand, which is also comparable to the CAPEX range generated by the model. Moreover, the model's average CAPEX (2,268 and 2,307 USD/kW) is also similar to that of WPPs in the Philippines, Vietnam, and Thailand (2,374 USD/kW) as reported by ACE (2019). Finally, CAPEX of a modelled WPP in the vicinity of Sidrap WPP in Sulawesi Selatan is 2,047 and 2,049 USD/kW for point-grid and square-grid approach, respectively. These values are within less than 5% difference compared to the Sidrap WPP CAPEX as declared by The World Bank Group (n.d.), which amounts to 2,120 USD/kW. To conclude, the findings above validate this study's CAPEX based on the reviewed literature and empirical project cost data.

5.6.2. Offshore wind power plant

Validation of CAPEX for offshore WPP is more challenging compared to its onshore counterpart for two reasons. First, there are very limited studies in the economics of offshore wind in Asia, let alone in ASEAN and Indonesia. As shown in Table 27 of Appendix B, the CAPEX in Indonesia can range from 3,580 – 8,706 USD/kW depending on the characteristics of WPP location (Bosch et al., 2019; NEC, 2021). Most offshore WPP CAPEX values produced by the model lie within this range (see Table 18). Nonetheless, the minimum CAPEX value in this study is lower than the aforementioned range. This is largely due to the different assumptions in determining transmission, installation, and decommissioning costs. Bosch et al. assign distance-dependent functions in calculating these costs: the distance is calculated from WPP site centroids to the closest coastline. While implementing this approach can result in a lower transmission cost compared to this study (which uses demand centers as connection points), the resulting installation cost is arguably higher compared to the corresponding value of this study. As explained in Subsection 4.3.2, this study adopts a distance-independent installation cost, because determining the 'appropriate' nearest coastline as the reference in distance calculation is challenging given the archipelagic nature of Indonesia. Additionally, Bosch et al. set decommissioning cost equal to 60 – 70% of the installation cost, whereas this research neglects decommissioning cost in computing CAPEX. Overall, the larger installation and decommissioning cost may have counteracted the lower transmission cost. This explains the mismatch in minimum CAPEX with respect to Bosch et al.'s study. Meanwhile, the missing CAPEX breakdown from NEC (2021) does not allow a similar cost comparison and reasoning. Another important insight is that this study's median CAPEX is comparable to the global weighted average of total offshore WPP installed cost published by IRENA (2020) at 3,887 USD/kW: the difference between these values is less than 4%. Hence, the CAPEX assumed for offshore WPP in this study is theoretically validated to a certain extent.

Second, the implementation of floating offshore WPP is arguably still at its early stage given the deployment of pilot farms in recent years. Commercial-scale implementation is expected in the 2020s as the technology progresses (DNV GL, 2020). Moreover, this study includes offshore sites with depths up to 1,000 m, which exceeds the design limits of recent foundation technologies (Bosch et al., 2019). For these reasons, theoretically validating offshore WPP CAPEX becomes more challenging compared to its onshore counterpart. Essentially, the model's CAPEX is based on conservative cost assumptions which are expected to be lowered in the future with technology and supply-chain developments (DNV GL, 2020).

5.7. Validation of technical and economic potential results

The technical potential computed in this study is theoretically validated in comparison with the results of other publications. Table 19 shows a wide variety of Indonesia's technical WEP figures available in the literature. Technical potential of onshore WPP derived in this study is understandably lower than the estimates of NREL (2014) and MEMR (2017) due to the different assumptions underlying both studies. NREL applies an onshore turbine density of 5 MW/km^2, which is more than two times the corresponding value for this research. This is likely to the different choice of wind turbine and WPP design, which result in a different array efficiency value. Additionally, NREL's site selection constraints are less restrictive: only urban, protected, and high-elevation areas are completely excluded. The remaining areas are partially excluded depending on a suitability factor. Hence, this allows for a larger cumulative AEP and APO. Furthermore, although MEMR assumes a lower turbine density, they only exclude forest areas from the potential calculation. Therefore, the potential is measured based on a broader area, which translates to the larger potential. On the other hand, this research's APO is larger than that of Shell, whose values are taken from Deng et al.'s (2015) study of realistic potential of wind. This is arguably due to the higher wind speed threshold in site selection (i.e. 6 m/s) adopted by the study.

Table 19. Comparison of this study's calculated wind energy average power output in Indonesia to figures from similar studies

Application	*Approach*	*Average power output (GW)*					
		This study	*NREL (2014)*	*MEMR (2017)*	*Bosch et al., (2019)*	*ESMAP (2019)*	*Shell (n.d.)*
Onshore	Point-grid	**30.9**	236.1	60.7	-	-	2.2
	Square-grid	**17.6**					
Offshore	Point-grid	**595.6**	1,483.1	-	1,229.9	277	449.5
	Square-grid	**470.6**					

This study's offshore APO are comparable to Shell's because of the similar site selection constraints being employed. Moreover, NREL's (2014) estimate is larger than the APO calculated in this study due to the greater turbine density used by NREL, which is more than twofold of this study's. Similarly, Bosch et al. (2019) uses a higher turbine density and considers sites at farther location (up to 370 km from shore). Consequently, their

APO estimate is greater than this study's. Lastly, ESMAP (2019) produces a much lower APO because they only consider sites with wind speeds above 7 m/s.

Economic potential of wind, as described by LCOE, is validated by comparing the resulting figures of this study (see Table 20) with those of other techno-economic analysis publications. There is a broad range of onshore wind LCOE available in the literature. LCOE ranges from point-grid and square-grid approach show overlaps with those of similar studies. For example, IESR (2019) reports LCOE range of 7.7 – 16.5 USD ct/kWh. Moreover, economic potential studies on neighboring ASEAN countries produce LCOE range of 9.6 – 18.1 USD ct/kWh (ACE, 2019) and 4.3 – 22.6 USD ct/kWh (Lee et al., 2019). The difference in maximum LCOE between this research and the other studies stems from the more restrictive site selection constraints adopted by the latter studies, which can include a CF threshold (Lee et al., 2019).

Table 20. Statistics of levelized cost of electricity for the modelled onshore and offshore WPP

Application	*Approach*	*Levelized cost of electricity (USD ct/kWh)*			
		Min	*Max*	*Average*	*Median*
Onshore	Point-grid	6.1	38.2	22.8	22.8
	Square-grid	8.7	34.1	23.1	22.9
Offshore	Point-grid	13.4	68.5	44.5	48.2
	Square-grid	13.5	67.2	43.9	48.2

Table 20 also lists the LCOE statistics of the offshore WPP as derived by the two approaches. The lowest LCOE, i.e. 13.4 and 13.5 USD ct/kWh, is roughly in agreement with that of Gernaat et al. (2014) and Bosch et al. (2019). Gernaat et al. find the minimum LCOE to be approximately 11.3 USD ct/kWh. This lower LCOE may be attributed to the different cost functions being used for calculating CAPEX, which influence LCOE. For example, the transmission cost is calculated based on distance to shore instead of distance to a demand center. Furthermore, Gernaat et al. determine the CAPEX function based on a regression analysis on investment costs in European countries (e.g. Denmark and the UK), where large-scale deployment of offshore WPP and wind energy technology development have taken place. In other words, their study does not utilize cost figures tailored to the Indonesian context.

On the other hand, Bosch et al. find that the minimum LCOE lies between approximately 10 – 12.5 USD ct/kWh. One possible reason for this lower estimate is the different method of estimating transmission and installation cost (see Subsection 5.6.2). Another reason pertains to the adopted site selection criterion: unlike this study, Bosch et al. do not exclude artisanal fishing area. As will be discussed in Chapter 8, this makes offshore areas located roughly 10 – 15 km from the coastline ineligible for WPP deployment, even though deploying WPPs at these areas can introduce lower transmission and installation costs. It is also noteworthy that average LCOE of offshore WPP in this study is approximately two times of its onshore counterpart. This observation is shared with LCOE figures in other publications (IRENA, 2020; Kost et al., 2018; Moné et al., 2017).

This chapter presents the techno-economic analysis results, which include site selection, technical potential, and economic potential of wind energy. Moreover, the impact of natural disaster proneness on these potentials is also provided. Finally, this chapter ends with sensitivity analysis and results validation. A further discussion on the results will be provided in Chapter 8.

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PART II:

INSTITUTIONAL ANALYSIS

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Chapter 6. Institutional Analysis: Theoretical Background & Methodology

This chapter begins with an introduction to Williamson's four layers of institutions framework in Section 6.1. It is followed by a review of the framework's usage as a tool for institutional analysis and design in Section 6.2. Section 6.3 and Section 6.4 conclude this chapter with the methodology of institutional assessment and recommendation.

6.1. Williamson's four layers of institutions

Institutions can have different meanings depending on the field of study. This study uses a definition of institutions by Hodgson (2016): "systems of established and prevalent social rules that structure social interactions" (p. 2). Essentially, institutions restrict and facilitate human activities through rules. Furthermore, institutions shape and stabilize human behavior: they establish a consistent expectation of others' behavior (Hodgson, 2016). Institutions pertain to both informal and formal (written) rules and entail an enforcement that invokes consequences for incompliant actions (Rayhanna, 2017).

RE policies, such as FiT and power plant subsidies, are part of institutions surrounding wind energy development. They play a major role in realizing RE potential. Institutional analysis becomes a critical tool to establish these policies: their impact is reflected by both the implicit and explicit institutions which form the sociotechnical system (Iychettira et al., 2017). In this research, an institutional analysis is conducted to extend the interpretation of technical and economic WEP in Indonesia with respect to existing institutions.

Institutions can be analyzed from the new institutional economics (NIE) perspective. NIE highlights the significance of institutions and utilizes economic theory apparatus to scrutinize the institutions' determinants (Williamson, 2000). Based on NIE, Williamson (1998) conceived a framework: four levels of social analysis, which is also known as Williamson's four layers of institutions framework (WLIF). As shown in Figure 29, WLIF comprises *embeddedness* (L1), *institutional environment* (L2), *governance* (L3), and *resource allocation and employment* (L4). There are interconnections between consecutive layers: top-down arrows signal constraints being imposed on the lower layer by the upper layer, whereas bottom-up arrows indicate feedback.

Williamson (2000) explains that among these layers, NIE focuses on L2 and L3 and takes the embedded, informal institutions in L1 as given. As shown in Figure 29, changes of L1 institutions occur at the slowest pace compared to the other levels. L1 encompasses informal and embedded institutions including customs, norms, religion, and traditions. A majority of institutional analysts take L1 institutions as given or exogeneous because of the institutions' inertia and slower rate of change compared to that of political organizations or their structure (Baumgartner & Cherlet, 2015; Beckmann & Padmanabhan, 2009). Nevertheless, these institutions can have a far-reaching influence on the decisions at the lower levels (Beckmann & Padmanabhan, 2009).

L2 consists of formal rules of the game such as laws and constitutions. Stemming from political processes, these rules govern the economic activity by allocating power across the different levels of government. Property rights, particularly ownership right related to resource allocation, are also defined at this level. Ownership right comprises the right to utilize a resource, to collect rent from a resource, and to alter its properties (Williamson, 1998). Moreover, L2 institutions delineate and enforce contract laws and property rights. Importantly, 1st-order economizing exists at L2, namely, to provide the appropriate institutional environment.

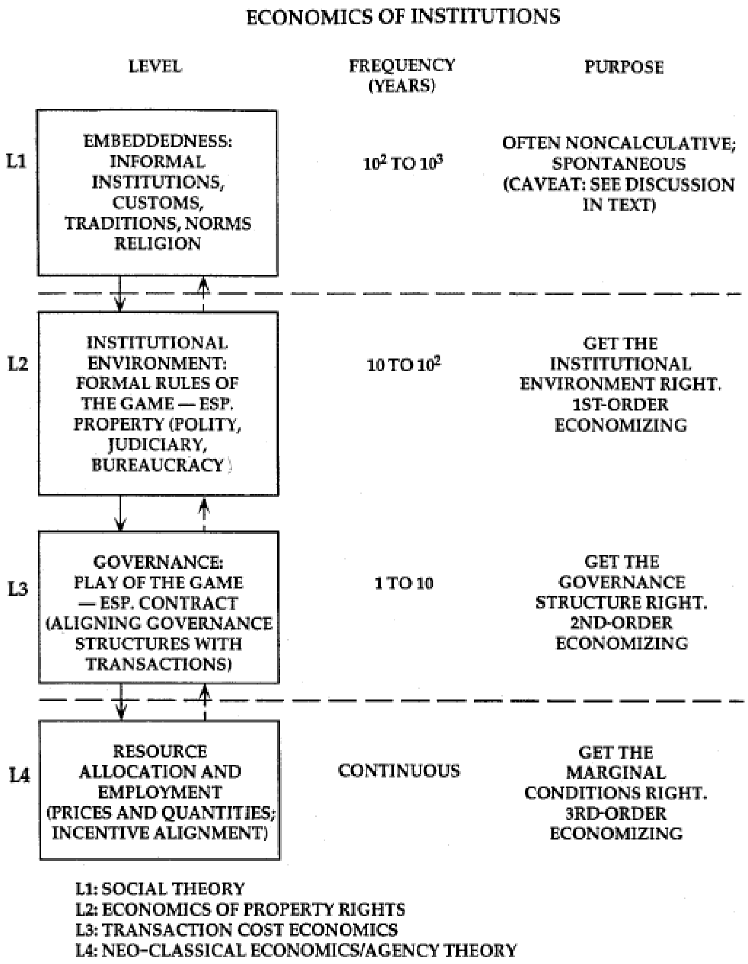

Figure 29. An illustration of the four levels of institutions in Williamson's framework (Williamson, 1998)

Institutions in L2 are further operationalized in the play of the game (L3). Embodied by contracts, institutions of governance are placed at L3. From the transaction cost economics viewpoint, governance entails creating *order*, which in turn prevents *conflicts* and achieves *mutual gains* (Williamson, 2000). In other words, the contracts enable coordination among actors by the provision of incentives. Thus, it is important to implement a suitable governance structure, i.e. through 2nd-order economizing. Finally, L4 pertains to neoclassical economics with marginal analysis on price and output to counter market condition alterations (Williamson, 1998). Particularly, this level concerns the decision-making and behavior of actors in their daily activities. At this level, 3rd-order economizing exists to obtain the appropriate marginal conditions. Assignment of an efficient incentive alignment is contained within L4 (Williamson, 2000).

WLIF is suitable for institutional analysis based on three reasons (Rojas, 2020). Firstly, the properties of institutions (e.g. their evolution and the extent to which they can be influenced) can be derived based on the institutions' placement on the WLIF layers. Secondly, the feedback loops depicted in Figure 29 are in accordance with how the institutions within a sociotechnical system are interrelated. Thirdly, WLIF befittingly implies the different nature of institutions in terms of their rate of change and susceptibility to change.

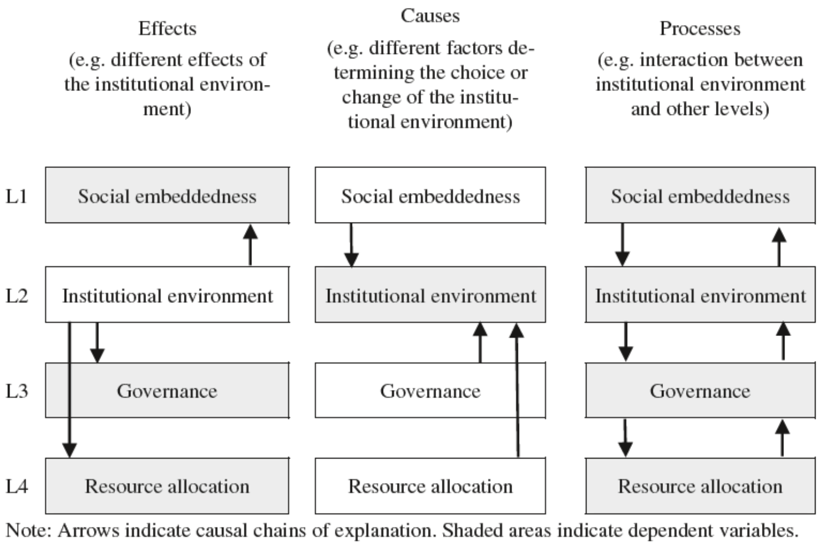

Figure 30. Three types of research questions underlying an institutional analysis using WLIF (Beckmann & Padmanabhan, 2009)

According to Beckmann & Padmanabhan (2009), WLIF can be combined with the three types of research questions commonly employed in institutional analyses (see Figure 30). The first one pertains to *effects* of institutions and their changes at the different layers. The second type relates to *causes* governing the establishment of a set of institutions and its evolution. Additionally, the last type concerns *processes*, which are signified by interactions between institutions of different layers and feedback loops.

6.2. Framework for institutional analysis and design

This section motivates WLIF usage as an analytical tool and design tool utilized in this study in Subsection 6.2.1 and Subsection 6.2.2, respectively.

6.2.1. Institutional analysis framework

One can use a technological transitions approach in analyzing institutions. In this approach, the Multi-Level Perspective framework of Geels (2002) offers a three-layered structure to portray the complex dynamics of a sociotechnical transition. The interplaying layers include landscape developments, sociotechnical regimes, and technological niches. In particular, Geels defines the regime level as a semi-coherent collection of institutions/rules implemented by actors of different social groups joined in a network. The actors and the institutions are classified into seven interconnected dimensions: *industrial networks*, *techno-scientific knowledge*, *sectoral policies*, *markets and user practices*, *technology*, *infrastructure*, and *technology's cultural and symbolic meaning*. Nevertheless, the framework has been criticized for the under-theorized power and politics that underpin policy creation and enforcement (Geels, 2014). Therefore, a technological transitions approach is not pursued in this study.

This research takes an alternative approach that instills more focus on actors, their power, and politics. Among the institutional-focused frameworks available in the literature, the two prominent ones are the Institutional Analysis and Development framework (IADF; Ostrom, 2009) and WLIF (Ghorbani et al., 2010). IADF is comprised of a general set of variables pertaining to actor interactions within an institutional setting (Ostrom, 2009). These variables are grouped into external variables (i.e. biophysical conditions, attributes of the community, and rules-in-use), action situations, interactions, evaluative criteria, and outcomes (Ostrom, 2009). Notably, the framework requires institutional analysts to postulate the action situation elements, which include *actors' characteristics*, *positions, actions*, *information*, *control*, *net costs and benefits*, and *potential* *outcomes*. Despite sharing the same goals, IADF and WLIF are different in nature (Ghorbani et al., 2010) and can deliver complementary insights in an institutional analysis of complex systems.

There are a few exemplary studies that apply IADF and WLIF in tandem. Ghorbani et al. (2010) use these frameworks to conceptualize an extended version of the Kauffman model for an agent-based modelling of a sociotechnical system. WLIF's role is enabling the structuring of distinct behavioral levels to reason a formation of norms and cultures in an evolutionary model. On the other hand, Rayhanna (2017) comprehensively applies IADF on geothermal energy investment in Indonesia and discusses a misalignment among institutions at the different levels of WLIF. She attributes the misalignment between energy provision norm (L1) and RE laws and regulations in place (L2) to a mindset change of the Indonesian people, instead of being an institutional flaw.

van Es (2017) uses WLIF to investigate critical institutional issues and action arenas in urban water cycle management. The identified issues and action arenas are then fed into IADF for an institutional redesign with the aim of achieving a closed system of water cycle. Finally, Rojas (2020) develops an agent-based model to investigate the necessary techno-institutional circumstances in establishing thermal energy communities in the Netherlands. WLIF is employed along with IADF in the model's conceptualization, implementation, and analysis. Specifically, WLIF facilitates an elaboration of institutions which are demarcated based on the four layers. Moreover, IADF and WLIF are applied to investigate relevant actors and their actions in forming thermal energy communities.

In this study, however, the institutional analysis and recommendation design are solely based on applying WLIF. The reason for this decision stems from the flexibility of research scoping offered by WLIF. WLIF gives analysts more liberty compared to IADF in analyzing the layers: analysts are required to conceptually conceive the institutions that each layer contains (Ghorbani et al., 2010). This allows for a more focused analysis of a set of institutions that is deemed most influential and relevant to the case at hand. Furthermore, WLIF's flexibility fits the national scope of this study. IADF is arguably more suitable for more localized or regional context because the framework requires a precise definition of its elements. An example of such IADF application is the comparative case study by Lestari et al. (2018) on off-grid RE technology implementation at several locations in Bogor, Indonesia. The study of Lammers & Hoppe (2018) serves as another example of the appropriateness of IADF for analyzing local-level institutional setting of RE planning and implementation in the EU. Moreover, *attributes of the community*, one of IADF's core elements, can vary widely across the diverse Indonesian population. For these reasons, IADF is deemed unsuitable for this research. They also motivate the use of WLIF in this study.

In the literature, WLIF has been applied for various cases of institutional analysis and derivation of institutional recommendations. One example is the study by Baumgartner & Cherlet (2015), who utilize WLIF to comprehend how activities at the different layers may aid in promoting sustainable land management in China, Guatemala, Kenya, and Tunisia. Based on institutional economics, they analyze the supportive and restrictive institutional environment (L1 to L3) influencing the relevant actors to allocate resources (L4) pertaining to land management. Subsequently, they devise possible actions to be taken at the different layers in order to support sustainable land management. Examples of the actions include establishing new, synthetic cultural values (L1), reforms in vertical and horizontal distribution of power among agencies (L2), alteration of property rights regime (L2), creation and enforcement of supportive policies (L3), and moral suasion to induce behavioral change of landowners (L4).

Another exemplary study was conducted by Kucharski & Unesaki, who perform an institutional analysis on Japan's energy transition. The analysis incorporates sociological, economic, and political viewpoint on institutions. Particularly, they scrutinize the evolution of institutions before and after the Fukushima disaster and how relevant institutions govern market and non-market coordination among actors. The study integrates WLIF with interpretive theories such as neo-institutionalism, sociotechnical transitions, and policy paradigms. The objects of analysis are limited to the institutional environment (L2) and institutions governing transactions (L3) with a focus on top-down influences of institutions. Furthermore, only a selection of institutions deemed most relevant to the energy transition is analyzed, e.g. policy paradigm, market structure, bureaucracy (L2), industry structure, and electricity trading scheme (L3).

6.2.2. Institutional design framework

Despite the predictability and stability they offer, institutions are dynamic: their alterations are possible given the relationship between institutions at different levels and exogenous processes (Koppenjan & Groenewegen, 2005). This property of institutions facilitates an institutional (re)design which may be motivated by several reasons, including requirement of new systems and negative implications in the workings of an existing system (Koppenjan & Groenewegen, 2005). Hence, the design aims at incentivizing actors' actions and in turn, safeguarding the attainment of the system's goals (Scholten & Künneke, 2016).

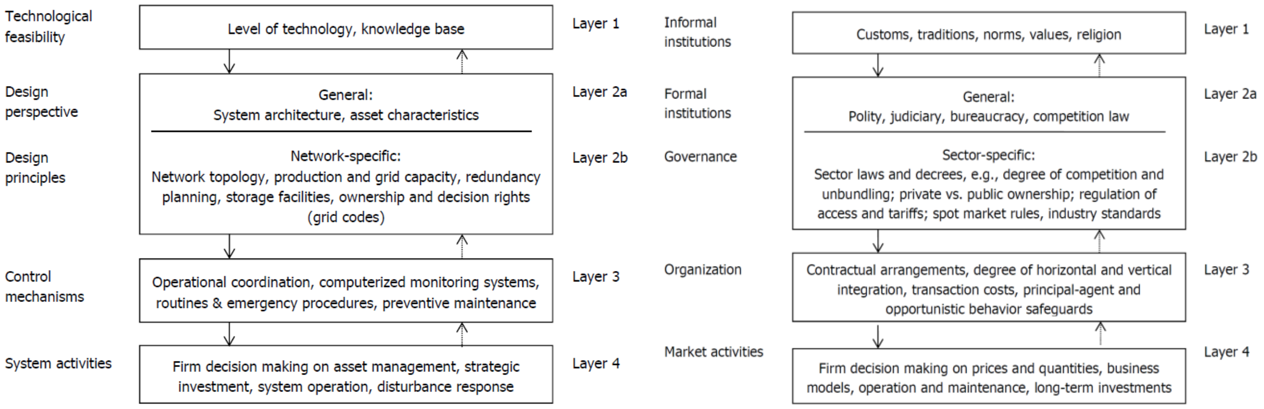

Figure 31. Four layers of energy infrastructures' design variables (left) and economic institutions (right) (Scholten & Künneke, 2016)

Institutional design can range from devising institutional recommendations to comprehensively designing novel institutions to amend or complement the existing institutions. The former type of design is exemplified by Baumgartner & Cherlet (2015) as explained in the previous subsection. Meanwhile, the latter type may entail the use of an adapted version of WLIF. An exemplary study that develops WLIF for design is done by Scholten & Künneke (2016). They produce a comprehensive design framework, incorporating both engineering and economic perspective, for energy infrastructures. Inspired by WLIF, they create layers of design variables from both perspectives based on the variables' specificity and abstractness (see Figure 31). Importantly, the same layers of both perspectives correspond to analogous access, responsibility, and coordination. It is essential to achieve consistency between institutions of different layers within the same perspective, and between institutions of different perspective within the same layers. The two schemes in Figure 31 present an operationalization of WLIF for energy infrastructures.

6.3. Institutional assessment methodology

To answer SQ2, an institutional assessment is conducted using a qualitative approach. Case study is selected as the analysis method because it aims to scrutinize contextual conditions – in this case, the institutional setting surrounding wind energy development – which can be crucial to the studied subject (Mwangi &

Bettencourt, 2017). A single-case, descriptive case study is employed to produce an information-rich elaboration (Mwangi & Bettencourt, 2017) of the relevant institutions in Indonesia. Nevertheless, this method entails a major limitation: there may be a lack of trust in the procedure's credibility (Yin, 2012). To circumvent this issue, a systematic procedure of data analysis is adopted by using WLIF. Moreover, another issue stems from the crucial role of time in institutional analysis due to the ever-changing nature of institutions (Beckmann & Padmanabhan, 2009). Hence, this research mainly focuses on present institutions, while also briefly looking into recent and anticipated changes in the near future.

The methodology for Part II of this study consists of two analyses, i.e. stakeholder analysis and institutional analysis. These analyses are conducted in parallel: relevant actors are compiled and analyzed while scrutinizing the institutions.

6.3.1. Stakeholder analysis

The objective of conducting a stakeholder analysis in this study is to comprehend the relevant stakeholders' attributes – namely their interests, objectives, and relational dependencies – which are later used to propose institutional recommendations. To obtain these attributes, this study partially uses the actor analysis procedure of Enserink et al. (2010). The procedure contains six steps: (1) problem formulation, (2) creation of actor inventory, (3) formal chart construction, (4) determination of actors' attributes, (5) interdependencies analysis by inventorying actors' resources and involvement, and (6) revisitation of the initially formulated problem based on findings of the previous steps. Considering the aforementioned objective and this research's resource limitations, not all of these steps are applied: only step (1) to (4) are implemented in this study.

In Step (1), the institutional barriers derived from the institutional analysis are taken as the problems being addressed. As will be explained in the next subsection, these barriers pertain to four institutional components: electricity pricing, governance in planning, property rights, and governance in contracts. Subsequently, the actor inventory is also derived from the institutional analysis: a list of relevant actors is made while reviewing laws and regulations on formal policymaking positions. In other words, a *positional* approach (Enserink et al., 2010) is adopted in Step (2). Step (3) entails further scrutiny on institutional documents related to each actor as the basis of a formal chart. The chart depicts formal relationships, i.e. formal hierarchical relations and authorities, between the actors concerning the four institutional components. Meanwhile, informal, daily interactions between the actors are outside the scope of this research's literature review-based analysis. However, a validation interview at the end of this study sheds some light on these informal relationships. In turn, Step (4) comprises identifying the actors' interests and objectives, which are inferred based on a literature review.

In summary, the stakeholder analysis methodology is designed to be closely tied with the institutional analysis. Accordingly, a focus is placed on the four institutional components and their entailed (formal) policymaking and governance. Furthermore, the stakeholder analysis takes government documents, academic publications, news, and NGO reports as the input data. The data is gathered by means of a literature review (desk study). Finally, the results include a description of each actor and a formal chart.

6.3.2. Institutional analysis

Scope of analysis

As mentioned in the previous subsection, the analysis' scope is limited to four institutional components, i.e. *electricity pricing*, *governance in planning*, *property rights*, and *governance in contracts*. This scoping decision is motivated by the following reasons. First, this study's economic WEP assessment builds upon *electricity* *pricing* regulations (see Section 4.3). Inclusion of *electricity pricing* is aligned with economic institutions of energy infrastructure (Scholten & Künneke, 2016), in which *regulations on tariffs* is included as a component of L2 (see Figure 31). Second, the spatial characteristic of techno-economic analysis fits well with electricity generation infrastructure planning at both national and regional level. The computed WEP of each province can be correlated with existing infrastructure plans. Therefore, this research also investigates the *governance in planning*. Third, *property rights* (L2) and *governance in contracts* (L3) serve as additional institutional components because they pertain to NIE theory, on which WLIF is based. Moreover, the inclusion of *governance in contracts* is inspired by the economic institutions of energy infrastructure (Scholten & Künneke, 2016), which introduces *contractual arrangements* as one of the L3 institutions. A consequence of this scoping is the possibility of overlooking other institutional issues hampering wind energy development than the four components. Hence, this is deemed as a limitation of this study (see Subsection 8.8.2).

The scope of analysis signifies a focus on L2 and L3 institutions. There are three arguments to support the emphasis on these institutions. First, the four institutional components being analyzed pertains to institutions at L2 and L3. Second, as the grounding theory of WLIF, NIE mainly focuses on L2 and L3 institutions (Williamson, 2000). Such approach is commonly used in the literature: Kucharski & Unesaki (2018) adopted a similar scope when studying the Japanese energy transition (see Section 6.2). Third, this research scope enables an alignment between institutional analysis and the techno-economic analysis in terms of the study's resolution, i.e. at the national level.

Data collection

The institutional analysis involves a novel application of WLIF in the Indonesian wind energy sector. As a diagnostic tool of institutional barriers, WLIF requires qualitative input data to be plotted into its layers. Literature review is selected as the data gathering method because it enables the collection of large amounts of data in a shorter time and cheaper manner compared to questionnaires or interviews (Johannesson & Perjons, 2014). The literature search for this analysis initially focuses on journal articles regarding wind energy institutions. These articles were searched in Scopus and filtered to only include those being published after 2011 due to the dynamic nature of institutions. In turn, backward snowballing is conducted using these articles to find relevant sources of grey literature, such as government documents (e.g., laws, bills, and regulations) and NGO reports. In turn, these sources are subjected to backward and forward snowballing. To describe recent developments of the institutions, this research references news articles from prominent media outlets.

Approach and procedure

As stated in SQ2, this research seeks to determine institutional barriers that hamper Indonesia's wind energy development. To achieve this objective, linkages between the institutions at the different layers are established by looking at their *causal* relationship (see Figure 30). Particularly, the relationship is examined with respect to L4: it addresses how institutions at L2 and L3 determine the actors' decision to allocate their resources at L4. This implies an emphasis on analyzing *top-down* influence of institutions. In other words, feedback from lower-level institutions to higher-level institutions is not studied in this research. To summarize, having a *causal* and *top-down* approach allows the identification of barriers to wind energy development.

Institutional analysis is conducted on the four components in the following order: *electricity pricing*, *governance in planning*, *property rights*, and *governance in contracts*. Analyzing the first component begins with examining recent changes in wind-based electricity pricing and the barriers emanating from such change. In turn, this study looks at forthcoming institutional alterations in pricing. Importantly, a correlation is drawn between the techno-economic analysis results (e.g. LCOE and economic WEP) and the institutional analysis results to extend the interpretation of Indonesia's WEP.

Regarding the second component, national- and regional-level plans on power generation infrastructure by respective governments and PLN is investigated. The analysis aims to assess whether the prevailing plans sufficiently incorporate WEP exploitation at promising locations. Therefore, the regional-level analysis is narrowed down to the plans of five provinces with the most promising economic WEP, as identified in this study's techno-economic analysis.

The third component, i.e. *property rights*, pertains to WPP project ownership and the possibility of ownership transfer. Thus, regulations stipulating project ownership allocation are scrutinized. Lastly, assessment of *governance in contracts* covers processes in establishing electricity purchase contracts or PPA between PLN and project developers (IPPs). The assessment is divided into two elements: before and after PPA signing.

Generally, the analysis' results are firstly presented by describing the current institutional setting. The description is then followed by an explanation of institutional barriers. A summary of these barriers is then displayed using the WLIF structure.

6.4. Institutional recommendations methodology

This part produces institutional recommendations to proliferate wind energy development (SQ3). They do not involve a comprehensive institutional design; instead, this research follows the methodology of Baumgartner & Cherlet (2015) as explained in Section 6.2. Moreover, the recommendations entail changes to L2 and L3 institutions. Stakeholders' attributes and the identified barriers serve as the input for this part. Furthermore, a correlation is made to the insights from the sensitivity analysis of techno-economic analysis variables, i.e. average LCOE and economic potential. To bolster the recommendations, this study incorporates some lessons-learned from successful wind energy policy implementations in other countries based on academic publications and NGO reports. The recommendations are subsequently linked to the institutional barriers at their respective WLIF levels. Consequently, this ensures that the identified barriers are completely addressed by the proposed recommendations.

6.5. Results validation methodology

Expert interviews were conducted to validate the institutional analysis results and recommendation. The interviews are aimed to elicit subjective and objective opinions of the respondents mainly on the stakeholder analysis (formal chart), institutional barriers, and institutional recommendations. The opinions concern the extent to which respondents agree with the results, and potential improvements to the recommendations and to the analysis in future studies. Hence, the interviews provide practical insights to complement the literature review findings.

In total, there are four respondents participating in three validation interviews. The first respondent is Brent Elemans, a RE consultant from Pondera Consult. He provides a private-sector perspective on the results validation. The second respondent is Martha Maulidia, PhD, an independent researcher on climate and energy policy. She is affiliated with the Global Subsidies Initiative of the International Institute for Sustainable Development (IISD). Finally, the last interview involves two IESR representatives, namely Agus Tampubolon and Dr. Handriyanti Puspitarini. IISD and IESR are independent think-tanks in the field of climate policy and energy transition. Due to the limited time of this research, no government and PLN representatives are interviewed in this study.

An overview of research findings was sent to the respondents prior to the interviews. Moreover, all respondents were subjected to the same set of interview questions (see Appendix F). Each interview lasted for 1 – 1.5 hours via an online meeting with a semi-structure format: while there is a set of questions guiding the interview, the discussion could continue based on follow-up questions. Additionally, all interviews were conducted and video-recorded at the end of June 2021 in English (with Brent Elemans) and Bahasa Indonesia (with other respondents). In turn, the interview results are summarized and translated into English (see Appendix G). Key insights from the interviews are presented in Chapter 7.

To conclude, this chapter elaborates the institutional analysis theoretical background and methodology. WLIF is firstly introduced as the overarching framework of this study, both for analyzing institutions and devising recommendations. Subsequently, the methodology for stakeholder analysis, institutional analysis, institutional recommendations, and results validation are presented. Results of Part II are presented in the next chapter.

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Chapter 7. Institutional Analysis: Results

Institutional analysis results are presented in this chapter. It starts with Section 7.1 which provides a background on Indonesia's policy system and governance in the electricity sector. An analysis of relevant stakeholders is then shown in Section 7.2. Afterwards, Section 7.3 and 7.4 present the analysis of institutions at L2 and L3 of WLIF, respectively. Section 7.5 poses the proposed institutional recommendations. Finally, Section 7.6 ends this chapter with results validation.

7.1. Indonesia's electricity policy system and governance

This section describes existing regulations within the Indonesian RE policy system partly based upon a summary by Sastrawijaya et al. (2020). Before analyzing the relevant institutions, it is useful to understand the hierarchy of legislations in Indonesia (see Figure 32) to depict the ordering of laws and regulations. There are two main regulations that found the system: Law 30/2007 (2007) on Energy and Law 30/2009 (2009) on Electricity. Article 1(6&7) of Law 30/2007 defines RE as the energy derived from renewable energy sources, i.e. energy sources that are produced from sustainable energy resources if managed properly. These sustainable energy resources encompass geothermal, wind, bioenergy, water flow and waterfall, and movement and temperature difference of sea layers. Additionally, Article 3 stipulates an optimal, integrated, and sustainable management of energy resources as one of goals of energy management. On the other hand, Article 2 of Law 30/2009s specifies the principles for national electricity development, including sustainability and regional autonomy. Importantly, Article 6 mentions that priority shall be placed on NRE sources in the utilization of primary energy.

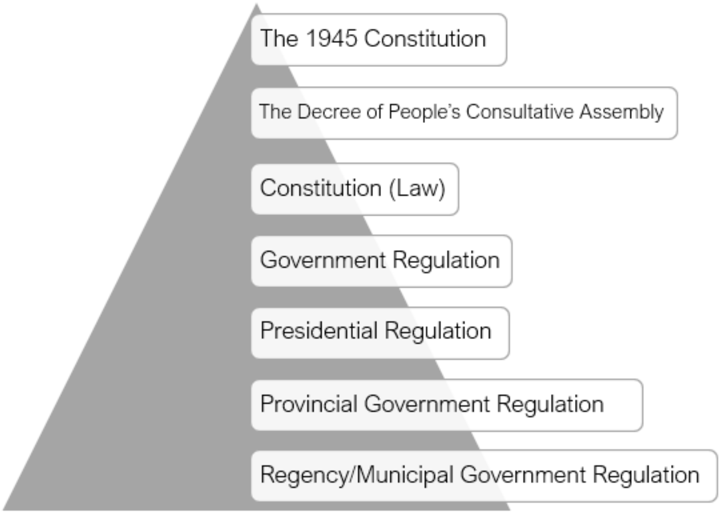


Figure 32. Hierarchy of Indonesia's legislations; adapted from (Rayhanna, 2017)

The governance structure in the Indonesian energy sector is regulated in Law 30/2007s. According to the regulation, provision of NRE shall be increased by the central government (hereinafter referred to as *the Government*) and the regional government based on their authority. They have the authority to facilitate and/or incentivize enterprises and individuals in providing NRE for a specified period until its economic value is achieved. Moreover, the Government has the power to devise legislations and determine national policies, standards, and procedure; whereas the regional government – i.e. provincial and district/city government –

are authorized to devise Regional Regulations, supervise and monitor the enterprises, and establish policies within their jurisdiction.

In addition to these officials, there is the National Energy Council (*Dewan Energi Nasional* or NEC) acting as an independent national body. Formed and headed by the President, NEC is responsible for drafting the National Energy Policy (*Kebijakan Energi Nasional* or KEN). KEN shall then be approved by the House of Representatives (*Dewan Perwakilan Rakyat* or DPR) as the Parliament, before being set by the Government. Furthermore, NEC establishes the General Plan for National Energy (*Rencana Umum Energi Nasional* or RUEN). Members of NEC include the Minister being responsible for the energy sector, government officials, and several stakeholder representatives.

Law 30/2009 lays out the governance structure of the electricity sector. Besides having the capability to create legislations, the Government is authorized to establish national electricity policies, electricity guidelines and standards, General Plan for National Electricity (*Rencana Umum Ketenagalistrikan Nasional* or RUKN), and guidance for setting the electricity tariff. Notably, the Government has the power to set the tariff of the electricity being supplied by the Government-elected Electricity Supply Business License (*Izin Usaha Penyediaan Tenaga Listrik* or IUPTL) holders. Furthermore, the regional government has the authority to issue Regional Regulations on electricity and determine the General Plan for Regional Electricity (*Rencana Umum Ketenagalistrikan Daerah* or RUKD). They are also authorized to set the tariff of electricity being supplied by regional government-elected IUPTL holders.

The Government and the regional government may grant IUPTL for enterprises that provide electricity for public-use. Importantly, the law enables private enterprises to be involved in electricity provision alongside state-owned enterprises. Services that can be included in IUPTL include electricity (a) generation, (b) transmission, (c) distribution, and/or (d) sales. These services may be performed in an integrated manner, namely, from (a) to (d). Additionally, enterprises must also be assigned to a Business Area (*Wilayah Usaha*) by the Government prior to engaging in electricity distribution and/or sales, or the integrated services. Currently, PLN is the sole enterprise in the natural monopolistic electricity transmission and distribution, unless a Business Area is granted to private entities. Furthermore, PLN is the main off-taker of electricity produced at power plants in Indonesia (Sastrawijaya et al., 2020).

At the end of 2020, an omnibus law (Law 11/2020, 2020) was enacted to support investment and create new jobs in multiple sectors including electricity. The law amends several articles of the Electricity Law (Law 30/2009, 2009), including those which designate the authorities of the Government and the regional government in issuing electricity business licenses or *Business Licensing*. This change will be described in more detail in Section 7.4. Nonetheless, the institutional analysis in subsequent sections mainly studies the barriers and issues prior to the omnibus law's enactment, since the law's actual implication on the electricity sector is likely to depend on forthcoming implementing regulations.

Another key actor in the electricity sector is MEMR. As part of the Government, MEMR is in charge of managing the energy and electricity sector, including creating and implementing policies (PR 68/2015, 2015). MEMR has several subdivisions to execute this task. Among others, these subdivisions include Directorate General of Electricity (DGE) and Directorate General of New Renewable Energy and Energy Conservation (DGNREEC).

7.2. Stakeholder analysis

This section presents an actor-by-actor analysis and in turn establishes linkages between the stakeholders in a formal chart.

National Energy Council (NEC)

Law 30/2007 (2007) defines NEC as a national, independent, and permanent body that is responsible for KEN. As mentioned in Section 7.1, NEC is composed of high-level government officials and stakeholder representatives (see Figure 33) which are appointed by the President and the Parliament, respectively. Looking at its composition, NEC arguably has a large amount of power to direct Indonesia’s energy development. Accordingly, the main task of NEC is to design high-level, long-term plans for the energy sector. In addition to devising KEN and setting RUEN, NEC’s duty also includes supervising the implementation of energy policies across sectors. Given these responsibilities, NEC has an interest in a sustainable energy provision. Moreover, NEC’s objective is to ensure an energy management based on principles of fairness, sustainability, and environmental-friendliness in order to establish energy independence and security.

Leaders

Chairman: President of the Republic of Indonesia

Vice Chairman: Vice President of the Republic of Indonesia

Daily Chairman: Minister of Energy and Mineral Resources

Members

Government representatives

- Minister of Finance
- Minister of National Development Planning
- Minister of Transportation
- Minister of Industry
- Minister of Agriculture
- Minister of Research, Technology, and Higher Education
- Minister of Environment and Forestry

Stakeholder representatives from:

- Academia
- Industry
- Consumers
- Technology
- Environment

Figure 33. The organization structure of NEC; adapted from (NEC, n.d.)

PR 26/2008 (2008) further details the position of stakeholder representatives in NEC. These representatives consist of 8 persons: 2 experts in energy from universities, 2 practitioners from the energy industry, 1 expert in energy technology engineering, 1 environmental expert in the energy sector, and 2 representatives from energy consumer society. Furthermore, the regulation does not prescribe the organizations or companies from which the representatives originate. After the representatives’ five-year tenure, the Minister of Energy and Mineral Resources (MoEMR) administers a selection process for their successors. The selected individuals are then proposed to the President and appointed by the Parliament.

Ministry of Energy and Mineral Resources (MEMR)

Section 7.1 introduces MEMR as the ministry being responsible to devise and implement policies in energy and electricity sector. MEMR is also responsible for supervising the execution of tasks within these sectors. MoEMR, who is appointed by the President, leads this ministry in its operation. By helping the President in the administration of energy and mineral resources, MEMR aims to manage and exploit Indonesia’s natural resources for the people’s benefit as stipulated in the 1945 Constitution. As described in previous sections, MEMR is heavily involved in operationalizing KEN into RUEN and RUKN. Furthermore, MEMR plays an important role in policymaking related to electricity purchase price and property rights.

Two MEMR subdivisions which are relevant to this study are DGE and DGNREEC. In general, DGE is in charge of creating and implementing policies in the electricity sector, as well as devising relevant norms, standards, procedure, and criteria (PR 68/2015, 2015). Based on these responsibilities, it can be inferred that DGE has an objective of providing reliable and safe electricity in sufficient amounts by focusing on the electricity sector's business activities, technical workings, safety, and the environment. Meanwhile, DGNREEC is mandated to conceive and enforce policies in the development, control, and oversight of NRE and energy conservation (PR 68/2015, 2015). Analogous to DGE, DGNREEC is tasked to create norms, standards, procedures, and criteria pertaining to NRE and energy conservation. Thus, it can be concluded that DGNREEC's objective is to safeguard electricity provision with the integration of RE into the system.

Ministry of Finance (MF)

PR 57/2020 (2020) stipulates the authorities of the Ministry of Finance (MF). MF is mainly assigned to aid the President in administering the state's finances through several functions. Among others, these functions include devising and enforcing policies in state budgeting, taxation, and expenditures management. MF is also tasked with providing recommendations for fiscal and monetary policies. Therefore, MF is capable of creating RE incentives through tax policies and financing (Bridle et al., 2018) that can lower RE investment cost. Moreover, MF proposes the maximum state budget allocation for the subsidy to PLN (ADB, 2020b), which is key for electricity price-setting. In summary, the objective of MF is to ensure the financial health of the state, including in the electricity sector.

Ministry of State-Owned Enterprises (MSOE)

As stipulated in PR 81/2019 (2019), the Ministry of State-Owned Enterprises (MSOE) assists the President in the governance of state-owned enterprises (SOE). MSOE is authorized to conceive and implement policies in, among others, creating sustainable growth and enhancing business performance of SOEs including PLN. As a shareholder of PLN, MSOE monitors and evaluates the management of PLN in achieving their targets (ADB, 2020b). Hence, MSOE can indirectly influence PLN's generation infrastructure planning and contracting with IPPs. The objective of MSOE is to ensure an alignment between PLN's business practices and the principles of economics with a view of maximizing profits (Rayhanna, 2017).

Ministry of Investment / BKPM

Formerly known as *Badan Koordinasi Penanaman Modal* or BKPM, the Ministry of Investment was recently established through PR 31/2021 (2021). The Ministry is responsible not only in for the implementation of existing regulations on investment (as was done by BKPM), but also for policymaking related to investments (Putri, 2021). Moreover, the Ministry continues its task of issuing *Business Licensing* for electricity sector enterprises (ADB, 2020b). Looking at the involvement in funding/investment and licensing, the Ministry has an important role in addressing issues surrounding the governance of contracts (see Section 7.4). In conclusion, the Ministry's objective is to reach a targeted amount of investment in multiple sectors, including the power sector.

Regional governments

Regional governments have the responsibility to take part in RUKN formulation and subsequently create RUKD as the regional-level plan. Along with MoEMR, regional governments are authorized to approve or reject RUPTL of electricity enterprises such as PLN. As will be highlighted in Section 7.4, regional governments have an important role after PPA signing: sufficient coordination among capable human resources is pivotal in RE projects. The success of Sidrap WPP is heavily influenced by the support from the local government, who in return obtained infrastructures (e.g. access roads) built by the developer (Maulidia, Dargusch, Ashworth, & Wicaksono, 2019). Another important task of regional governments is to devise regional policies, including fiscal policies and incentives for RE projects (Yudha & Tjahjono, 2019). The aforementioned responsibilities are tied to the objective of meeting regional electricity demand as prescribed in the General Plan of Regional Energy (RUED) to facilitate economic growth in the region.

The Parliament (DPR)

DPR has three main functions: legislation, budgetary, and oversight (Sekretariat Jenderal DPR RI, n.d.). Along with the President, DPR can legislate Laws which have been subjected to discussion among members of the Parliament. Notably, DPR is authorized to accept or reject the legislation of GR as a replacement of Law. This authority signifies DPR's key role in establishing RE regulatory framework (Bridle et al., 2018) and power infrastructure planning. Regarding the budgetary function, DPR has the authority in approving state budget allocation for ministries, including the subsidy for PLN (Bridle et al., 2018). Given these functions, it can be inferred that DPR's objective pertains to safeguarding the people's (or the constituents') interests within the Government's activities so that public electricity provision is in accordance with the 1945 Constitution.

PLN

As an SOE, PLN is mandated by the Government to be the monopolist in electricity transmission and distribution. PLN acts as a single buyer for power generating enterprises, such as IPPs and PLN subsidiaries. Being a single buyer, PLN has a considerable influence over power plants to be constructed at each province through RUPTL and over the negotiation of PPA with IPPs. However, PLN is highly dependent on high-level actors, such as on MF (for receiving subsidy) and on MEMR and the regional governments (in infrastructure planning and property rights allocation). As a company, PLN aims to provide a sufficient amount of reliable electricity while also making an economic profit (MEMR MD 39/2019, 2019). In general, PLN supports the development of RE plants; nevertheless, the company also considers the development's impact on price efficiency and supply-demand balance (MEMR MD 39/2019, 2019).

RE Independent Power Producers (IPPs) and Financier/Investors

An IPP's objective is to make economic profit through power generation. The fulfillment of this objective largely depends upon the agreed PPA tariff between the IPP and PLN as the return on RE infrastructure investment (Bridle et al., 2018). In developing RE plants, IPPs typically obtain funding from financiers or investors. Some investors have an objective of making economic profit, and therefore, they require a high rate of return given the institutional uncertainties in Indonesia's power sector (see Section 7.3). On the other hand, project funds can also be obtained through development partners, i.e. international agencies which offer funding and technical expertise (Bridle et al., 2018). In such case, the financier's objective is to bolster RE advancement particularly in developing countries. Overall, IPPs have minimum influence on policies (Bridle et al., 2018) and other actors.

Formal chart

Based on the stakeholder analysis and the institutional analysis (as will be presented in the next sections), a formal chart is constructed to summarize the linkages between the aforementioned stakeholders (see Figure 34). There are three main observations that can be derived from the chart. Firstly, actors located at the top of the chart have a high level of power in RE and electricity sector. These actors include the Government, NEC, and the Parliament. Moreover, the chart indicates a high level of power possessed by regional governments within their jurisdiction. Secondly, the chart signifies the difficult position of PLN (Setyowati, 2021): the company is under the 'command' of at least four actors, i.e. regional governments, MEMR, MSOE, and MF.

These actors may have different interests and policy priorities which PLN must consider in its operations and governance. Therefore, PLN directors have a challenging task to satisfy the requirements from these actors. Thirdly, one can notice that the formal chart does not display the position of academic organizations, NGOs, environmentalists, industry associations (e.g. fossil-fuel and RE IPP associations), and consumers. Formally, they are represented in the institutional and governance setting by the NEC, through the stakeholder delegates. Nonetheless, this excluded group of actors expectedly has informal interactions (e.g. lobbying) with and thus exerts pressure on the actors within the chart. The missing actors' influence on policymaking will be reflected in the validation interviews (Section 7.6).

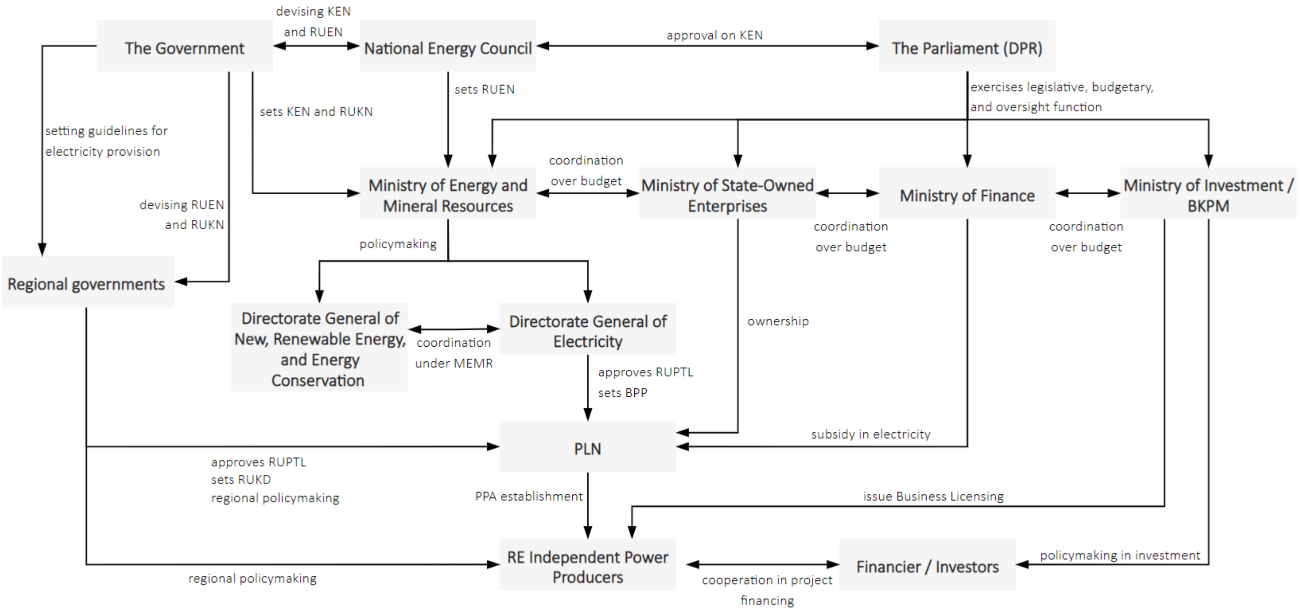


Figure 34. A formal chart containing stakeholders in the RE-based electricity sector

7.3. Layer 2 analysis: Institutional environment

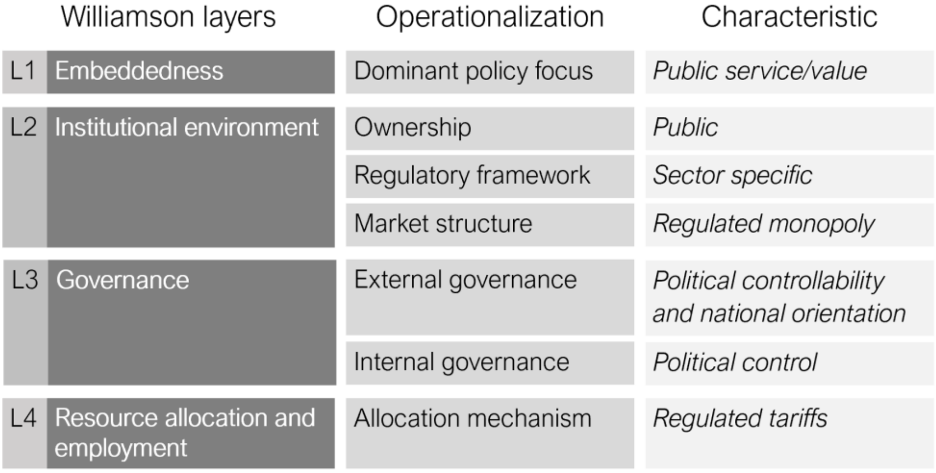
Analysis of institutions at L2 are described in three consecutive parts: electricity pricing, infrastructure planning, and property rights.

7.3.1. Electricity pricing

Institutional setting

In Indonesia, certain categories of natural assets shall be publicly managed and controlled. This is stipulated in Article 33 of the 1945 Constitution of Indonesia: the land, waters, and natural resources within Indonesia shall be under the powers of the State. Furthermore, these assets shall be utilized for the greatest wealth of the people. Accordingly, the Government exerts its powers in managing these resources through SOEs (Rahman et al., 2021). Electricity is among the vital utilities managed by these enterprises. As the monopolist in the electricity market, PLN is mandated by the Government to meet the people's electricity demand at a fair and reasonable price (Guild, 2019; Setyowati, 2020) to keep electricity accessible for the poorest communities (Maulidia, Dargusch, Ashworth, & Ardiansyah, 2019). Hence, the Government, subject to the Parliament's approval, sets the retail electricity price and subsidizes PLN to compensate for revenue losses. In other words, the high cost of electricity generation and transmission cannot be imposed onto customers (Guild, 2019).

Another repercussion of Article 33 of the 1945 Constitution is the infeasibility of electricity sector liberalization. In 2004, the Supreme Court decided to repeal Electricity Law of 2002. The repealed law presented more opportunities of private sector involvement and introduced competition in the electricity market, such as by setting retail electricity prices based on market dynamics (Maulidia, Dargusch, Ashworth, & Ardiansyah, 2019; PwC, 2018). Under the prevailing constitution, Indonesia's electricity sector is organized according to the public utility model (Künneke & Fens, 2007). The model's institutional characteristics as demarcated by the WLIF layers are shown in Figure 35. The Indonesian norms and values (L1) are found on the perception that the electricity sector shall serve the people as a public service. Moreover, the 1945 Constitution (L2) regulates the sector as a regulated monopoly and assigns public ownership of most power infrastructures to PLN.



Williamson layers		Operationalization	Characteristic
L1	Embeddedness	Dominant policy focus	*Public service/value*
L2	Institutional environment	Ownership	*Public*
		Regulatory framework	*Sector specific*
		Market structure	*Regulated monopoly*
L3	Governance	External governance	*Political controllability and national orientation*
		Internal governance	*Political control*
L4	Resource allocation and employment	Allocation mechanism	*Regulated tariffs*

Figure 35. Features of public utility model in organizing the electricity sector; adapted from (Künneke & Fens, 2007)

Based on the higher-level regulations, RE-based electricity pricing scheme is specified by Ministerial Regulations (MR). The scheme has undergone a series of changes in the last few years. In 2012, FiT for RE-based electricity was implemented through MEMR MR 4/2012 (2012). FiT entails a fixed payment from PLN to IPPs over a period of 20-30 years. This scheme incentivizes private investment in RE by providing IPPs with financial certainty, namely, in evaluating the appropriateness of risk and return of investment (Guild, 2019). However, the regulation only stipulated PLN's obligation to purchase electricity at a certain tariff from small to medium-sized RE power plants (up to 10-MW capacity). FiT's spatial dimension was represented by a region-based multiplier to the tariff. For instance, the multiplier for Java and Bali region was 1, whereas that of Maluku and Papua region was 1.5. In the following years, FiT regulations for geothermal, hydropower, biomass/biogas, and solar were enacted. Despite the incentives these regulations offered, RE development only occurred at meager rates. Guild (2019) attributes the ineffective FiT to poor quality of governance, Indonesia's political economic stance given the presence of fossil-fuel incumbents, energy market structure and politics, frequent tariff adjustments, and PLN's ownership of the majority of power generators which utilize fossil-fuels.

Pricing scheme for large-scale WPP was not determined until new regulations were enacted in 2017. MEMR MR 12/2017 (2017) on the utilization of RE resources for electricity was established as a guideline for PLN to purchase RE-based electricity from IPPs. This regulation introduced *Biaya Pokok Penyediaan Pembangkitan* (BPP), i.e. the cost of electricity provision by PLN which includes power generation and excludes transmission. BPP is determined by MoEMR based on PLN's proposal. One of the regulation's objective is lowering BPP at local electricity systems. Additionally, the regulation is aimed at enticing private RE investment in areas with high BPP, such as rural areas in the eastern part of Indonesia (Setyowati, 2021). Consequently, the electricity price was set to depend on the relative value of regional BPP to the national-average BPP. If regional BPP exceeded national-average BPP, the price was capped at 85% of the regional BPP. Otherwise, the price was set equal to the regional BPP. The regulation was amended by MEMR MR 43/2017 (2017), however, only on hydropower pricing: the pricing scheme for wind-based electricity remained unchanged.

Later in 2017, the regulation was annulled by MEMR MR 50/2017 (2017). Compared to the annulled regulation, the new regulation prescribes a different pricing mechanism for wind-based electricity when the regional BPP is lower than or equal to the national-average BPP. In such case, electricity purchase price is set based on an agreement between PLN and the IPP. The agreed price is derived by negotiation between the two parties, which is then specified in a PPA. Additionally, the electricity purchase must be approved by MoEMR. Amendments to MEMR MR 50/2017 were done sequentially through MEMR MR 53/2018 (2018) and MEMR MR 4/2020 (2020). MEMR MR 53/2018 extends the pricing scheme to cover liquid biofuel. Meanwhile, MEMR MR 4/2020 removes the explicit objective of lowering regional BPPs from PLN's preconditions to purchase wind-based electricity: instead, the regulation stipulates the local electricity system's capability to accept wind-based power as the sole precondition. Moreover, the regulation also stipulates that PLN's electricity purchase shall be conducted according to their Electricity Supply Business Plan (RUPTL; see Subsection 7.3.2 for more information) with a maximum period of 30 years. The regulatory changes with respect to wind-based electricity pricing is summarized in Table 21.

Table 21. Regulatory changes on wind-based electricity pricing

	MEMR MR 12/2017	*MEMR MR 50/2017*	*MEMR MR 4/2020*
Preconditions for PLN to purchase wind-based electricity	a. The local electricity system can accept wind-based electricity supply; b. The purchase is meant to lower regional BPP; and/or c. The purchase meets electricity demand at locations which do not have any other primary energy source.	a. The local electricity system can accept wind-based electricity supply; b. The purchase is meant to lower regional BPP; and/or c. The purchase meets electricity demand at locations which do not have any other primary energy source.	The local electricity system can accept wind-based electricity supply.
Electricity price			
Regional BPP > national-average BPP	Maximum 85% of regional BPP	Maximum 85% of regional BPP	Maximum 85% of regional BPP
Regional BPP ≤ national-average BPP	Regional BPP	Agreed price between PLN and IPP	Agreed price between PLN and IPP

Institutional barriers

There are two key barriers to wind energy development stemming from the current pricing scheme. First, the frequently changing scheme leads to regulatory uncertainty for IPPs and investors (PwC, 2018; Setyowati, 2020). Conducted in a relatively short period, these changes are done without an adequate discussion with the stakeholders (Maulidia, Dargusch, Ashworth, & Wicaksono, 2019). Additionally, these changes are also affected by reprioritization of policies due to the unpredictable leadership change in the ministry (Setyowati, 2020). Consequently, investors are left discouraged by this situation: a survey by PwC & APLSI (2018) revealed that 94% of respondents – consisting of IPP owners and investors, PLN, and government bodies – perceive regulatory uncertainty as a major hindrance for investment in large-scale power generation.

Guild (2019) also highlights the alternating criteria and benchmarks (e.g. geographical region and generation cost) within the seemingly ad-hoc regulation amendments. These adjustments exemplify a lack of impact assessment in policymaking in this field. Such institutional environment imposes a higher risk (Bridle et al., 2018) and costs for project developers and investors since additional time and effort are required to assess the impact of and comply with the new regulation (Setyowati, 2020). Therefore, project developers voiced their frustrations when FiT was replaced by the BPP-pegged pricing scheme (Bridle et al., 2018).

The frequently changing pricing scheme is exacerbated by inconsistencies among regulations. An example of the misalignment arises between the current pricing scheme and PR 4/2016 (2016) on the acceleration of power infrastructure development (Maulidia, Dargusch, Ashworth, & Ardiansyah, 2019). The PR was aimed to support RE development by emphasizing on energy security and sustainability, however, the present pricing scheme seems to only prioritize electricity affordability.

Second, the effective pricing scheme is deemed unfavorable to make RE projects financially viable. The maximum allowable PPA tariffs are too low to provide return on investment with reasonable profits (Bridle et al., 2018). An empirical proof can be inferred from the success of Sidrap WPP, Indonesia's first large-scale wind farm (Maulidia, Dargusch, Ashworth, & Wicaksono, 2019). PPA of Sidrap WPP was signed in 2015, before the BPP-pegged pricing scheme was implemented. Despite the absence of regulation for wind-based electricity pricing at that time, the PPA tariff was set analogous to a FiT: the agreed tariff was greater than the regional BPP in Sulawesi Selatan. Similarly, PPA of Tolo-1 WPP, Indonesia's second large-scale WPP, was signed before the current regulation was enacted (i.e. in 2016) with a tariff higher than the regional BPP (Meilanova, 2018). These examples show the effectiveness of FiT in enticing investors in wind energy. Furthermore, the examples seemingly affirm the unattractiveness of the current pricing scheme: no large-scale WPP has been commissioned since the present pricing scheme was enacted.

Capping the price based on BPP is problematic for RE investments in two ways. Firstly, this scheme provides little to no incentives for RE projects at regions with low BPP such as Sumatera, Java, and Bali Island (Bridle et al., 2018; PwC, 2018). This study's techno-economic analysis confirms this problem (see Chapter 7): although there is a considerable amount of technical WEP in Sumatera and Java Island, only up to two onshore WPP sites (100 MW) are economically feasible. Meanwhile, there is no economic potential for offshore wind. Wind energy becomes uncompetitive due to the cheaper fossil-fuel-based electricity at these islands. On the other hand, the greater *maximum allowable PPA tariff* at other islands is economically more favorable for RE projects, albeit a further check on the presence of sufficient electricity demand and infrastructure is necessary. Furthermore, despite the tariff-setting flexibility provided by MEMR MR 4/2020s for cases in which regional BPP is smaller than national-average BPP, the agreed tariff is largely under PLN's control through a business-to-business mechanism. As will be elaborated in Section 7.4, such condition may induce a strategic behavior of PLN given the possible conflicts of interest.

The second problem of a BPP-pegged tariff emanates from the determination of BPP itself. As summarized by Maulidia, Dargusch, Ashworth, & Ardiansyah (2019), there are several points of critique to how BPP is presently calculated. BPP calculation does not consider transmission costs, distribution costs, and future inflation. Moreover, BPP calculation does not take into account the components of LCOE (Maulidia, Dargusch, Ashworth, & Ardiansyah, 2019) and profits for the project developer, including PLN (ADB, 2020c). Another critique stems from the omission of negative externalities from BPP calculation. Most regional BPPs are set by fossil-fuel power plants which generate electricity at a low cost. Nevertheless, the externality cost of air pollution and carbon emitted by these plants are not factored into the calculation. Attwood et al. (2017) estimates the externality cost for coal plants to be as high as 6 USD ct/kWh. Adding this amount to regional and national BPP is likely to increase the economic potential of wind energy.

The already-uneven playing field between RE and fossil-fuels is worsened by government subsidies for the coal industry. These subsidies indirectly lower national-average BPP by creating an artificial generation cost (Bridle et al., 2018), which ultimately determines RE-based electricity prices. Essentially, current BPP calculation favors conventional power plants while undervaluing the potential RE investment and the benefits of RE generation (ADB, 2020c, 2020a). A final critique to BPP concerns its backward-looking nature in calculating costs, namely, by utilizing historical figures. ADB (2020c) asserts the importance of using forward-looking marginal costs to represent PLN's future CAPEX, OPEX, and the fluctuating fuel costs more precisely. In conclusion, although a BPP-pegged pricing scheme may be effective in lowering regional generation costs, the scheme is largely inhospitable for RE development in Indonesia.

Anticipated institutional alterations

Efforts are made by the Government to overcome the aforementioned issues. A PR which introduces a new pricing scheme for RE-based electricity is anticipated in 2021. According to Hidranto (2021), the regulation is still under the scrutiny of MF to safeguard sufficient incentives and fiscal support for PLN. The support is set to take form in a compensation for PLN for cases in which the regional BPP is lower than the PPA tariff. Moreover, a widely circulating PR draft entails multiple pricing schemes depending on RE source and generation capacity (Hidranto, 2021). The schemes include FiT, price cap, agreed price by negotiation, and lowest bidding. A region-dependent multiplying factor (i.e. locational factor) is also applied in the tariff calculation for privately-funded power plants (Meilanova, 2021b). For wind energy, FiT is expected to only be applicable for WPPs of up to 5 MW capacity. WPPs having larger capacities will be subjected to a price cap on the tariff. Lastly, the PPA tariff will be reviewed within 3 years, which may allow a tariff adjustment after the plant comes into operation.

Dadan Kusdiana, the Director General of New, Renewable Energy, and Energy Conservation of MEMR, revealed that the PR draft sets FiT for wind energy to 12 USD ct/kWh, whereas the price cap for WPP with capacities above 20 MW is set to 10 USD ct/kWh (I. N. Sari, 2021). The proposed price cap (excluding location factor) can lead to an increased economic potential of onshore wind to 2.7 GW (from 2.5 GW) and 0.6 GW (from 0.5 GW) using this study's point-grid and square-grid approach, respectively (see Section 5.5). WPPs contributing to this additional economic potential are connected to capitals in Aceh, Sumatera Utara, Jawa Barat, Jawa Tengah, Jawa Timur, and Sulawesi Selatan. Given the high population density and electricity demand at these provinces, the PR is likely to be effective in reducing the barrier for onshore wind energy investment. Meanwhile, the proposed scheme does not affect the economic potential of offshore wind if the locational factor is not considered. The inclusion of such factor can further increase both onshore and offshore WEP.

On top of the direct pricing scheme changes, MEMR recently initiated a voluntary emission trading pilot in the electricity sector in order to establish a national Emission Trading System (ETS) and get stakeholders accustomed to the system (ICAP, 2021). The pilot involves operators of 80 coal-fired power plants which make up for 75% of carbon emission in this sector (ICAP, 2021). Establishing the system may enable the incorporation of negative externalities in future BPP formulation. Another notable institutional change is anticipated through the New and Renewable Energy Bill. Among others, the bill obliges the Government to compensate PLN revenue losses when purchasing RE-based electricity. Moreover, the bill paves way for the creation of NRE fund, which is drawn from national budget, regional budget, and carbon trading funds. The NRE fund is aimed at financing RE infrastructures, incentives, and subsidies (Mulyana, 2021).

Overall, the forthcoming institutional alterations may be a step in the right direction since it addresses the issue of economic viability. Nevertheless, the extent to which the aforementioned institutional barriers can be circumvented remains to be seen as it can highly depend on the quality of governance in implementing the regulation.

7.3.2. Generation infrastructure planning

Institutions of the national and regional government

The rules in energy and electricity planning are schematically represented in Figure 36. Planning in the energy and electricity sector at multiple levels of governance is governed by Law 30/2007 (2007) and Law 30/2009 (2009), respectively. At the national level, planning for energy development until 2050 is guided by KEN: a national energy management policy aimed at achieving energy independence and security. As mentioned in Section 1.1, KEN (Government Regulation (GR) 79/2014, 2014) stipulates the target for RE contribution in the total primary energy supply. Subsequently, the Government drafts RUEN as the operationalization of KEN. Serving as the high-level plan to accomplish KEN, RUEN encompasses energy management planning to meet regional, inter-regional, or national energy demand (ADB, 2020c). Regional governments are also involved in RUEN drafting, while public opinion and suggestions are considered. Following its formulation, RUEN is finally set by NEC. At the provincial level, the regional government devises General Plan of Regional Energy (RUED), which takes RUEN as its guideline. RUED is then formalized in a Regional Regulation.

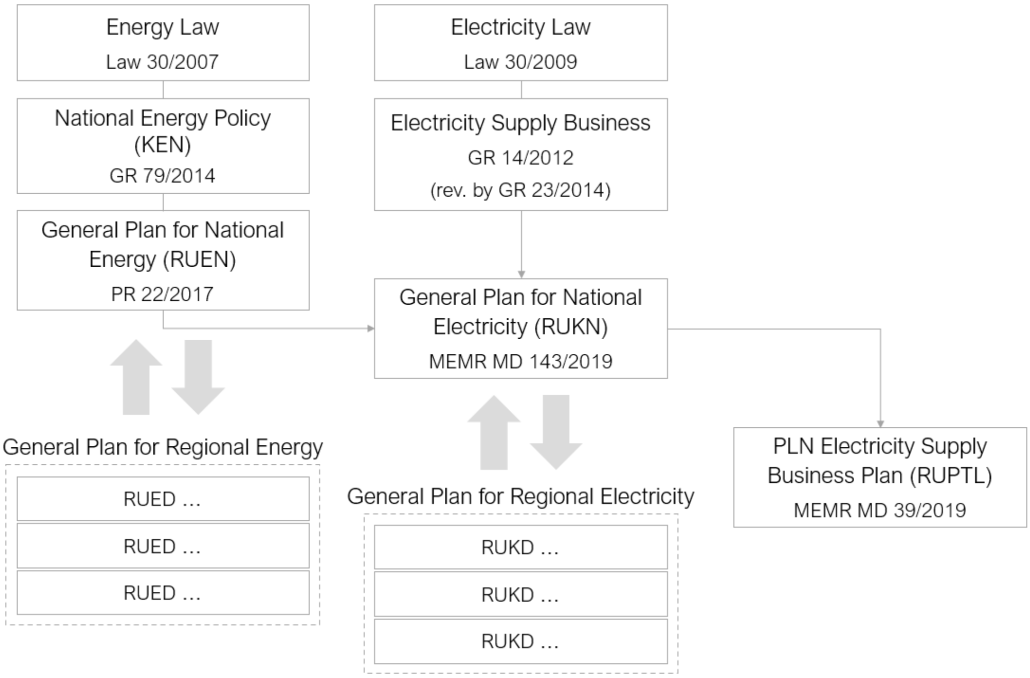


Figure 36. A schematic representation of institutional arrangement pertaining to electricity and energy planning; adapted from (ADB, 2020c; Bappenas, 2012)

High-level planning of electricity development is presented in General Plan of National Electricity (RUKN), which takes RUEN and KEN as reference. RUKN covers system development planning for electricity generation, transmission, and distribution to meet electricity demand at the national level. MEMR Ministerial Decree (MD) 143/2019 (2019) is the legislation underpinning RUKN. On the other hand, electricity development planning at the regional level is contained in General Plan of Regional Electricity (RUKD; GR 23/2014, 2014).

The omnibus law on job creation (Law 11/2020, 2020) slightly alters the infrastructure planning process by amending some articles of the Electricity Law (Law 30/2009, 2009). Generally, the amendment underlines the Government's authority in setting guidelines (norms, standards, procedures, and criteria) for electricity provision. These guidelines shall be adopted by regional governments through the regional autonomy. Moreover, RUKN and RUKD are still devised by the Government and the provincial government, respectively. Nevertheless, the Government does not need the Parliament's approval in forming RUKN. While this alteration may result in an expedited formulation of RUKN, the Government needs to sufficiently consult with the stakeholders to avoid erroneous planning. Furthermore, the guidelines for RUKN formulation are now stipulated in a GR instead of MEMR MR 24/2015 (2015). Overall, there are signs of a shift towards a more centralized planning. The shift may be intended to overcome the complications in promoting RE in a multi-level governance environment such as Indonesia (Sharvini et al., 2018). These complications are further elaborated in Section 7.4.

GR 25/2021 (2021) on the administration of energy and mineral resources serve as the implementing regulation of the omnibus law to specify RUKN formulation guidelines. According to the GR, any electricity provision activity for the public shall be in accordance with RUKN and RUPTL. Legislated through a MEMR MD, RUKN still serves as the reference and guideline to RUKD and RUPTL. The projections contained in RUKN are merely indicative: it does not include a list of forthcoming infrastructure projects. The project list is instead presented in RUPTL. Moreover, RUKN is organized and set by MoEMR, as the Government representative, according to KEN planning period. After RUKN is legislated, RUKD is formulated and formalized through a Governor Decree at the provincial level. In turn, RUKD shall be considered in subsequent RUKN amendments, as depicted in Figure 36. Besides electricity system development plans, RUKN and RUKD contain policies in electricity sector, current conditions of electricity provision, and electricity demand and supply projections (GR 25/2021, 2021).

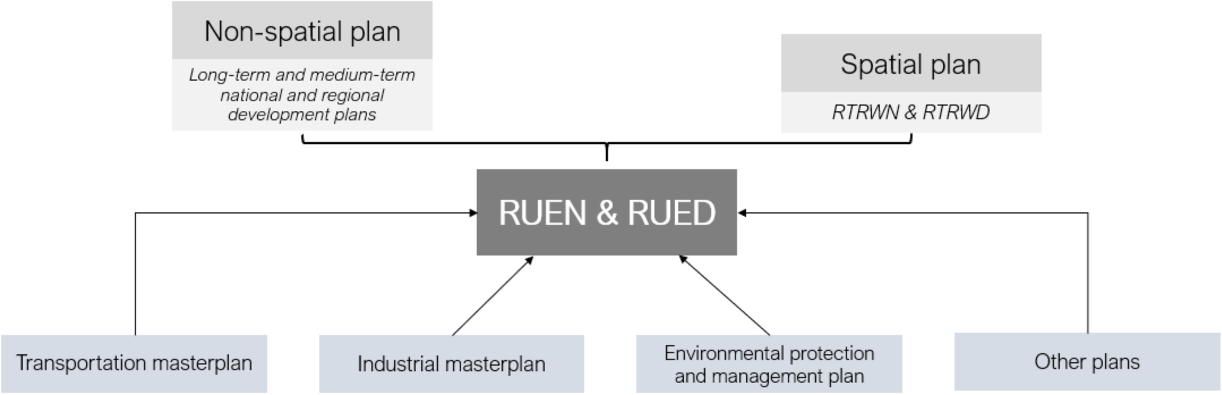


Figure 37. A schematic representation of linkages between RUEN, RUED, and other planning regulation; adapted from (Bappenas, 2012)

One of the crucial parts of infrastructure planning is spatial planning. As shown in Figure 37, RUEN and RUED formulation closely consider the prevailing spatial plans (Bappenas, 2012). The planning consists of national spatial plan (*Rencana Tata Ruang Wilayah Nasional* or RTRWN) and regional spatial plan (*Rencana Tata Ruang Wilayah Daerah* or RTRWD) as devised by the government at respective levels. Natural disaster proneness is among the factors considered when creating these plans. In relation to wind energy, PwC (2018) notes that PR 4/2016 (2016) (as amended by PR 14/2017 (2017)) allows WPP and its supporting infrastructure to be built in natural reserve and natural conservation areas according to relevant laws and regulations. Furthermore, the regulation stipulates the possibility of changing the spatial plan if the prospective site is assigned to a different allotment. In this case, the project developer may need to provide compensation as prescribed in GR 25/2021 (2021) and other environmental regulations.

Institutions of power companies

GR 14/2012 (2012) requires IUPTL holders operating in electricity distribution, sales, or integrated services to prepare an Electricity Supply Business Plan (RUPTL). RUPTL entails a ten-year planning of IUPTL holders with integrated electricity business such as PLN. PLN's latest RUPTL (2019-2028) is formalized as MEMR MD 39/2019 (2019). According to the decree, RUPTL of PLN is created in several steps. First, PLN headquarters determines basic assumptions considering existing government policies and RUKN. For example, these assumptions include electrification ratio target, economic growth, and RE development targets. Subsequently, a demand forecast is formulated based on the basic assumptions by means of a bottom-up approach, namely, by aggregating projected electricity load from each province as computed by PLN regional offices. In the next step, PLN headquarters and its regional offices create a consolidated planning for all Business Areas of PLN in a form of RUPTL draft. Finally, PLN directors submit the draft for MoEMR's approval.

MEMR MR 10/2019 (2019) further details the draft approval process. On behalf of MoEMR, the Director General of Electricity of MEMR verifies the RUPTL draft and requires the IUPTL holder to revise the document if necessary. After the verification process is completed, MoEMR will then approve the RUPTL. The regulation also stipulates a yearly review to be conducted by the IUPTL holder. If the review results in a revised RUPTL, the IUPTL holder will undergo the same process of obtaining MoEMR's approval.

RUPTL of PLN includes a detailed list of existing and planned generation infrastructure in each province. Although the planned power plants' locations are listed in the document, they are only indicative: they may be changed according to system requirements and project preparation developments. The planned power plants are categorized into three project ownership types: PLN project, IPP project, and unallocated project. Unallocated projects are those which are not yet assigned to a developer or sponsor, and thus, they remain open for PLN or IPP ownership.

In this study, institutional analysis of generation infrastructure planning encompasses national- and regional-level planning on wind energy development. Therefore, the documents being scrutinized include RUKN, RUED, and RUPTL. RUKN is chosen to represent infrastructure planning at the national level because it specifically addresses electricity. Instead of RUKD, this study analyzes RUED as the regional-level planning since the latter planning is more recently updated. An analysis of national- and regional-level electricity generation infrastructure planning is presented in subsequent paragraphs.

Examining national-level plans

General Plan for National Electricity (RUKN)

Formalized as MEMR MD 143/2019 (2019), the latest RUKN covers the national electricity planning for 2019-2038. RUKN stresses the goal to reach and sustain 100% electrification ratio from 2020 onwards given the anticipated population and electricity demand growth. However, this goal was not met: the ratio stands at 99.2% in 2020 (KarimSyah, 2021). To provide electricity access, a power generation infrastructure development is necessary. Referring to Law 30/2009 (2009), RUKN is devised according to three main principles in power generation development: ensuring electricity with sufficient quantity, good quality, and a reasonable price. A sufficient quantity of electricity prevents power oversupply and overinvestment in generation infrastructure, which can be detrimental for investors' finances. Meanwhile, ensuring electricity quality encompasses maintaining voltage and frequency levels within the tolerable limits as stipulated in the grid code. Finally, achieving reasonably-priced electricity entails efficient electricity provision and aims to support a strong economic growth. Consequently, an increase of national-average BPP and regional BPP shall be averted. Furthermore, RUKN assigns top priority of primary energy source utilization to NRE in order to meet existing climate targets.

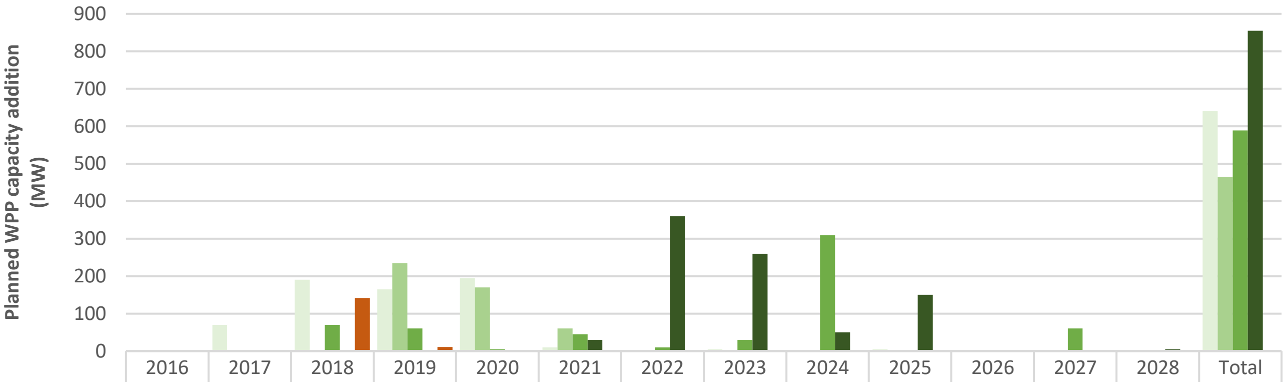
RUKN assumes an average electricity demand growth of 6.9% per year throughout the 20-year period based on a modelling exercise on each province. Based on the aforementioned assumptions and principles, the required average annual addition of generation capacity amounts to 8.5 GW up to 2038. However, intermittent RE is planned to occupy only 6 GW out of the total 170 GW addition in 2019-2038.

In constructing the upcoming generation infrastructures, and given a sufficient budget, PLN is directed to build *peaker* plants and generating capacity for villages and frontier, outermost, and disadvantaged regions. Since WPP is not a *peaker* plant, wind energy development thus depends on the investment of other SOEs and/or private actors through the IPP scheme.

Electricity Supply Business Plan (RUPTL) of PLN

RUPTL of PLN 2019-2028 builds upon RUKN in establishing the national-level planning for RE infrastructures. As shown in Figure 38, the total WPP capacity to be built over the period is 855 MW. This amount is equivalent to roughly 5% of the total RE generation capacity to be constructed over the period. Meanwhile, geothermal (4.6 GW) and hydropower (8 GW) energy dominates the capacity addition with greater than 75% share. Therefore, it can be inferred that wind energy is expected to have a relatively minor role in electricity generation capacity expansion until 2028. Additionally, even if the WPP deployment as prescribed in the RUPTL is achieved, the target stipulated in RUEN to have 1.8 GW WPP installed capacity by 2025 (PR 22/2017, 2017) will not be met.

Figure 38 further illustrates an increasing trend of the total planned WPP capacity addition within each 10-year period since RUPTL of PLN 2017-2026 was released. This trend affects wind energy development positively as PLN becomes more receptive of WPP integration into the electricity system. It is also noteworthy that some of the yearly planned capacity additions are changed significantly based on RUPTL's annual update. For example, there is a considerable difference between the capacity figures in 2019 and in 2020.



	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	Total
■ RUPTL 2016-2025	0	70	190	165	195	10	0	5	0	5				640
■ RUPTL 2017-2026		0	0	235	170	60	0	0	0	0	0			465
■ RUPTL 2018-2027			70	60	5	45	10	30	309	0	0	60		589
■ RUPTL 2019-2028				0	0	30	360	260	50	150	0	0	5	855
■ Realization	0	0	142	11										

Figure 38. Changes in planning of additional WPP capacity based on RUPTL of PLN (DGE MEMR, 2020; MEMR MD 5899/2016, 2016; MEMR MD 1415/2017, 2017; MEMR MD 1567/2018, 2018; MEMR MD 39/2019, 2019)

Although a positive trend is observed, there are two adverse implications of such inconsistent planning. Firstly, it becomes challenging to objectively evaluate PLN's performance in meeting the plans. Failure to conduct the evaluation may ultimately result in unrealistic long-term planning, which defeats the purpose of RUPTL, and incorrect decisions on infrastructure investment. Reports evaluating RUPTL fulfillment shows a sizable difference between the actual generation capacity addition and the planned figures (PwC & APLSI, 2018). A possible reason for the difference is the unrealistic assumptions used in devising the business plan, such as the overly-optimistic economic growth projections and faulty baseline emission values (ADB, 2020a; M. Brown, 2020). Consequently, there is currently an oversupply of electricity in some regions in Indonesia, which can lead to a curtailment of forthcoming RE power generation plans (Setiawan, 2021b; Sommeng & Anditya, 2018). Secondly, an inconsistent planning creates institutional uncertainty which deters investors' interest in this sector. RUPTL lacks a transparent vision throughout the planning because of the sudden, major changes from year-to-year (PwC & APLSI, 2018). Hence, an improved way of planning and monitoring is necessary to add stability to the relevant institutions.

Examining regional-level plans

This study scrutinizes the regional plans of top five provinces according to the total economic WEP as derived by the point-grid approach (see Appendix D): Nusa Tenggara Barat, Nusa Tenggara Timur, Sulawesi Selatan, Maluku, and Papua. The subsequent paragraphs convey the current conditions and planning on wind energy development at each province based on RUKN, RUED, and RUPTL. It is important to note that only 20 out of the 34 provinces have legislated their respective RUED up to March 2021 (NEC, 2021). Sulawesi Selatan, Papua, and Maluku are among the provinces which have not completed their RUED at the time this study is conducted. Therefore, the analyzed regional plans for these provinces are limited to RUKN and RUPTL.

Nusa Tenggara Barat (NTB)

According to RUKN (MEMR MD 143/2019, 2019), NTB's electrification ratio in 2018 is 90.82%. Furthermore, the projected average electricity demand growth is 8.4% per year for 2019-2028, or 5.4% per year for 2019-2038. To achieve 100% electrification ratio and meet the forecasted demand, the annually required generation capacity addition amounts to 96 MW for 2019-2028, or 67 MW for 2019-2038. In addition, RE contribution in power generation is targeted to increase from 7.3% in 2019 to 20.2% in 2038. To achieve this target, an increased intermittent RE plant capacity of merely 20 MW until 2038 is asserted in RUKN. Meanwhile, the remaining generation capacity to be constructed is dominated by coal and gas plants (1,067 MW).

In NTB's RUED (NTB Provincial Regulation 3/2019, 2019), the regional government underlines suboptimal development of RE utilization, and an imbalance between electricity demand growth and generation capacity expansion as issues in the province's electricity sector. In turn, RUED of NTB lists prospective areas for WPP, namely, Southern Lombok and Dompu. Furthermore, the RUED refers to RUPTL of PLN 2016-2025 for the list of power plants to be built up to 2024. A majority of the listed power plants are coal-fired plants. Meanwhile, WPP is only allocated a capacity quota of 10 MW. In other words, a large-scale WPP is not being planned by the regional government until 2024. Notably, the RUED refers to an older version of RUPTL of PLN, which is likely to prescribe an outdated planning compared to its latest version. For the longer term, the regional government sets a target of at least 25 MW and 50 MW WPP capacity by 2025 and 2050, respectively.

RUPTL of PLN 2019-2028 specifies a list of power generation plants to be built at NTB within the period. In contrast to the RUED, the RUPTL does not list any planned construction of WPP. This discrepancy may be attributed to the frequent amendment of RUPTL to which the RUED refer. Moreover, the RUPTL notes a potential 115 MW WPP development at Lombok to satisfy the local electricity system's needs. However, the potential's realization remains unplanned. In conclusion, there is a misalignment between the WPP development plans at NTB created by the different levels of government.

Nusa Tenggara Timur (NTT)

RUKN registers electrification ratio of NTT as 62.07% in 2018. Given this low ratio, an electricity infrastructure development in this province is highly necessary. The projected annual electricity demand growth at NTT amounts to 6.5% and 6% for 2019-2028 and 2019-2038, respectively. Thus, the required generation capacity addition is approximately 238 MW by 2028 or 375 MW by 2038. With a 47.6% RE share target in place for 2038, the addition of intermittent RE capacity is set to approximately 36 MW until 2038.

RUED of NTT (NTT Provincial Regulation 10/2019, 2019) suggests several challenges in the energy sector, including the suboptimal management of RE potentials and the limited access to energy and energy infrastructure. In 2015, a majority of electricity in this province was supplied by diesel power plants. One of the regional government's strategies to reduce fossil-fuel dependency and meet climate targets is to foster wind energy development. The regional government plans to support the development by increasing the quality and quantity of RE potentials survey, facilitating land provision, and providing incentives to achieve the targeted 30 MW WPP capacity by 2050.

Table 22. Planned WPPs in NTT according to RUPTL of PLN 2019-2028

System	*Power plant type*	*Capacity (MW)*	*Target Commercial Operation Year*	*Developer*
Flores	Solar/wind/ocean current	7	2021	IPP
Timor	Wind	10	2022	IPP
Sumba	Solar/wind	3.8	2022	Unallocated
Timor	Wind	10	2023	IPP

RUPTL of PLN 2019-2028 lists 4 planned WPPs in NTT with a total of 30.8 MW capacity as shown in Table 22. Some of these plants are still tentative: they can be substituted by another type of power plant. Notably, the planned WPP capacities are relatively small compared to NTT's economic potential as found by this study. In addition these plants, PLN also registers four potential WPPs to be developed in Oelbubuk-Soe (20 MW), Sumba Timur (3 MW), Kupang (30 MW), and Sumba (3 MW). Based on the above, power generation infrastructure plans of NTT at the different levels of government are relatively coherent. Nevertheless, utilization of the abundant WEP as identified in this study remains unplanned.

Sulawesi Selatan

Compared to the previous two provinces, the electrification ratio at Sulawesi Selatan is closer to 100%, namely, 99.99% in 2018 (MEMR MD 143/2019, 2019). In RUKN, the electricity demand in Sulawesi Selatan is expected to grow by 8.8% per year in 2019-2028, or 7.6% per year in 2019-2038. Meeting this demand increase requires the annual generation capacity construction of 191 MW in 2019-2028 or 224 MW in 2019-2038. The target RE share in the electricity production of Sulawesi electricity system is 47.2% in 2038. To attain the target, 89 MW generation capacity is allocated for intermittent RE until 2038.

In its RUPTL, PLN recognizes the large amount of WEP in Sulawesi Selatan. Accordingly, a 60 MW capacity quota is reserved for IPPs to develop a WPP in the Southern Sulawesi electricity system (MEMR MD 39/2019, 2019). The WPP is expected to operate in 2023. Furthermore, PLN lists 4 potential WPP to be developed in Selayar (5 MW), Sidrap II (63 MW), Jeneponto II (72 MW), and Bulukumba (50 MW). Sidrap II and Jeneponto

II are the expansion of Sidrap and Tolo-1 wind farm, respectively. Overall, the identified potential WPP projects indicate a promising wind energy development at this province in the future.

Maluku

Based on RUKN, Maluku has an electrification ratio of 90.95% in 2018. Furthermore, the province has an average annual electricity demand growth of 1.5% (2019-2028) and 2.1% (2019-2038). In turn, the required generation capacity addition is 41 MW per year in 2019-2028, or 32 MW per year in 2019-2038. For the Maluku electricity system, RE share target in power generation is set to 51.1% in 2038. Notably, only 4 MW of the capacity addition is allocated for intermittent RE until 2038. Most of the planned capacity expansion takes form in gas-fired (272 MW), coal-fired (142 MW), and hydropower and pumped storage (217 MW) plants.

The list of planned power plant construction in Maluku as presented in RUPTL of PLN 2019-2028 does not include WPP. The allocated intermittent RE capacity is designated for solar PV power plants, which will be implemented in isolated areas and villages. It is noteworthy that PLN also lists four potential WPPs to be developed in Ambon (20 and 15 MW), Maluku Tenggara Barat (5 MW), and Keikecil (5 MW). In conclusion, RUKN and RUPTL is aligned in terms of generation infrastructure planning in Maluku. Looking at the plan to build baseload power plants, it can also be inferred that the Government prioritizes access and quality of electricity in future system developments. Thus, up to 0.71 GW economic WEP as identified in this study is unlikely to be realized in the near future.

Papua

According to RUKN, Papua has an electrification ratio of 90.47% in 2018. Moreover, average annual increase in demand is estimated at 5% (2019-2028) or 6% (2019-2038). Accordingly, RUKN stipulates a requirement of annual average generating capacity increase of 89 MW (2019-2028) or 74 MW (2019-2038). Although the objective is to reach 54.3% RE share in power generation in 2038, intermittent RE power plant construction is only limited to 3 MW until 2038. A majority of capacity expansion in Papua is contributed by coal-fired (419 MW), gas-fired (269 MW), and hydropower and pumped storage (763 MW) power plant. Consistent with RUKN, RUPTL of PLN 2019-2028 allocates intermittent RE quota to solar power generation. Consequently, wind energy development is not planned up to 2038.

Table 23. A summary of planned generation capacity addition at the top five provinces based on the economic potential identified in this study

Province	Intermittent RE capacity addition *(RUKN 2019-2038; in MW)*	Planned WPP development *(PLN RUPTL 2019-2028; in MW)*	Potential WPP development *(PLN RUPTL 2019-2028; in MW)*	Economic potential of wind as identified in this study *(in MW)*
Nusa Tenggara Barat	20	-	115	up to 120
Nusa Tenggara Timur	36	31	56	up to 1,153
Sulawesi Selatan	89	60	190	up to 239
Maluku	4	-	-	up to 713
Papua	3	-	-	up to 8,139

A summary of intermittent RE capacity addition, planned WPP development, and potential WPP development for the five provinces are shown in Table 23. The evaluation of regional-level planning results in several insights. First, there is a general alignment between the regional-level planning conducted by actors at different layers of governance, except for Nusa Tenggara Barat. Second, wind energy has a peripheral role in forthcoming electricity generation at these provinces. The ambitious climate RE share targets in these provinces are mainly attained by constructing hydropower and pumped storage. Third, intermittent RE capacity expansion at these provinces are restricted to small amounts. This is likely due to the priority of establishing a stable electricity supply using baseload power plants. These plants have high CF and low operational flexibility; hence, they cannot provide the flexibility required to deal with intermittent RE-based electricity (Sommeng & Anditya, 2018). Fourth, most of the wind energy potential identified by PLN and by this study is not included in the current plans. It can be inferred that wind energy is less competitive compared to alternative energy sources for power generation, especially in NTB, Maluku, and Papua. Finally, none of the reviewed documents consider offshore wind as a viable energy source. This insight is in agreement with the finding of this study's techno-economic analysis: considering the current conditions, the minimum LCOE of onshore WPP is less than that of offshore WPP. Therefore, the lack of offshore WPPs' cost-competitiveness underlies their omission from existing plans.

7.3.3. Property rights

Regulations governing property rights on RE-based electricity underwent revisions in recent years. MEMR MR 12/2017 (2017) did not prescribe any conditions on property rights for wind power generation. It was then revoked by MEMR MR 50/2017 (2017), which stipulates a cooperation scheme between PLN and the IPP in RE projects. Particularly, electricity purchase from WPP shall be conducted through Build, Own, Operate, and Transfer (BOOT) cooperation: an IPP is obliged to transfer the WPP ownership to PLN at the end of the concession (or PPA) period, which is capped at 30 years (PwC, 2018).

The BOOT scheme invited criticisms from RE-sector stakeholders due to the issues it causes. As elaborated by Maulidia, Dargusch, Ashworth, & Wicaksono (2019), BOOT is problematic because the ownership transfer influences the envisioned return on investment. Land ownership transfer is included in the scheme without prior market value appraisal. Considering the space-intensive nature of WPP and the embedment of assets within it (Burke et al., 2019), the transfer is likely to be disadvantageous for IPPs. Furthermore, the land can no longer be used as a collateral in project financing. Essentially, the transfer results in RE projects being not bankable and creates uncertainty and contracting costs. Hence, this discourages private sector investment in wind energy. The latest regulation, i.e. MEMR MR 4/2020 (2020), replaces BOOT with Build, Own, and Operate (BOO) cooperation scheme between PLN and IPPs while considering civil and agrarian laws. Therefore, ownership transfer is no longer mandatory.

Another aspect of property rights pertains to project ownership. As will be explained in Section 7.3.3, funding is one of the main challenges in RE development in Indonesia. Private and foreign investment are required because RE development cannot be done by solely depending on PLN's finances. Foreign investment entails foreign participation and ownership, which are limited by *the negative list*. PR 44/2016 (2016) defines *the negative list* for multiple sectors including electricity: foreign ownership of small-scale WPP (1-10 MW) is permitted up to 49%, whereas foreign ownership of large-scale WPP (> 10 MW) is capped at 95% and 100% for IPP and Public Private Partnership case, respectively. This regulation posed a challenge for small hydropower projects (PwC, 2018), however, none of the reviewed literature mention the adverse impact directly on wind energy projects.

PR 44/2016 was recently revoked by PR 10/2021 (2021), i.e. an implementing regulation of the omnibus law on job creation (Law 11/2020, 2020). The latter PR may present a significant breakthrough in RE investment: ownership of electricity generation projects is now presumably unrestricted to foreign investments (Panggabean et al., 2021). This change is arguably advantageous for forthcoming RE development. Nevertheless, the practical implementation and effectiveness of this novel PR remain to be seen.

There are some restrictions imposed on ownership or share transfer throughout the concession period. In previous regulations, these restrictions were perceived by stakeholders as a barrier to RE investment: the regulations limit the possibility of risk re-allocation by requiring MoEMR's approval for share transfers. Furthermore, any transfer prior to the plant's commercial operation date can only be done under certain conditions. Such restrictions adversely affect the project's economic viability (PwC & APLSI, 2018). However, the latest regulation (MEMR MR 48/2017, 2017) partly alleviates the restriction by only requiring the IPP to report the transfer. Hence, the regulation change has improved the institutional setting for RE investments.

Overall, the institutional barriers on property rights have been addressed by recently enacted legislations. Nonetheless, the impact of these legislations on proliferating RE investment can only be observed once they are fully enforced and understood by the stakeholders.

7.4. Layer 3 analysis: Governance of contracts

Institutional setting

L3 of WLIF concerns the governance of transactions in the form of contracts. There is a wide variety of contracts in the power sector, such as agreements between shareholders, EPC contracts, O&M contracts, and project insurance (PwC, 2018). Among the different types of contracts, this study scrutinizes PPA, i.e., the contract between PLN and IPPs in the transaction of electricity. PPA is governed by MRs which are located at L2 of WLIF.

The corresponding regulation on PPA principles is MEMR MR 10/2017 (2017), as amended by MEMR MR 49/2017 (2017) and MEMR MR 10/2018 (2018). A list of provisions which a PPA shall contain are presented in these regulations. Among others, the provisions address PPA duration, rights and obligations of contracting party, risk allocation, commissioning and commercial operation date, transaction, and penalties for incompliance. However, the regulation only applies to geothermal, hydropower, and biomass power plants. PPA standardization for intermittent RE power plants is supposedly governed by a separate MR.

Based on a literature review, the only regulation relevant to PPA for intermittent RE is MEMR MR 50/2017 (2017) as amended by MEMR MR 4/2020 (2020). For wind energy, these regulations prescribe the possibility of electricity purchase by *direct selection* and *direct appointment* mechanism. The latter mechanism can only be done if (1) the local electricity system is in crisis or emergency for electricity supply, (2) the purchase involves excess power, (3) there is a generation capacity enhancement of existing power plants, or (4) there is only one candidate of RE-based electricity supplier. Importantly, electricity purchase from intermittent RE power plants shall be based on RUPTL and the *capacity quota*, i.e., the maximum generation capacity offered to IPPs within a certain period under a predetermined tariff. Furthermore, PPA tariffs shall be subjected to MoEMR approval prior to PPA signing.

MEMR MR 50/2017 also obliges PLN to publish a PPA standard for each RE type. Nevertheless, this study's literature search suggests that the standard for wind energy is not publicly accessible. According to DGE (personal communication, June 8, 2021), PPA draft for intermittent RE will be sent to prospective bidders at the beginning of PLN's project procurement process. There is, however, a study by Simaremare et al. (2020) of PLN Research Institute that lists clauses/provisions contained in a typical WPP PPA in Indonesia. Overall, the provisions are largely similar to those prescribed in MEMR MR 10/2017. For example, typical WPP PPA provisions include transaction arrangements, settlement of disputes, agreement termination, project construction and commissioning, and force majeure conditions.

Barriers stemming from the institutional setting of contracts can be segregated into two parts: before PPA signing and after PPA signing.

Institutional barriers: before PPA signing

One of the key contract components is the agreed PPA tariff. Under certain conditions, the current pricing regulation requires a negotiation between PLN and IPPs over the tariff (see Section 7.3). In practice, tariff negotiation can be a prolonged and difficult process that hampers RE development (Bridle et al., 2018; Maulidia, Dargusch, Ashworth, & Ardiansyah, 2019). To understand the reason behind the prolonged negotiation, it is necessary to examine the intricate position of PLN. PLN is required by law to provide electricity and its supporting infrastructure for the Indonesian people. As a vertically-integrated company, PLN owns 79% of Indonesia's power generation (Maulidia, Dargusch, Ashworth, & Ardiansyah, 2019), most of which are fueled by non-renewable energy sources. Having PLN involved in tariff negotiations with IPPs is likely to introduce a conflict of interest: PLN is directly competing with the IPPs for the market share in power generation (Guild, 2019), and thus, PLN may act strategically to avoid revenue loss from conventional generators and their possible abandonment (Bridle et al., 2018).

Another cause of the problematic PPA negotiation is PLN's dependence on government subsidies. The Government allocates a portion of the national budget to financially support PLN in order to ensure electricity affordability and sustain PLN's financial health. This dependence signifies a strong control of the Government over PLN. Since the Government also wishes to reduce the subsidies (ADB, 2020c), PLN arguably becomes more reluctant to grant premium tariffs, i.e. tariffs which can make RE projects economically viable. Therefore, the negotiation may be stalled due tariff disagreement. On the other hand, PLN also needs to minimize costs to deal with the reduced subsidies (ADB, 2020c) and the revenue losses stemming from the lowered demand during the COVID-19 pandemic (ADB, 2020a). One way to do so is to capitalize on the Government's fossil-fuel subsidy: the Government applies a domestic market obligation for domestic coal which mandates a quarter of its production for power generation with a certain price cap (Burke et al., 2019). In addition, existing PPAs with coal IPPs are inflexible (M. Brown, 2020) and are still valid in the long-term (Burke et al., 2019). Accordingly, PLN becomes less likely to reach an agreement over a premium PPA tariff for RE projects. In summary, PLN's intricate position and its entailed possibilities of hampering PPA establishment demonstrate a poor governance structure currently in place.

Adding to PLN's intricate position is the company's opaque administration of procurement and bidding process. A study by Setyowati (2021) reveals that the process is insufficient in terms of transparency and predictability: IPPs wishing to engage in the process must undergo a long and unclear selection procedure. Notably, the selection criteria to filter out unqualified IPPs are not transparently disclosed. For wind energy projects, this problem may occur in the *direct selection* mechanism. Hence, the current administration of procurement and bidding can lead to corruption (Setyowati, 2021). In turn, such poor administration is likely to impede wind energy development.

The lack of intermittent RE PPA standard also poses a challenge for wind energy development. As explicated above, current PPA standard only applies to geothermal, hydropower, and biomass energy. For wind energy, however, the PPA is not standardized by formal regulations. Setyowati (2020) finds that a standardized PPA can entice IPPs by conceiving a hospitable investment climate. Contrarily, the ongoing practice of direct negotiation between IPP and PLN halts the finalization of potential PPAs.

Institutional barriers: after PPA signing

Once the PPA has been signed, there are three institutional barriers impeding wind energy development. The first barrier pertains to law and contract enforcement. Guild (2019) conducted a comparative analysis on the effectiveness of FiT scheme in proliferating RE development. He found that FiT performed better in the Philippines than in Indonesia partly because of the superior quality of governance in the former country. Using 2017 data, he comparatively assessed the quality of governance based on three of The World Bank's (2020) Worldwide Governance Indicators: *government effectiveness*, *regulatory quality*, and *rule of law*. In this study, the focus is placed on *rule of law*: the degree of confidence in and abidance to institutions on, among others, the quality of property rights, contract enforcement, and the judicial system (Kaufmann et al., 2011). Contrasted to 2019 data, Indonesia showed signs of improvement in this indicator, although the country is still positioned at 42 percentile rank globally (The World Bank, 2020c). Moreover, Burke et al. (2019) also highlight Indonesia's poor performance according to The World Bank's (2020a) Doing Business indicators: Indonesia ranks 139 and 106 out of 190 countries in *enforcement of contracts* and *registering property*, respectively. This implies an ample room for improvement in law and contract enforcement in order to attract investors in RE.

The second barrier concerns the lack of coordination and leadership within the multi-level governance of the electricity sector. According to Sharvini et al. (2018), there is a deficient level of awareness regarding national visions at the subnational government level. Moreover, Marquardt (2014) explains the complexity in of multi-level governance in the horizontal and vertical direction. In the horizontal direction, decision making in the electricity sector involves several ministries (as shown in Figure 34) who can veto the support for RE. Meanwhile, complexity in the vertical direction concerns the extensive degree of decentralization in the power sector, such as the regional government's role in issuing licenses and permits, project execution, and infrastructure planning. The decentralization, however, is not properly equipped with a strong leadership at the regional level: local implementation of RE has been hindered by insufficient human and financial capital at the regional governance level (Kurnia, 2021). In combination, these vertically- and horizontally-oriented complexities impose a challenge to RE development. This motivates a possible change to the existing governance and decision-making structure.

The recently enacted omnibus law on job creation (Law 11/2020, 2020) is expected to alleviate this barrier by streamlining complex, overlapping regulations in multiple sectors including electricity. The omnibus law amends some articles of the Electricity Law (Law 30/2009, 2009) including the removal of regional government's authority in issuing some licenses (e.g. IUPTL) and approvals. Baker McKenzie (2020) asserts that it was not clear whether the removal is imminent, since other sections of the law indicate that regional governments still have a role to play in this matter. Moreover, the law signals a centralization in determining licenses' norms, standards, procedures, and criteria: they are set by the Government. However, the legislated implementing regulations thus far have not fully clarified the regional government's authority.

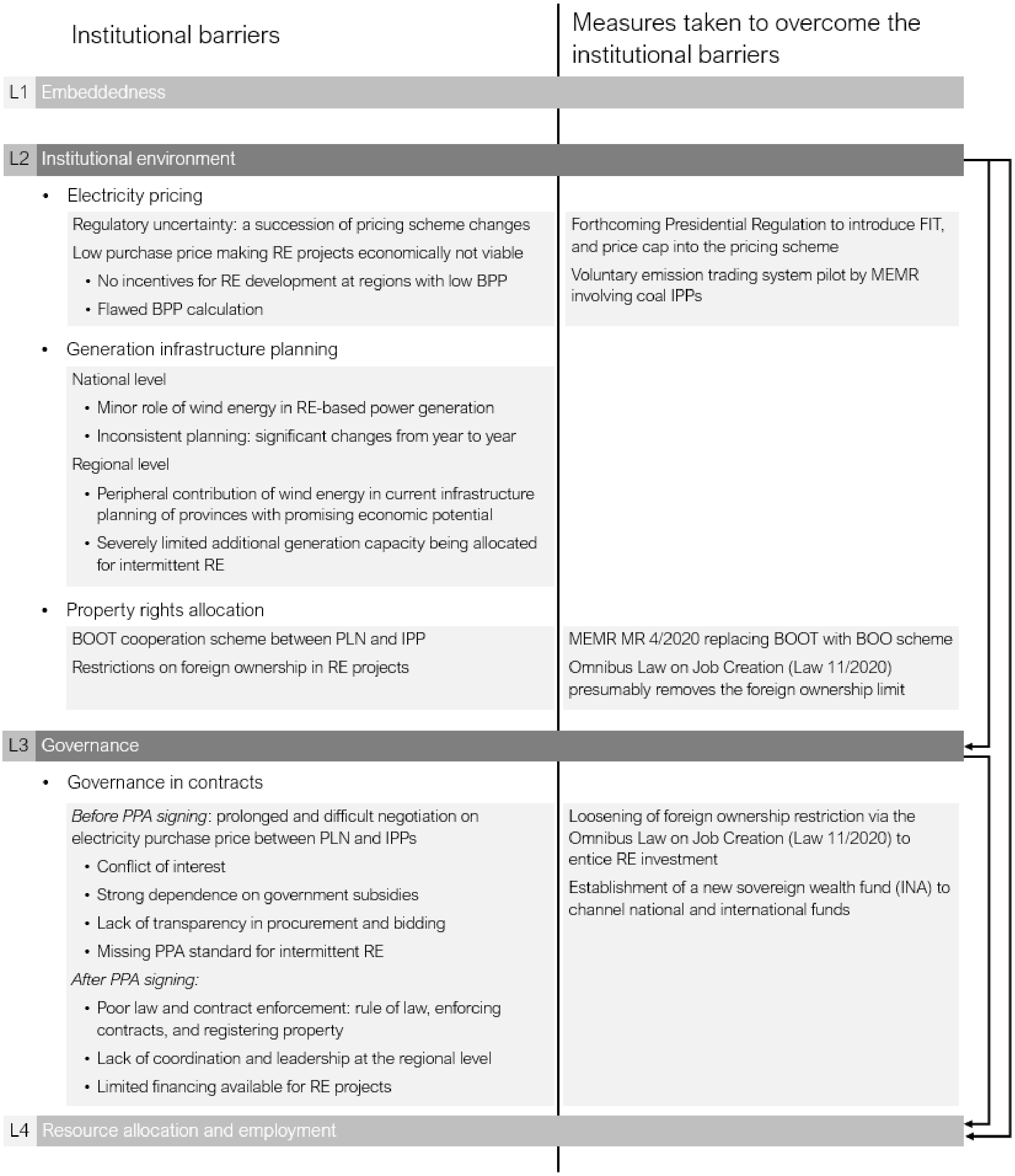
The implementing regulations of the omnibus law in the electricity sector are GR 5/2021 (2021) and GR 25/2021 (2021). GR 5/2021 stipulates the application of risk-based *Business Licensing* to the electricity sector. Essentially, each business activity is categorized based on the level of risk, which in turn corresponds to a particular licensing procedure. For instance, power generation for the public is considered a high-risk activity (KarimSyah, 2021). The second implementing regulation is GR 25/2021 (2021) on the administration of energy and mineral resources sector. This regulations segregates *Business Licensing* into several types of licenses, such as the license for electricity generation for the public (*Izin Usaha Penyediaan Tenaga Listrik untuk kepentingan Umum* or IUPTLU) and the license for electricity generation for own interest (*Izin Usaha Penyediaan Tenaga Listrik untuk kepentingan Sendiri* or IUPTLS). An operationalization of the procedure to obtain these licenses is anticipated in a form of another GR or MR. In conclusion, it remains ambiguous whether the decision making in this sector will be more centralized to address the multi-level governance issue.

The third barrier encountered after PPA signing relates to the sizable amount of finance required to execute RE projects. Although the International Trade Administration (2020) considers the energy sector as the best prospect industry sector for exports and investments in Indonesia, securing funding or reaching a financial closure has been a major issue for IPPs in advancing the project (PwC, 2018). This resulted in a cancellation of RE PPAs by PLN, such as those established in 2017 (ADB, 2020a). Another consequence of this issue is the postponement of the ambitious *35 GW Electricity Development Program* (PwC, 2018). To understand this barrier, it is useful to review the sources of finance for Indonesian IPPs. The sources include global commercial banks, regional multilateral development banks, the World Bank, and foreign government investment authorities (PwC, 2018). The latter three sources typically grant direct, soft loans with lower-than-market expected returns and extended grace periods (PwC, 2018). Moreover, the use of public funds (e.g. national and regional budget) is recently made possible to support electricity provision for underdeveloped areas (GR 25/2021, 2021). However, foreign aids and public funds alone are not enough to support RE implementation, and consequently, private finance contribution becomes fundamental in this sector (Setyowati, 2020).

Section 7.3 already conveys the private agents' reluctance in RE investment given the unfavorable institutional setting, which in turn makes RE projects not bankable. In other words, the investors' required rate of return, as represented by WACC, is unlikely to be met under the current regulatory circumstances. The techno-economic analysis of this study corroborates this assertion: the base case WACC of 10% generates a small amount of economically feasible WPPs, which is equivalent to up to 8% and 1.4% of onshore and offshore technical WEP, respectively. The corresponding sensitivity analysis (see Section 5.5) further shows how lower WACC can significantly improve the economic potential of wind energy. Nonetheless, a survey by PwC & APLSI (2018) suggests that investors in Indonesia's electricity generation sector expect returns ranging from 15% to 30%, which are higher than the global average of expected return for infrastructure projects of 10.6% in 2016. Such high rates signify the investors' perception of a high investment risk stemming from the unpredictable institutional changes (PwC & APLSI, 2018). Therefore, the introduction of a stable regulatory regime that can safeguard project's economics through a fair electricity pricing scheme is anticipated.

The Government has recently conducted several institutional reforms to overcome the financing constraint. One of them is through the omnibus law: The Government loosened the foreign ownership restriction in power generation projects (see Section 7.3). However, the extent to which this policy can increase the attractiveness of RE investment remains to be seen. Moreover, the implementing regulation of omnibus law also asserts the need to increase investment in the energy sector by, among others, providing funds through national and regional government budget (GR 25/2021, 2021). Another example of the recent reform is the founding of Indonesia Investment Authority (INA) in early 2021. INA is mandated to manage a new sovereign wealth fund with a vision to support sustainable national development and build wealth for generations to come (INA, 2021). One of the key investment sectors of INA is RE, in which INA aims to support the mobilization of national and international funds to provide an alternative means of funding (Artanti, 2021).

The institutional barriers identified in L2 and L3 institutions and the recent measures taken by the Government to overcome the barriers are summed up in Figure 39.



Institutional barriers	Measures taken to overcome the institutional barriers
L1 Embeddedness	
L2 Institutional environment	
• Electricity pricing	
Regulatory uncertainty: a succession of pricing scheme changes Low purchase price making RE projects economically not viable • No incentives for RE development at regions with low BPP • Flawed BPP calculation	Forthcoming Presidential Regulation to introduce FIT, and price cap into the pricing scheme Voluntary emission trading system pilot by MEMR involving coal IPPs
• Generation infrastructure planning	
National level • Minor role of wind energy in RE-based power generation • Inconsistent planning: significant changes from year to year Regional level • Peripheral contribution of wind energy in current infrastructure planning of provinces with promising economic potential • Severely limited additional generation capacity being allocated for intermittent RE	
• Property rights allocation	
BOOT cooperation scheme between PLN and IPP Restrictions on foreign ownership in RE projects	MEMR MR 4/2020 replacing BOOT with BOO scheme Omnibus Law on Job Creation (Law 11/2020) presumably removes the foreign ownership limit
L3 Governance	
• Governance in contracts	
Before PPA signing: prolonged and difficult negotiation on electricity purchase price between PLN and IPPs • Conflict of interest • Strong dependence on government subsidies • Lack of transparency in procurement and bidding • Missing PPA standard for intermittent RE *After PPA signing:* • Poor law and contract enforcement: rule of law, enforcing contracts, and registering property • Lack of coordination and leadership at the regional level • Limited financing available for RE projects	Loosening of foreign ownership restriction via the Omnibus Law on Job Creation (Law 11/2020) to entice RE investment Establishment of a new sovereign wealth fund (INA) to channel national and international funds
L4 Resource allocation and employment	

Figure 39. A summary of institutional barriers and measures taken to address them within WLIF

7.5. Institutional recommendations

This section proposes institutional recommendations based on institutional and stakeholder analysis findings. In the following subsections, three recommendations are provided along with a brief discussion on their feasibility and on the role of relevant stakeholders. The recommendations largely entail changes of institutions at L2 of WLIF in order to establish suitable institutional environment and governance structure for wind energy development. Changes to L1 institutions are not proposed because modifying these informal rules would require a prolonged period, whereas immediate changes to accelerate WPP deployment is needed to meet the climate targets in the near future.

7.5.1. Introducing a masterplan of electricity pricing scheme

The first proposal is to alter the formal laws on electricity pricing scheme (L2), so that wind energy projects can become economically attractive for IPPs and financiers. The proposal addresses three issues: low RE electricity pricing (L2), prolonged PPA negotiation (L3), and inadequate source of project funding (L3). Therefore, altering the pricing scheme exploits the top-down influence of L2 institutions on L3 institutions by means of 1st-order economizing: getting the institutional environment right (see Figure 29). In turn, changes to these institutions can lead to a conducive institutional setting, which incentivizes PLN and IPPs to allocate their resources in wind energy projects (L4).

Subsection 7.3.1 has mentioned that a regulatory alteration in pricing, which includes several capacity-dependent tariff schemes, is still under the Government’s review. Although the alteration is likely to benefit IPPs and investors in the short term, it is pivotal to also examine the long-term repercussions. A starting point of this examination is to consider the three key elements founding the selection of policy instrument to proliferate wind energy development according to IRENA (2019). First, policies should be adjusted according to country-specific characteristics and goals. Second, policies shall produce a stable investment environment in the long-run. Finally, cost trends should be considered in policymaking. Regarding the last element, policies must be adapted to suit the dynamic market condition.

There is a variety of economic policy instruments available to stimulate wind energy development. Among these instruments, Enzensberger et al. (2002) consider FiT, tender systems, and Renewable Portfolio Standards (RPS) as the most important instruments. As introduced in Section 7.3, FiT obliges system operators to buy the electricity produced by WPPs at a fixed price in a long term. Meanwhile, tender systems or reverse auctions enforce competitive bidding between project developers to arrive at a fixed feed-in tariff. The developer proposing the lowest bid is awarded with the contract or PPA. Moreover, RPS prescribe a targeted share or quota of RE-based electricity to be used by parties along the electricity supply chain. This instrument is typically coupled with a green electricity certificate trading system, which allows the parties to fulfill the quota by purchasing these certificates.

Considering these options, this study proposes the establishment of a masterplan for wind-based electricity pricing. This proposal involves a new institution, i.e. the masterplan, to be introduced as a formal rule at L2 of WLIF. The masterplan entails a long-term plan of the instruments’ implementation to provide regulatory certainty for investors. A key feature of the masterplan is the instruments’ phased implementation in two dimensions: time and location. Phasing with respect to time means that the masterplan prescribes a sequence of policy instruments to be purposefully applied within a specified period. Meanwhile, staging the implementation based on location means that the plan can first be applied to several provinces with promising wind resources before its implementation in the other provinces.

FiT is arguably the most appropriate scheme to kick-off the masterplan. The objective of employing FiT is to stimulate initial waves of wind energy investment. A key feature of FiT that can help to achieve the objective is the provision of long-term, above-market tariffs. Hence, the scheme offers institutional certainty and makes WPP projects economically viable. Furthermore, FiT is supported by the already-proven wind power technology: this combination enables a long-term secured cashflow for IPPs (ADB, 2019). In turn, the stable cashflow reduces wind energy projects' investment risk and facilitates WACC reduction (McKenna et al., 2021). As shown in Subsection 5.5.2, having an appropriate level of FiT can increase the economic WEP. Moreover, the lower investment risk is likely to aid IPPs in securing funding from financiers, and hence, the institutional barrier at L3 can simultaneously be addressed. Another benefit of FiT stems from the clarity and transparency in establishing PPAs (ADB, 2019): FiT circumvents the problematic negotiation process between PLN and IPPs, which is another institutional barrier of L3. Thus, FiT is expected to reduce the likelihood of PLN's strategic behavior in cooperating with IPPs. PPA can thus be issued in a shorter period, inducing cost-savings for IPPs.

The selection of FiT as the initial scheme is motivated by the current conditions in Indonesia: the country's RE sector is characterized by a low level of WPP deployment and an ambivalent institutional setting. For emerging markets having these characteristics, Guild (2019) finds that FiT can be more effective than auction mechanisms. His conclusion was drawn based on the success of FiT in the Philippines, which had similarities with Indonesia in terms of RE development, geographical challenges, and economic and political landscape. In 2013, the Philippines employed a single, above-market rate FiT for each RE source. In combination with some fiscal incentives, the FiT was implemented straightforwardly with a long-term view: IPPs were allowed to submit their offers within a three-year window to fulfill a predetermined capacity quota. Importantly, the FiT was fixed throughout the period for all RE sources except for solar energy, since solar attracted a larger interest from IPPs than anticipated. Consequently, the policy successfully enticed a swift RE development in the Philippines from 2013 to 2017.

Despite the aforementioned benefits, FiT entails several challenges that one shall be aware of. Among others, ADB (2019) highlights tariff-setting as a challenging process. Suboptimal tariff can either lead to an overstimulated wind energy deployment if the tariff is too high, causing a significant burden on the Government in compensating PLN, or a stagnating wind energy sector if the tariff is too low. Therefore, the tariff must be carefully determined and periodically-evaluated to prevent these adverse effects. For example, FiT was employed to stimulate RE investment in Thailand, Vietnam, and the Philippines (ADB, 2020c). Adjustments to the scheme were then made after a certain period, such as by FiT quotas application, downward FiT amendments, and replacement with another scheme. This example motivates the implementation of a capacity quota for FiT so that overinvestment can be prevented. The quota shall be set in such a way that it allows for the niche wind energy market to grow and establish a sufficient industrial capability in Indonesia.

Another challenge to a successful FiT application concerns political economy factors. Besides an appropriate FiT design, Guild (2019) attributes the Philippines' success to the possibility of passing high power generation cost to consumers, simultaneous market structure reform and unbundling, and the less-established incumbent fossil-fuel actors compared to Indonesia. As elaborated in Subsection 7.3.1, the 1945 Constitution makes it unlikely for consumers to bear the high cost and for unbundling to take place. Hence, a continued subsidy from the Government to PLN becomes crucial for the success of FiT in Indonesia. A proposal on how this subsidy can be conducted will be discussed further in Subsection 7.5.2.

After the FiT quota is fulfilled, the next stage entails tender systems with the objective of reducing wind power generation costs. By introducing competitive bidding, the resulting price can more accurately reflect the true cost-competitiveness of wind energy compared to FiT (ADB, 2019) given the technological advancement and learning in the industry. Similar to FiT, reverse auctions foster cashflow stability in the long run (ADB, 2019) and eliminate the issues related to PLN-IPP negotiation (L3). Furthermore, reverse auctions lessen the possibility of over-subsidizing RE (Bridle et al., 2018). The auction scheme shall also include a price cap and a capacity quota to mitigate overinvestment.

Employment of FiT or tender systems at industrialized regions, e.g. provinces in Java and Sumatera, can be coupled with RPS. In this scheme, PLN and large electricity consumers are obliged to purchase green certificates to meet their respective contributions. This scheme has been implemented in India. Although the implementation is imperfect, Burke et al. (2019) argue that RPS employment in Indonesia should be more straightforward because of the more centralized sectoral governance compared to that of India. Coupling of supply-push (e.g. FiT and tender systems) and demand-pull instruments was key to Denmark's success in fostering wind energy development (Buen, 2006). Despite possible differences between Indonesia and Denmark in terms of contextual factors, the Indonesian Government can attempt to replicate this coupling to stimulate wind energy development.

In terms of regional phasing of the masterplan, FiT should first be applied to provinces with promising economic WEP. As listed in Table 23, these provinces include NTB, NTT, Sulawesi Selatan, Maluku, and Papua. There are three benefits of adopting this regional approach. Firstly, the approach can decrease the power generation cost at these provinces. This is due to the relatively high regional BPP compared to LCOE at the modelled WPP sites (see Chapter 5). Secondly, the approach is aligned with the Government's goal of achieving a national electrification ratio of 100%. Subsection 7.3.2 shows that most of these provinces have much lower electrification ratios than the national-average. Therefore, initiating FiT at these provinces means prioritizing WPP deployment in areas in need of generation infrastructure. Lastly, the approach allows time for technological learning to take place in Indonesia's wind energy industry. Technological learning is expected to lower the investment cost of subsequent WPP deployments. In turn, this translates to an increased cost-competitiveness of wind energy before the masterplan is introduced to the western provinces of Indonesia, in which power generation cost is already low. Besides creating new legislations, implementing the masterplan requires an amendment to the planned WPP capacity addition in RUED and RUKD (L2) at these provinces. Accordingly, consistency between the plans and their realization can be safeguarded.

Under the current governance structure, MEMR shall devise the masterplan draft in coordination with MF and MSOE. Through DGNREEC and DGE, MEMR ensures that the plan will help the provision of reliable and affordable electricity while meeting RE objectives by determining the schemes' tariff levels and capacity quota. Meanwhile, MF assesses the feasibility of implementing these schemes from the budgetary perspective: subsidies for PLN are mandatory to purchase electricity at the predetermined tariff. Furthermore, MSOE examines the plan's influence on the long-term financial health of PLN. The draft can then be subjected to the approval of NEC and the Parliament.

7.5.2. Establishing financial support for wind energy projects

This study recommends two institutional changes related to the financial issues hampering wind energy development, which are situated at L3 of WLIF.

Establishing new funding sources to sustain the subsidy for PLN

The first recommendation pertains to the Government's subsidy to PLN for RE. To support the implementation of FiT (see Subsection 7.5.1), PLN will need to pay a premium tariff to IPPs. In turn, PLN will need a continued financial support from the Government. Ensuring an adequate allocation of the state budget for the subsidy is therefore essential. This may be achieved by creating new sources of funds for the budget, which will then be ‘redirected’ to PLN. One way to do this is by reallocating subsidies on fossil-fuels to PLN for the purpose of administering FiT-based transactions. The Government has acknowledged that fossil-fuel subsidy reduction is essential for numerous reasons, including fiscal restrictions and the hindrance the subsidy causes to RE development (MEMR & MF, 2019). The reallocation shall be done gradually to contain the resistance from incumbent energy companies and incentivize the reorientation of their business to RE. Moreover, such reallocation entails a political process involving relevant ministries and the Parliament according to the prevailing governance structure (L3). The process’ result, i.e. the state budget reallocation for RE subsidy to PLN, will then be formalized as a Law (L2). Hence, this recommendation pertains to a 1st-order economizing within WLIF.

Another possible source of funding for the subsidy is the revenue from carbon pricing mechanisms, such as ETS and carbon tax. Founded on GR 46/2017 (2017), an ETS pilot was recently commissioned in Indonesia’s power sector in 2021 (see Section 7.3.1). However, formulation of a PR that forms a framework for carbon pricing mechanisms, including ETS, is still underway. The PR is meant to support a full implementation of ETS by 2024 (ICAP, 2021). This signifies the necessity for an institutional change at L2. Meanwhile, implementing a carbon tax also requires an alteration to L2 institutions: an amendment bill on general provisions and tax procedures is expected to enforce a carbon tax on individuals or entities in purchasing goods containing carbon and/or performing activities that produce carbon emission (Victoria, 2021). To conclude, enabling carbon pricing mechanisms as revenue sources requires institutional changes at L2 before the financing issue at L3 can be tackled. It is also noteworthy that the combination of fossil-fuel subsidy phase-out and internalization of fossil-fuel negative externalities through ETS support the founding of a more equal playing field for RE technologies (Bridle et al., 2018; Burke et al., 2019).

Administration of the RE subsidy can follow the proposal of ADB (2020c). According to ADB, the subsidy shall be equal to the difference between an RE power generation cost and PLN’s *avoided cost*. The avoided cost is defined as financial cost that PLN would otherwise bear in the absence of the RE power plant. Additionally, ADB recommends a price cap on RE power generation cost at its economic valuation, which is derived by summing PLN’s avoided cost and societal cost of externalities. Consequently, RE over-subsidizing can be prevented. To obtain the subsidy, PLN estimates and proposes the amount of subsidy needed annually by considering RE generation infrastructure planning. Afterwards, the proposal is examined by MEMR and MF to validate the economic values and avert possible overestimation of costs. The final step entails an approval from the Parliament for the allocation of the state budget. Disbursement of the subsidy will involve a post-closing settlement of differences between PLN’s proposed subsidy and the actual RE power generation. In conclusion, despite its inability to reduce PLN’s dependence on the Government, this first recommendation can bolster FiT implementation (L2) and potentially reduce PLN’s reluctance in signing RE PPA for cost-saving reasons (L3).

Promoting local participation and ownership

The second recommendation is aimed at resolving the financing issue of RE projects (L3) by promoting local participation and ownership. This recommendation is in line with Marquardt's (2014) assertion that bottom-up RE support, such as by creating local niches, should be advocated. Moreover, the recommendation is inspired by the promotion of consumer ownership in Denmark: there was a strong support for such ownership and thus, private consumers became the pioneers in wind farm deployment (Ratinen & Lund, 2015). Among others, the policy takes form in an investment subsidy for individuals and organizations living close to the wind farm. The subsidy was paired with tax deductible investment and excess electricity sales to the grid (Buen, 2006).

In Indonesia, such participation incentives can be realized through a Provincial Regulation by regional governments (L2), particularly the governments of provinces with promising economic WEP (see Subsection 7.3.2). Moreover, the incentives shall be directed towards individuals, private businesses, and regional-owned enterprises. In designing the incentives, regional governments shall consult with the Government, specifically MF and the Ministry of Investment, to ensure institutional consistency at the national and the regional level. Importantly, there must be a close coordination and expectation alignment between the IPP, participating local communities, and PLN as the transmission and distribution system developer and operator. Consequently, unmet expectations of the local communities on the electricity supply, such as occurred in the Sidrap WPP case (Setyowati, 2021), can be avoided.

7.5.3. Forming an independent regulator in the electricity sector

As presented in Figure 39, there are major institutional barriers in generation infrastructure planning (L2) and contracting (L3). Planning inconsistency and inefficient contracting process, both of which originate from the governance of PLN and MEMR, are at the heart of these issues. PLN made significant planning changes on a yearly basis and faces a conflict of interest in contracting. Meanwhile, Section 7.2 demonstrates the strong power and position MEMR has over the electricity sector: MEMR is responsible not only for devising and implementing policies, but also for supervising/regulating the activities within the sector. Consequently, this governance structure may instigate conflicts of interest in MEMR as the actor having political and economic interests while also serving as the regulator (ADB, 2020b). Looking at the above-mentioned barriers, this study proposes a change to the governance and decision-making structure (L3) in order to support wind energy development.

The proposal builds upon the idea of ADB (2020b) on creating a dedicated regulatory body in electricity. Essentially, the regulator shall be independent, namely, free from any short-term political interests of the Government. Furthermore, the regulatory body should have a long-term perspective on sectoral objectives and planning, while periodically monitoring the progress and compliance with the initial agreements made. Thus, the stakeholders will perceive the regulator as a reliable ‘referee’ with strong integrity (ADB, 2020b) with respect to all actors’ activities within the sector. Such regulatory body has been adopted in many countries including OECD members (e.g. the United States and Germany) and ASEAN countries (e.g. Singapore and the Philippines). For instance, the Philippines’ Energy Regulatory Commission has the authority to approve PPA terms and proposed FiT rates to be implemented for RE (Guild, 2019).

In the proposed structure, NEC remains in charge of devising high-level, long-term plans in energy. Accordingly, the Government is responsible for creating more concrete plans as guidelines for MEMR in regulating the electricity sector. However, MEMR and its subdivisions have an additional responsibility, i.e., to secure long-term agreements with RE actors, especially in wind energy. For instance, the pertinent actors can include PLN, IPPs, financiers, and wind energy technology experts from academia and the industry. One of the envisioned agreements is regarding the electricity pricing scheme as proposed in Subsection 7.5.1. Such agreement is inspired from the Danish success in triggering a significant amount of WPP deployment. In 1984, the Danish government struck a ten-year deal with electricity enterprises on wind power purchase obligations, grid connection guarantees, and an allocation of the associated costs (Buen, 2006). The deal was later extended to further incentivize the actors in supporting wind energy development. By integrating the agreement as part of the generation infrastructure plan, MEMR fosters decisional predictability of governance in the institutional environment, which was found to be pivotal for WPP investments (Friebe et al., 2014).

In terms of planning, the regulator safeguards the coherence between plans at multiple government levels and validates the planning of MEMR and PLN. The regulator may approve the proposed plans or request MEMR and PLN to revise the draft. Moreover, the regulator ensures the consistency between the electricity infrastructure development plans and their realization. Notably, the regulator safeguards an adequate level of political inclusion in performing its tasks. This means the regulator should absorb the stakeholders' aspirations and monitor their incorporation in the proposed plans. Hence, the finalized plans can be considered as inclusive policies, which are expected to bolster the growth of wind energy niche (Ratinen & Lund, 2015). To conclude, having an independent regulatory body overseeing the long-term planning formulation and implementation can potentially alleviate existing inconsistencies and uncertainties.

Besides validating the proposed plans, the regulator shall scrutinize and approve/reject electricity pricing scheme proposal of MEMR. Similar to the regulator's work in planning, stakeholders' inputs and the extent to which they have been incorporated in the proposal are considered in the examination. This practice is likely to prevent the reoccurrence of frequently-changing regulations and in turn, create regulatory certainty for IPPs and investors. Furthermore, MEMR shall devise and publish PPA standards for wind energy and other intermittent RE. The regulator's task in this case is to approve the standard, monitor the progress and transparency of PPA establishment, and check whether the signed PPA complies with prevailing regulations.

Despite the foreseen positive impact that the governance structure change may bring, it is important to consider the change's feasibility under existing regulations**.** ADB (2020b) notes that a similar independent regulatory body, named the Electricity Market Supervisory Agency (BPPTL), was once formed in 2002. BPPTL was responsible for overseeing the implementation of regulations and electricity supply at competitive regions. However, BPPTL was suspended by the Supreme Court along with its founding legislation, i.e. Electricity Law of 2002, due to the regulation's incompliance with the 1945 Constitution. Although the regulatory body as proposed in this study has a similar task to BPPTL's, the regulatory body does not entail privatization of electricity supply. Thus, the regulatory body would presumably not infringe the Constitution. Nevertheless, establishing this regulatory body calls for a legislation (L2) to define the regulator's position, power, and authority within the institutional and governance setting.

A recap of the recommendations and the barriers being addressed as arranged within WLIF is presented in Figure 40. As explained in the previous subsections, the proposed changes necessitate reforms to the existing institutional environment (L2) and governance structure (L3). In other words, 1st- and 2nd-order economizing of institutions shall be performed to overcome the barriers at L2 and L3 and subsequently, to support wind energy development in Indonesia. Moreover, reforming the institutions at the two levels capitalizes on the top-down relationship between L2 and L3 institutions. Subsequently, this relationship will also affect the actors' decisions in employing and allocating resources at L4. Furthermore, the figure indicates that all the barriers in WLIF have been addressed by the proposed institutional changes. The effectiveness and feasibility of these changes, however, shall be subjected to scrutiny in future studies.

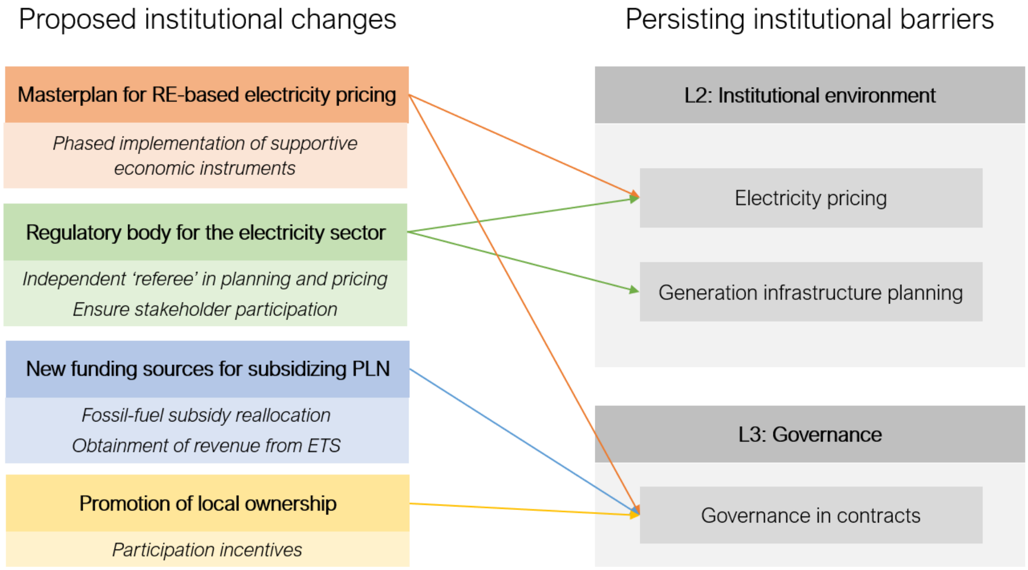


Figure 40. A summary of the proposed institutional changes and the barriers they address within WLIF

7.6. Results validation

This section presents interview results to validate the institutional analysis findings. In the following subsections, the respondents' opinions on the stakeholder analysis (formal chart), institutional barriers, and institutional recommendations are presented sequentially. In turn, this section is concluded with general remarks from the respondents on Indonesia's wind energy development. A summary of each interview can be found in Appendix G.

7.6.1. Stakeholder analysis validation

Overall, the respondents deem that the formal chart (see Figure 34) already comprehensively covers the relevant actors, especially government-related stakeholders, and their interrelations. However, there are three insights from the validation interviews to be considered. The first one relates to PLN as the central actor in the chart. Based on his experience in a project in Sumba Island (NTT), B. Elemans (personal communication, June 25, 2021) mentioned that PLN headquarters has a strong role in generation infrastructure planning through RUPTL: while the regional government can request changes to the RUPTL, PLN headquarters eventually has the final say on the document. Such observation is also shared by M. Maulidia (personal communication, June 28, 2021), who asserted that the planning is highly centralized and dominated by PLN. This implies the weaker role of regional governments in planning, despite the authorities they have according to the laws (see Subsection 7.3.2). Moreover, M. Maulidia also mentioned that although PLN is squeezed by the interests of several ministries, PLN commonly prioritizes MSOE's mandates. This is due to the authority of MSOE in setting key performance indicators of PLN directors (A. Tampubolon & H. Puspitarini, personal communication, June 29, 2021). Thus, the direct line from MSOE to PLN can sufficiently describe this relationship.

The second insight is regarding the missing actors from the chart. The four missing actors are the Ministry of Marine Affairs and Fisheries (MMAF), Bappenas/the Ministry of National Development Planning, foreign governments, and the Indonesian Wind Energy Association (AEAI). MMAF is likely to be responsible for the policymaking of offshore wind; such policies are presently unavailable (B. Elemans, personal communication, June 25, 2021). In national planning, Bappenas devises a medium-term plan which acts as a framework for the ministries to formulate their respective work plans (A. Tampubolon & H. Puspitarini, personal communication, June 29, 2021). Furthermore, B. Elemans stated that foreign governments can support WPP deployment by stimulating government-to-government cooperation projects which involve foreign developers. Finally, A. Tampubolon & H. Puspitarini argued that AEAI, an association of Indonesian wind energy industry stakeholders, has an important role in promoting wind energy development.

The third insight concerns possibly lacking interrelationships among actors. The chart shows that DGNREEC has a dead-end with respect to the actors outside of MEMR. B. Elemans saw this as a possible flaw in the system: DGNREEC probably does not have enough power to push for RE development given their lack of influence in the decision-making process. Another possibly missing relationship is a link between DGE and the Ministry of Investment. A. Tampubolon & H. Puspitarini observed that to initiate a wind energy project, IPPs must report to the Ministry while attaching DGE's approval. The approval indicates the readiness of the local electricity system to receive intermittent wind-based electricity. Consequently, a link between DGE and the Ministry may be added to the chart.

7.6.2. Institutional barriers validation

Electricity pricing

Generally, the respondents agree that electricity pricing is one of the barriers to wind energy development. B. Elemans (personal communication, June 25, 2021) claimed that due to the current BPP-pegged scheme, RE development is pushed to the eastern part of Indonesia (as corroborated by the techno-economic analysis in Chapter 5), away from islands with high population density. In addition, he agreed that BPP calculation is problematic since the downsides of carbon emission, e.g. air pollution and adverse health repercussions, are not taken into consideration.

While she agreed that electricity pricing is one of the issues, M. Maulidia (personal communication, June 28, 2021) pointed to a more fundamental issue which is closely-tied to the pricing, namely, PLN's revenue model. As the single buyer of electricity, PLN obtains its revenue from the consumers' payment based on a government-determined price. However, the price is lower than the cost of power generation and the paid amount to IPPs. This price difference creates a more fundamental issue than the electricity pricing itself. This issue is related to two aspects: the electricity law and prevailing political tenets. The former aspect concerns the annulment of the Electricity Law of 2002 that entails liberalization in the sector. Meanwhile, the latter aspect is manifested by Indonesian politicians' objective of providing the people with as-cheap-as-possible electricity, instead of affordable electricity. She further mentioned that providing affordable electricity involves internalizing negative externalities of power generation. Moreover, the forthcoming Presidential Regulation will not solve this revenue model issue, because the Government's compensation for PLN is set to be conditional upon the state's financial situation. To summarize, she viewed electricity pricing as the largest barrier out of the four; nevertheless, PLN's revenue model is the more fundamental barrier to be addressed.

Generation infrastructure planning

All respondents also agree with inconsistent planning being an institutional barrier. They added two insights to complement the analysis on planning. First, there is a lack of transparency in how RUPTL is currently formulated (B. Elemans, personal communication, June 25, 2021). The current formulation procedure is highly centralized and dominated by PLN (see Subsection 7.6.1). Hence, B. Elemans argued that a market system should be introduced to allow the private sector to make RE project initiatives, which will in turn be transparently considered in formulating the plans. Second, there is an insufficient level of regionalization in the planning process: infrastructure planning is not delegated to regional-level governments (M. Maulidia, personal communication, June 28, 2021). Consequently, this hinders the development of small-scale and distributed RE-based power generation. A greater role for regional governments in planning may be beneficial for RE development.

Property rights allocation

All respondents concurred that property rights allocation of RE projects was an institutional barrier; however, it has been addressed by recent legislations. B. Elemans (personal communication, June 25, 2021) argued that implementing a BOOT scheme only allocates the risk to the developer and not to PLN. He further added that WPPs should be open for an ownership transfer to PLN at the end of project lifetime; nonetheless, the price has to be set by also considering future profits, i.e. not only considering the infrastructure cost. Additionally, B. Elemans and A. Tampubolon & H. Puspitarini (personal communication, June 29, 2021) agreed that the recent removal of foreign ownership restriction in electricity generation projects can benefit future RE development in Indonesia.

Governance in contracts

There are several comments from the respondents on the institutional barriers before PPA signing. B. Elemans (personal communication, June 25, 2021) questioned the 'honesty' of negotiations between PLN and IPPs on the PPA tariff given PLN's enormous power at the negotiation table. PLN's conflict of interest in negotiation is also caused by several long-term PPAs already in place as part of the *35 GW Electricity Development Program* (A. Tampubolon & H. Puspitarini, personal communication, June 29, 2021). Combined with the overcapacity of power generation in the Java-Bali system, the presence of these PPAs make PLN reluctant to engage in new contracts.

Another noteworthy feedback pertains to the inexistence of PPA standard for intermittent RE. B. Elemans underlined the vague standard being used to draft RE PPAs. Moreover, based on interviews with financiers, A. Tampubolon & H. Puspitarini noted the disparity of PPA standards across IPPs as a barrier in financing RE projects. Hence, the financiers proposed the Government to formulate such standard. Studies are being conducted to design and standardize a PPA that can support RE development without imposing a huge burden on PLN's and the state's finances (M. Maulidia, personal communication, June 28, 2021).

There are also some insightful feedbacks on the institutional barriers after PPA signing. B. Elemans agreed that contract enforcement is an institutional barrier: if IPPs are forced to accept PPA terms during the negotiation because of PLN's immense power at the negotiation table, legal issues may quickly arise as a result. Regarding the lack of RE project funding, he claimed that this barrier should occur before the PPA is signed. This is because of IPPs' parallel coordination with financiers while negotiations with PLN are conducted. However, changing laws that adversely impact the business case can result in a financing issue. Meanwhile, M. Maulidia accentuated the current take-or-pay form of PPAs as a barrier, given the recent drop of electricity demand due to the COVID-19 pandemic. An innovative PPA form is thus being sought. It can be introduced along with the forthcoming PPA standard.

Other barriers to wind energy development

The interviews revealed two additional institutional and non-institutional barriers to wind energy development. First, B. Elemans (personal communication, June 25, 2021) and A. Tampubolon & H. Puspitarini (personal communication, June 29, 2021) concurred on the local content restriction on the physical artifacts within wind energy projects being a barrier. Given the early stage of wind energy development in Indonesia, IPPs need to import high-quality wind turbines from abroad. The entailed cost of import constitutes a large chunk of a WPP investment, resulting in a low percentage of local content in the project. For this reason, a high local content requirement can seriously impede wind energy development. While such a protectionism policy is common, B. Elemans argued that policies should be well-balanced between national and foreign interests in order to attract foreign investments in RE.

The second additional barrier can be considered as a technological barrier. All respondents pointed to grid stability and readiness to accept intermittent electricity from WPP as an issue for wind energy development. According to M. Maulidia (personal communication, June 28, 2021), PLN sets a limit of maximum 10% of electricity being supplied from intermittent RE in their grids. Moreover, there is a locational mismatch between the necessity to add generation infrastructure and the grid capability to accept intermittent power (A. Tampubolon & H. Puspitarini, personal communication, June 29, 2021). For instance, the Java-Bali system has this capability; however, the state of overcapacity hinders intermittent RE power plant integration into the system. A related issue to this barrier is the cost allocation of battery energy storage, which can aid in stabilizing grid operations. Including the expensive cost in IPPs business case can make the case economically unattractive. In conclusion, a careful grid planning must not be overlooked since this issue can become a bottleneck in Indonesia's RE development (B. Elemans, personal communication, June 25, 2021).

7.6.3. Institutional recommendations validation

Masterplan for RE-based electricity pricing

All respondents agree with the proposed masterplan for electricity pricing. A. Tampubolon & H. Puspitarini (personal communication, June 29, 2021) outlined the importance of including a clearly-defined capacity quota in the masterplan to promote transparency. Additionally, they recommended to complement the masterplan with a similar plan for other RE sources which can balance wind energy's intermittency. Thus, the plans of provinces with promising WEP can be focused on wind energy development, while still being synchronized with the plan to develop supporting (grid-stabilizing) power plants. M. Maulidia (personal communication, June 28, 2021) further asserted that the masterplan can be an implementing regulation of the anticipated PR on electricity pricing.

Regulatory body for the electricity sector

There are mixed opinions on introducing a regulatory body in the electricity sector. On one hand, B. Elemans (personal communication, June 25, 2021) claimed that having the regulator as an independent referee can help to counter the strong lobbying of the coal sector in directing the policymaking on energy. Moreover, A. Tampubolon & H. Puspitarini (personal communication, June 29, 2021) also noted the benefit of having a regulator. However, they argued that introducing the 'regulator' role does not necessitate the creation of a new body; instead, this role can be taken by the NEC. By optimizing the role of NEC, redundancy in the governance structure can be avoided.

On the other hand, M. Maulidia (personal communication, June 28, 2021) interviewed relevant stakeholders and found a 50/50 split between those who think that having the regulator is effective in advancing RE development, and those who think otherwise. The stakeholders in the latter group believed that there are fundamental barriers that cannot be solved by the regulator (e.g. PLN's revenue model). Nevertheless, M. Maulidia agreed that the regulator can reduce the dependency of MEMR on PLN's recommendations in electricity sector policymaking.

New funding sources for subsidizing PLN

In general, the respondents concurred with the recommendation on creating new funding sources for subsidizing PLN. However, M. Maulidia (personal communication, June 28, 2021) mentioned that there can be an issue with its implementation: Indonesian politics do not favor ‘earmarking’ in its budgetary practices. Consequently, the reallocated funds cannot be easily earmarked to support RE development. Meanwhile, an alternative to this proposal is to establish a RE fund (A. Tampubolon & H. Puspitarini, personal communication, June 29, 2021). The fund is directed at IPPs (instead of PLN) as a loan with a competitive interest rate. By lowering the interest rate, the electricity selling price to PLN can thus be reduced.

Promotion of local ownership

Similar to the previous recommendation, the respondents agree that the promotion of local ownership can help to advance wind energy development. Nevertheless, implementing this proposal may be hindered by the economic capability of the people living nearby the WPP, especially in the eastern part of Indonesia (B. Elemans, personal communication, June 25, 2021). Investing in a WPP requires a long-term view, which might not be acceptable for the less-wealthy people. In such case, local ownership may be targeted to local enterprises with sufficient economic means.

7.6.4. Remarks on Indonesia’s wind energy sector

All respondents recognized the limited wind resource in Indonesia: promising resources are only located at a few locations within the country. However, they agreed that wind should still play a role in the future energy system considering the major challenge Indonesia faces in transitioning to RE. Future wind energy development may involve hydrogen as an energy carrier (B. Elemans, personal communication, June 25, 2021). For example, the electricity produced from WPPs in Papua and NTT can be transported to Java and Sumatera in the form of hydrogen. Furthermore, according to B. Elemans, there were high hopes for wind energy development when Sidrap and Tolo-1 WPP were established. Afterwards, PLN started tendering wind energy projects. However, the tendering stopped during the COVID-19 pandemic. Since then, the stakeholders seem to wait for the new PR on RE-based electricity tariff. The regulation’s enactment has been delayed since 2020. To conclude, having a start-stop policy regime deters the motivation of private parties in RE. Therefore, consistent with this study’s findings, steady and transparent policies are needed to support wind energy development.

As the closing chapter of Part II, this chapter has conveyed the results of this study’s institutional analysis. The results include stakeholder identification and mapping, identification of institutional barriers at L2 and L3 of WLIF, and institutional recommendations proposal. Finally, the results are validated and discussed by means of expert interviews. Overall, the experts agree with this study’s findings and recommendations, although there are some suggestions for improvement. In the next chapter, a general discussion of this study is presented.

PART III:

DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

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Chapter 8. Discussion

In this chapter, several topics of discussion regarding the methodology and results of this study are presented from Section 8.1 to Section 8.5. The discussion is followed by a reflection on scientific and societal relevance in Section 8.6 and Section 8.7. Subsequently, the limitations of this study are described in 8.8.

8.1. Possibility of realizing ‘power islands’

Being the largest archipelago, Indonesia consists of 17,508 islands of which only around 6,000 islands are inhabited (Embassy of the Republic of Indonesia Washington DC, n.d.). There is a possibility to utilize the uninhabited islands as power islands. As introduced in Subsection 4.3, power islands can be realized by implementing wind energy technology at islands with little to no inhabitants. The generated electricity can then be transmitted via submarine cables to a demand center at neighboring islands. ‘Power island’ is not an entirely new concept: Denmark has recently announced the plan to build an artificial energy island for wind power generation in the North Sea which may also be connected to Germany, the UK, and the Netherlands (BBC, 2021). In this study, two examples of possible power islands are Babar Island and Selaru Island in Maluku. Figure 41 illustrates how onshore WPP sites with economic potential on these islands are connected to Saumlaki as the demand center.

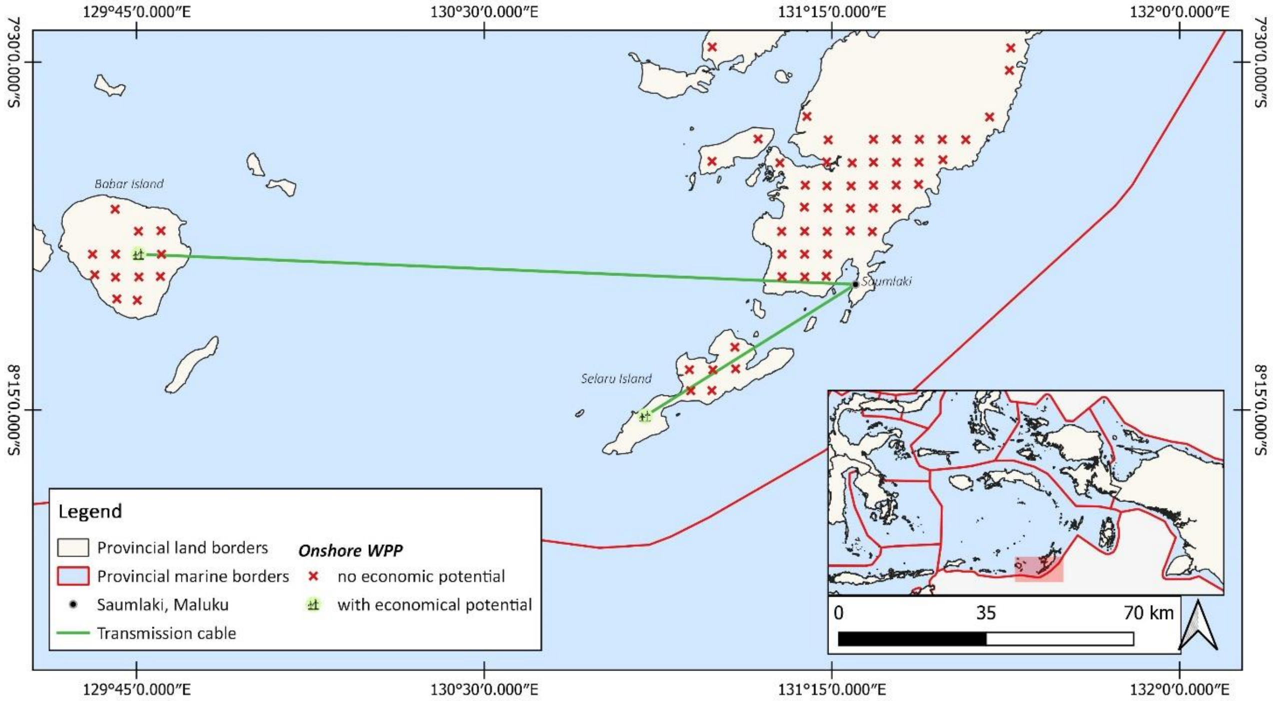

Figure 41. Babar Island and Selaru Island in Maluku as power island examples

The main benefit of developing power islands pertains to WPP site selection. Since there are little to no inhabitants, competition for land use is less likely to be an issue at these locations. Furthermore, this may eliminate possible NIMBY attitude of the surrounding community since noise and visual pollution is no longer a concern in WPP siting. Nevertheless, a sufficient amount of electricity demand at the nearest connection point must be ensured, especially considering the relatively low population density in the eastern part of

Indonesia where WEP is more prevalent. Alternatively, WPPs at the power islands can be connected by long-distance HVDC submarine cables to a connection point with sufficient demand. However, such approach may entail an expensive cost which jeopardizes the competitiveness of wind energy. One way to circumvent this issue is to increase the number of economically feasible WPP sites, such as by introducing a sufficient level of FiT. This engenders economies of scale to play a role in minimizing the transmission cost. Moreover, a detailed WEP assessment that considers electricity demand magnitude at relevant connection points are necessary to further explore the possibility of developing power islands.

8.2. Natural disaster proneness impact on wind energy potential

The results in Subsection 4.3.3 indicate the importance of rigorously analyzing the natural disaster proneness of prospective WPP sites as a means of risk management by IPPs. A deeper insight on the 'practical' technical and economic WEP can be gained if the IPPs' viewpoint on these results is understood. In this case, their viewpoint pertains to the decision rule they employ when deciding on WPP investment based on the sites' disaster-proneness. Because interviewing IPPs is not a part of this study, their viewpoint is instead gathered by inference based on two empirical cases.

According to the map of disaster-proneness, the area occupied by Sidrap WPP is categorized as having a medium-level earthquake and landslide proneness. Meanwhile, Tolo-1 WPP is located on an area with low and very low level of proneness to earthquake and landslide, respectively. None of these WPPs are subjected to the risk of being impacted by volcanoes and tsunamis. Based on these two cases, it can be assumed that areas with high-level earthquake and landslide proneness are unsuitable for wind power generation. Consequently, removal of the WEP at the corresponding sites reduces onshore wind technical potential by up to 16% and 4% based on earthquake and landslide proneness, respectively. On the other hand, up to 31% and 8% of the onshore wind economic potential is curtailed based on earthquake and landslide criteria, respectively. To conclude, disaster-proneness, especially with respect to earthquake and landslide, can significantly reduce Indonesia's WEP. Hence, future regional-level WEP assessments shall take this impact into consideration.

8.3. Revisiting the site selection process

Section 5.1 has displayed the results of site selection based on the adopted siting criteria. A sequential application of these criteria (see Figure 13) is employed on the prospective sites to minimize the computational load throughout the selection process. The frailty of such sequential procedure is the inability to isolate the influence that each criterion has on site selection. Additionally, it is not possible to easily remove/add a certain siting criterion. Given these limitations, this section only discusses two criteria which may be deemed overly restrictive, i.e. artisanal fishing and WPP site size.

Artisanal fishing

Artisanal fishing is included as an exclusion criterion in this research because of the conflicting elements that may arise between offshore WPP deployment and the fisheries sector. These elements comprise inadvertent damage to the WPP infrastructure, displacement of and disruption to marine species, diminishing traditional fishing areas, adverse economic consequences for fishers (i.e. increased operational cost), and socio-cultural tensions (European MSP Platform, 2018). The last element pertains to artisanal fishing as a cultural identity, namely, as an embedded value (L1 of WLIF) of the fishing community. Notably, these small-scale, coastal fisheries may not have the capacity to move their fishing grounds further from the coastline or to alter fishing methods (European MSP Platform, 2018). Hence, this motivates the use of artisanal fishing as an exclusion criterion. Coincidentally, the criterion can simultaneously address the restriction of offshore WPP siting based on tourism considerations. For example, Westerberg et al. (2013) recommend offshore WPPs to be located at least 12 km from the coastline after conducting a choice experiment on tourist preferences in the French Mediterranean.

As asserted in Section 5.7, employing the artisanal fishing constraint removes offshore WPP sites within 10 – 15 km from the coastline in the model. In other words, applying this constraint discards prime sites, namely, sites which have shorter transmission distances to the demand centers. Consequently, this criterion may be deemed too restrictive for WEP computation. It is therefore useful to understand the effect this constraint entails on the curtailment of nominal WPP capacity. By a rough approximation, the effect is quantified by multiplying the total artisanal fishing area by the offshore WPP capacity density (2.37 MW/km^2). This calculation results in a nominal offshore WPP capacity of 988.5 GW. In turn, this capacity is narrowed down based on wind speed and seabed depth constraints. Hence, the impact of artisanal fishing criterion is approximately equivalent to a nominal offshore WPP capacity of 177.9 GW. This figure is equal to around 5.1 – 6.6% of the total nominal offshore WPP capacity identified in Section 5.2 (2,688 – 3,462 GW). Despite the impact of employing the artisanal fishing criterion, the actual WPP deployment will largely depend on the prevailing institutions, i.e. spatial planning for offshore areas. Consequently, future studies shall focus on regional WEP assessment using spatial plans at the provincial level.

Wind power plant site size

Another criterion which may deemed overly restrictive is the WPP site size (area) which is employed in the square-grid approach. As explained in Subsection 4.2.2, WPP sites having area less than the *adjusted WPP area* are removed from consideration, even though they can still be occupied by WPPs of smaller capacities. Thus, it is useful to estimate the equivalent nominal WPP capacity that these sites represent. This is done by calculating the sum of their area times the respective WPP capacity density for onshore (1.65 MW/km^2) and offshore (2.37 MW/km^2) sites. The equivalent nominal onshore WPP capacity amounts to 71.7 GW, whereas the equivalent nominal offshore WPP capacity is 225.4 GW. These *equivalent* figures are equal to 70.4% and 8.4% of the nominal WPP capacity values for onshore and offshore case, respectively (see Section 5.2). This indicates a significant curtailment of WPP capacity due to site size criterion for the onshore case. The result is expected because onshore site selection criteria has more intricate shapes compared to the offshore counterpart, and therefore, many remaining eligible onshore areas take form in numerous tiny sites (e.g. less than 1 km^2) scattered over the Indonesian islands. In reality, it may not be possible to install large-scale turbines (corresponding to the aforementioned capacity density) and their interconnection at these tiny onshore sites. Thus, future research at the regional level may look into the WEP at these sites by instead modelling small-scale wind turbines.

8.4. Reflecting on the sensitivity analysis

One of the limitations of this study (see Section 8.8) concerns the use of a single version of investment cost assumptions instead of a range of cost figures. Consequently, it is beyond the scope of this research to derive insights on how the economic potential changes upon a variation of cost assumptions. Nevertheless, it is possible to approximate how LCOE changes as different cost assumptions, i.e. CAPEX values, are used by looking at the sensitivity analysis in Subsection 5.5.1. As shown in Table 2, LCOE is a function of CRF, CAPEX, OPEX, and the energy produced in a particular year (AEP). CRF and AEP are independent of the assumed costs, and therefore, they remain constant. Moreover, this study sets OPEX as a fixed percentage of CAPEX. Therefore, the LCOE equation implies LCOE being directly proportional to changes in CAPEX. This explains the sensitivity analysis result in Subsection 5.5.1: the average LCOE changes proportionally to the alterations of CAPEX. Building upon this observation, one can estimate the shift of LCOE if CAPEX is adjusted to reflect a mature state of wind energy development in Indonesia in the future. For example, changing the CAPEX of onshore WPP from the Indonesian context (Lee et al., 2019) as employed by this study, to the USA context (Moné et al., 2017) roughly corresponds to a 11.2% cost reduction (see Figure 6 for the CAPEX figures). Consequently, the reduction translates to a 11.2% decrease in LCOE figures: the minimum LCOE for onshore wind becomes 5.4 and 7.7 USD ct/kWh as derived from the point-grid and square-grid approach, respectively. This change is expected to increase the economic potential of onshore wind, especially in provinces with relatively low BPP and maximum allowable PPA tariff.

The sensitivity analysis further signifies the considerable influence of WACC on average LCOE. The influence is characterized by an increase in economic WEP as WACC decreases (see Subsection 5.5.2). As shown in Figure 28, a significant increment of both onshore and offshore wind economic potential occurs at WACC of 2 – 4%. It is therefore useful to check the feasibility of securing loans for projects in the electricity sector with such low interest rates.

As mentioned in Section 7.4, RE projects may require several sources of funding to drive down the loan's effective interest rate or WACC. One of the sources is the Clean Technology Fund (CTF), a multi-donor trust fund aimed at supporting the financing of low-carbon technologies demonstration, implementation, and transfer for middle-income and developing economies (Climate Funds Update, n.d.). Channeled through Asian Development Bank (ADB) and World Bank Group, CTF is focused on financing for, among others, RE projects through the provision of public and private sector investments. Indonesia is an eligible recipient of this fund: in 2020, a CTF loan is granted for geothermal projects in Indonesia with 1% and 2% principal repayments for year 11 – 20 and year 20 – 40, respectively (*Clean Technology Fund Loan Agreement*, 2020). Importantly, the agreed interest rate is 0.25% per year, with a maximum mark-up of 0.34%. This opens the possibility of applying for a similar low-interest loan for wind energy development. Another source of funding is ADB: as a developing member country, Indonesia can apply for a regular Ordinary Capital Resources loan for energy sector development. This loan charges a LIBOR[9]-based interest rate which is indicatively equivalent to a fixed swap rate of 1.9% per year over a twenty-year period (ADB, 2021). Although these international funding sources can help to lower WACC for IPPs, establishing a stable institutional environment for investors to address the identified barriers in Chapter 7 remains key to proliferating investments in RE.

8.5. Community resistance to wind energy development

In Chapter 6, it is mentioned that L1 institutions are out of the scope of this study: they are taken as given. Nevertheless, these informal institutions can seriously influence the deployment of RE power plants through societal acceptance. According to Wüstenhagen et al (2007), social acceptance of RE innovation can be conceptualized into three categories: socio-political acceptance, community acceptance, and market acceptance. Among these categories, this section only discusses *community acceptance*, namely, the consent on RE projects by local inhabitants and governments (Wüstenhagen et al., 2007).

Community resistance, which this study defines as the inverse of *community acceptance*, may halt or even cancel RE projects if the norms and values of the nearby community are breached. This is exemplified by the Balinese people's rejection on the Government's plan to build a geothermal power plant in Bedugul in 2013, on the basis of local wisdom infringement: the people regard mountains, beaches, forests, estuaries, and lakes in the island as sacred areas (Rhismawati, 2013). As a result, the Governor of Bali asked MoEMR to call off the project, although there was no environmental issue found in the project's Environmental Impact Analysis (Mardiastuti, 2019).

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[9] LIBOR stands for London Inter-bank Offered Rate, a reference interest rate for inter-bank lending between global banks.

Given the early stage of wind energy development in Indonesia, community acceptance, or the NIMBY problem, is yet to become a major issue. The resistance towards WPP once occurred in Bantul, D.I. Yogyakarta in 2013: the surrounding community was worried that Samas WPP would displace their agricultural land (Suryani, 2013). Two years later, however, the community became receptive to the proposed WPP after acknowledging the economic and environmental benefits that the project would bring (Suryani, 2015). In 2018, the IPP withdrew from the project due to undisclosed technical issues (Sidik, 2019). Consequently, the Samas WPP project was cancelled.

In conclusion, the examples above signify the crucial role L1 institutions play in RE development. Moreover, the examples also indicate the possibility of altering these institutions if efforts are made by the stakeholders. To address barriers at this level in the future, the Government can perhaps learn to foster social acceptance to wind energy from Europe, where this topic has been greatly studied. For example, Ellis & Ferraro (2016) review studies on social acceptance in Europe and find planning systems of wind energy projects to have a crucial part in establishing social acceptance. Obligatory co-ownership scheme and compensation for adjacent landowners are examples of Danish policies that can be considered to encourage the adoption wind power generation. Moreover, Ellis & Ferraro assert community ownership as being key to arrive at higher acceptance levels. A similar form of ownership is also proposed in Subsection 7.5.1 to address project financing issues.

8.6. Reflection on scientific relevance

Scientific relevance encompasses scientific contribution and a reflection on this study's methodology and results. In the following subsections, the scientific relevance of this study is presented in two parts, i.e. methodology and results.

8.6.1. Methodology

The reflection on methodology is divided into three topics, namely, techno-economic analysis, institutional analysis, and overall methodology. They are presented consecutively in the following paragraphs.

Techno-economic analysis

Scientific contribution

As explicated in Section 1.5, this research adapts and refines the novel GIS-based OTEC economic potential assessment of Langer et al. (2021) to suit the wind energy context, while drawing inspiration from the work of Bosch et al. (2019) and Deng et al. (2015). The novelty is signified by the comprehensive site selection criteria being applied and two approaches used (i.e. point-grid and square-grid) to provide upper and lower estimate of technical and economic WEP for each province. Moreover, another point of novelty is the incorporation of natural disaster proneness impact on the WEP assessment by classifying each site based on the categories of proneness. This is motivated by the relevance of natural disaster in Indonesia given the country's geographical location. Although the adopted methodology is not without limitations (see Subsection 8.8.1), an integration of onshore and offshore WEP evaluation across Indonesia and within its provinces is successfully delivered as an output of the analysis.

Reflection

In hindsight, the combination of GIS and Python programming worked effectively in assessing the spatially-distributed onshore and offshore WEP. Overlaying layers of site selection criteria and subsequently eliminating ineligible WPP sites was conducted well in QGIS. Furthermore, QGIS enables the display of results and the production of maps (as shown in Chapter 5) in an efficient manner. Another advantage of using QGIS is its integration with Python programming. WEP computations and some vector overlaying operations were done by importing and processing GIS files in Python. Accordingly, faster data-processing times can be achieved compared to fully running the operations in QGIS.

Researchers who intend to adopt and/or develop a similar methodology must carefully consider input data availability and reliability. Gathering GIS files for the Indonesian context was quite a challenging process: the data is not directly accessible on government platforms. One must open ArcGIS Rest Services of these platforms to download the files. However, some ArcGIS Rest Services are not reliable: their directories may be inaccessible due to connection issues or even changed from time to time. Another challenge in gathering the input data concerns the WPP investment cost assumptions. There is a wide variety of cost figures and cost functions available in the literature. As elaborated in Chapter 4, this research's approach is to use single cost values to represent the Indonesian context. An alternative approach is to employ cost ranges, and hence, a more nuanced interpretation of economic WEP can be obtained. This idea is further discussed in Subsection 8.8.1.

Institutional analysis

Scientific contribution

The institutional analysis involves a novel application of WLIF in Indonesia's wind energy sector. The institutional components at L2 and L3 are partly based on the operationalization of energy infrastructure economic institutions of Scholten & Künneke (2016). Notably, a focus on top-down influence of institutions, as adopted by Kucharski & Unesaki (2018), allows an understanding of the interrelation between the institutions and the barriers at the *institutional environment* level (L2) and the *governance* level (L3). In turn, such understanding is highly valuable in arriving at the institutional recommendations: the proposed recommendations exploit the top-down influence of institutions. Furthermore, institutional changes entailed by each recommendation are also mapped in WLIF, as conducted by Baumgartner & Cherlet (2015), to signify the levels where changes are needed. Another important aspect in formulating the recommendations is the consideration of the multiple actors with varying interests and objectives, as derived from the actor analysis procedure of Enserink et al. (2010). By integrating the aforementioned studies' methods, this research pioneers the institutional analysis on the Indonesian wind energy context from the NIE perspective for the determination of institutional barriers and their possible solutions.

Reflection

In this research, WLIF is proven to be an effective tool to guide the analysis and structure the institutions in an organized manner. WLIF also portrays how institutions at different levels influence one another and possibly form barriers in meeting policy objectives. For example, this study demonstrates how applying the current electricity pricing scheme (L2) gives rise to the lack of project funding available for IPPs to fulfill their contractual obligations (L3). These interrelations manifest the complex nature of institutions which analysts must be aware of when recommending institutional alterations and designing new policies. Furthermore, WLIF enabled a flexible scoping of analysis. Considering the limited time, this study is not intended to cover all policies related to wind energy; however, it focuses on four institutional components which are deemed most relevant to the techno-economic analysis and the NIE theory. Accordingly, WLIF helps institutional analysts in maintaining a coherent and focused review on the institutional components.

In proposing institutional changes, WLIF can function as a map that assists analysts in recognizing the issues being tackled by a particular solution and in turn, checking which issues remain unresolved. Another advantage of using WLIF lies in the identification of the levels of institutions where amendments are necessary to carry out a solution. Moreover, coupling WLIF with a stakeholder analysis is vital in analyzing the elements within the governance system and subsequently, devising the recommendations. The analysis sheds some light on each actor's attributes, i.e., relational dependencies, interests, and objectives. In turn, these attributes are valuable to envision how the actors are affected by a certain solution and what role the actors will play in it.

Overall methodology

This research employs a novel approach of conducting a WEP evaluation. The approach combines techno-economic analysis and institutional analysis in a single study. The former analysis is intended to quantify the technical and economic potential, whereas the latter analysis extends the potentials' interpretation from the institutional perspective. In other words, this approach attempts to establish linkages between the results of both analyses. As demonstrated in this study, this novel approach entails some advantages.

First, the techno-economic analysis results 'validate' the institutional analysis findings, and vice versa. For instance, results from both analyses confirm that wind energy development is geared towards the eastern provinces of Indonesia under the existing institutions. Another example is the results' agreement on the adverse effect of the BPP-pegged pricing scheme on wind energy project economic feasibility: the low purchase price of wind-based electricity resulted in only a small fraction of technical WEP having economic potential.

Second, the techno-economic analysis provides complementary inputs for the institutional analysis in three ways. Firstly, the spatial distribution of economic WEP aids in selecting provinces whose generation infrastructure plans are scrutinized. In turn, economic WEP at these provinces also serve as a reference for comparison against the planned WPP capacity. The comparison is useful to indicate the state of WEP underutilization in planning. Secondly, sensitivity analysis of economic WEP helps to assess the impact of anticipated institutional changes (see Subsection 7.3.1). Thirdly, although not shown in this study, the sensitivity analysis of economic WEP can be used as an input to determine policy recommendation parameters, such as the appropriate FiT level to be introduced at a certain province in the proposed masterplan.

A major downside of employing this approach is the limited selection of institutional components that can bridge the two analyses. As explained in Chapter 6, the link between Part I and Part II of this research is mainly provided by *electricity pricing* and *generation infrastructure planning*. These components can bridge the two analyses because of the components' spatial characteristics, which are exploited in GIS. Meanwhile, *property rights allocation* and *governance in contracts* do not have such characteristics; they are chosen as additional components because of their relevance to NIE. In other words, GIS does not present any additional value to the analysis of these additional components. Therefore, researchers intending to adopt this approach shall carefully choose the institutional components to be analyzed. Widening the scope of analysis may be useful to arrive at new alternatives of institutional components. For instance, one can scrutinize L1 institutions (e.g. norms and beliefs of the community) and correlate them with the locations of sacred sites (e.g. temples).

8.6.2. Results

Scientific contribution

This research contributes to the existing body of knowledge on WEP assessment in Indonesia by filling a crucial gap: the unavailability of a nationwide wind energy technical and economic potential assessment, which covers both onshore and offshore areas. As shown in Table 24 and Table 25 of Appendix A, existing WEP studies in Indonesia adopt a regional scope at mostly onshore areas. Meanwhile, global and supranational WEP evaluations (Bosch et al., 2019; Deng et al., 2015; Lee et al., 2019) either do not employ comprehensive site selection criteria or neglect the Indonesian territory because of the limited wind resource. Furthermore, a majority of these studies only analyze up to the theoretical potential (see Appendix A). By evaluating economic WEP in the onshore and offshore Indonesian territory and within each province using extensive siting criteria, this study addresses the knowledge gap.

Notably, this study identifies provinces with promising economic WEP by looking into the institutions on electricity pricing. As mentioned in Chapter 2, only a few WEP studies (KPMG et al., 2019; Kusumo et al., 2018; Martosaputro & Murti, 2014) extend the potentials evaluation by considering the prevailing institutions. These studies are applied at the regional level. Hence, this research contributes to the body of literature by extending the potentials analysis and its correlation with the institutions to a wider scale, i.e. at national level. Furthermore, this study paves way for future studies on provinces with promising economic WEP.

Another academic contribution stems from the correlation drawn between the spatial distribution of WEP and natural disaster proneness. This gives an insight into the 'feasible' portion of technical and economic WEP considering risk management practices of IPPs in developing wind energy projects. As shown in Chapter 5, earthquake and landslide are two types of geological natural disaster that can considerably curtail the identified technical and economic WEP. Such correlation is also missing in the existing body of literature.

This research also advances the body of literature on the institutions surrounding wind energy development in Indonesia, since none of the reviewed literature specifically analyze the institutions pertaining to wind energy. In addition, the incorporation of new legislations (e.g. the omnibus law on job creation) and the adoption of NIE approach in this study's institutional analysis may present novel insights for researchers in RE.

As asserted in the previous subsection, this research entails the novel application of WLIF to structure the institutions, identify the institutional barriers hampering wind energy development, and devise institutional recommendations to overcome the barriers. Importantly, this research enriches the institutional analysis on wind energy with the techno-economic analysis findings. The institutional analysis products are also sufficiently validated by credible experts in Indonesia's RE sector. For these reasons, it can be concluded that this study augments the body of knowledge on wind energy institutions.

Reflection

Looking at the results of the techno-economic and institutional analysis, it can be inferred that there are significant barriers to be surmounted before wind energy development can kick-off in Indonesia. Although the country in general does not have the best wind resources, there are some promising locations where wind power generation can benefit Indonesia in striving towards an energy transition.

As the techno-economic analysis suggests, there is a considerable amount of technical WEP in the western part of Indonesia, e.g. in Java, Kalimantan, and Riau Islands. Nonetheless, the current way of valuing electricity does not favor WPP deployment at these areas. Instead, wind energy development is pushed to the eastern part of the country, as suggested by the economic WEP distribution. While this pricing policy can increase the electrification ratio at the eastern provinces by captivating private sector investment, the western provinces are left relying on fossil-fuels to produce power. It is noteworthy that the western provinces have larger population density and electricity demand compared to the eastern provinces. In other words, the current regulation does not allow the ample WEP to be exploited at areas with high demand.

The institutional analysis also identifies other issues related to electricity pricing, i.e. the regulatory uncertainty stemming from frequent changes and the flawed BPP computation. Additionally, the validation interview shows that a more fundamental stumbling block related to pricing must be addressed: the revenue model of

PLN. Solving this barrier requires not only a change of laws, but also a change of Indonesian politicians' perception on the provision of 'affordable' electricity. Until these changes occur, it is unlikely for the Government to untangle the intricate situation of PLN and in turn, to promote wind energy development.

Inconsistent generation infrastructure plans also impose a barrier to WPP deployment. Such inconsistency adds to the institutional uncertainty for investors/financiers. Their perception of high investment risk in wind energy projects translates to high levels of interest rate imposed on their loans. In turn, this condition lowers the economic potential of wind energy. Moreover, an analysis of current national- and regional-level plans show a very limited capacity being allocated for wind energy. The experts also viewed the lack of transparency and delegation to regional-level actors in planning as an issue to be addressed. This practice arguably contradicts the regional governments' authority as stipulated in the formal rules. In other words, there is an inconsistency between the laws and their implementation. Hence, this situation calls for a change towards a transparent, inclusive, and consistent infrastructure planning.

The poor governance structure in electricity acts as another barrier for the establishment of WPP PPAs. PLN's conflict of interest, dependence on government subsidy, and enormous power in the PLN-IPP negotiation table cause a prolonged process of PPA signing. Furthermore, the experts regarded the missing PPA standard for intermittent RE as an impediment to project financing, namely, to establish IPP-financier cooperation. Another funding-related issue concerns the lack of available source of finance, which is likely to be caused by the inhospitable institutional environment for investment. To conclude, overcoming the barrier in contracts governance requires a reform to the governance structure and the institutions surrounding RE investment.

Three recommendations for institutional change have been proposed to alleviate these barriers. The experts largely agreed with the recommendations and suggested some possible improvements. Examples of such improvement include creating a complementary masterplan for baseload RE power plants and optimizing the roles of existing government bodies. In addition, the experts also anticipated some challenges that might lessen the recommendations' effectiveness. Among others, the challenges stem from Indonesia's budgetary practices and the economic capability of local communities with regards to participating in wind energy projects.

In conclusion, fostering wind energy development in Indonesia entails a strenuous process of altering not just the institutional environment (L2) and governance (L3), but also the norms and values (L1) of relevant stakeholders. Considering the existing institutions, it is highly questionable whether Indonesia can attain RE (and wind energy) contribution targets as stipulated in RUEN. Achieving the targets requires a set of inclusive, transparent, and consistent policies supported by the stakeholders' strong political will to realize the energy transition. Moreover, as the interviews suggest, institutional reforms need to be integrated with infrastructural development to support future RE utilization. Hence, the actors must continue to study alternative technological solutions, such as the development of a nationwide HVDC-interconnection through the *Nusantara Super Grid* (Setiawan, 2021a) and the establishment of Indonesia's energy storage system industry by the SOEs (Pertamina, 2021).

8.7. Reflection on societal relevance and recommendations

This study's societal relevance is embodied by the adopted theme, namely, RE development as a means to tackle climate change. As an archipelagic state, Indonesia will be hugely affected by rising sea levels due to climate change. Moreover, as the country with the fourth largest population, Indonesia has an important role to play in curtailing GHG emissions in multiple sectors including power generation. The projected economic and population growth further substantiate the importance of RE utilization. Given the slow RE (including wind energy) development taking place recently, this study aims to assist energy sector stakeholders in planning and designing for forthcoming energy system developments. A proper system development can address the challenge of fulfilling growing energy demand, while simultaneously contributing to the energy sector decarbonization. Practically, the author intends to develop an awareness of Indonesia's WEP and of the implications of existing institutions on wind energy development. The potential use of this study's results, i.e. techno-economic WEP determination and recommendations for institutional changes, outlines the societal contribution of this study.

To further accentuate the study's societal relevance, recommendations for the relevant actors are summarized below.

The Government and the Parliament

The Government (including relevant ministries) and the Parliament are the integral actors of policymaking in the electricity sector. Recommendations for both actors are as follows:

- Together with NEC, the Government (through MEMR) should set up a roadmap for wind energy. Encompassing a long-term plan, the roadmap can set provinces with promising economic WEP as the pioneering regions in wind energy development. The proposed electricity pricing masterplan can then be formulated and incorporated into the roadmap.
- The Government shall expedite the enactment of PR on RE-based electricity pricing. As learned from the expert interviews, tendering of RE projects and PPA negotiations are currently halted as actors wait for the new regulation. Thus, it is important to establish the new pricing scheme soon. Importantly, stakeholders in the RE sector shall be sufficiently involved in the PR's finalization.
- Similarly, the Government shall continue the finalization of the PR on carbon pricing mechanisms and the amendment bill on general provisions and tax procedures. Both regulations are required to support the implementation of ETS and carbon tax in order to establish a level playing field for RE.
- The Parliament should continue the finalization of the New and Renewable Energy Bill as the legal foundation for the NRE fund. Relevant stakeholders should also be sufficiently involved in the process.
- The Government shall introduce a regulator role in electricity in order to foster transparent, inclusive, and consistent policies. This can be done by either introducing a new regulatory body or augmenting NEC with the regulator authority. Moreover, the Government and the Parliament shall optimize the roles and authorities of government bodies to mitigate multi-level governance issue in RE.
- The Government and NEC should review and amend WPP capacity targets in KEN and RUEN by balancing between the plans' feasibility and level of ambition. Accordingly, MEMR shall revise RUKN to ensure its consistency with RUEN.
- In the longer term, the Government and the Parliament must review the interpretation of electricity 'affordability' and consider internalizing negative externalities of conventional power generation. In turn, both actors should also consider phasing-out electricity subsidy for consumers to alter the revenue model of PLN. Thus, PLN can be more independent in making investment decisions knowing that their financial health does not fully depend on government subsidies.
- The Government shall review local content restrictions on wind energy investment. For the initial phases of wind energy development, such restrictions may need to be loosened since wind turbines are off-the-shelf products. The restriction can be made stricter once the wind energy industry has sufficiently developed in Indonesia.
- The Government should foster more partnerships with countries having a successful experience in wind energy development. The partnership is not only meant to attract foreign investment, but also

to promote knowledge transfer to the Indonesian wind energy stakeholders. Regional governments of provinces with promising WEP can be involved in the knowledge transfer programs.

- The Government and the Parliament shall consider drafting regulations for offshore wind power generation to prepare for future WPP deployments at sea.

Regional governments

- Regional governments (especially those of provinces with promising WEP), shall invite MEMR and IPPs to conduct on-site wind resource assessments at promising WPP sites within their jurisdiction.
- In cooperation with the Government, regional governments should consider adjusting the onshore and offshore spatial plans at the promising WPP sites. It is important to safeguard the involvement of local stakeholders in the adjustment process.
- Regional governments shall devise policies which incentivize the participation of local communities and enterprises in wind energy projects.
- Regional governments, especially those of provinces with promising WEP, shall actively lobby for the incorporation of wind energy in the national-level plans (RUEN and RUKN). In turn, RUED and RUKD can be adjusted to suit the higher-level plans.
- To complement the top-down governance in infrastructure planning, regional governments need to engage in bottom-up initiatives for wind energy development. For instance, the governments can approach IPPs and PLN regional offices to prepare bottom-up project proposals, which will then be submitted to PLN headquarters and the Government to be included in the upcoming plans. Furthermore, the governments can initiate educational programs for local human resources to increase the receptiveness to and develop technical proficiency in wind power generation. These programs may be conducted in collaboration with MEMR, PLN, and IPPs.

PLN

- To reach its carbon neutrality goal by 2060 (Nangoy, 2021), PLN should create a roadmap on the phasing-out of conventional power plants. Moreover, PLN should adjust the RUPTL accordingly to reflect a balance between feasibility and ambition levels in integrating RE (including wind energy). Importantly, the planning must be consistent to avoid major changes from year-to-year.
- As stipulated in the law, PLN should create a PPA standard for intermittent RE to facilitate contract negotiations between PLN, IPPs, and financiers.
- In administering RE projects procurement and bidding, PLN shall promote transparency by, for instance, publishing the selection criteria and result to IPPs. Therefore, IPPs can reflect upon the result and improve for future selections.
- To advance wind energy development, PLN shall review the grid infrastructure planning of provinces with promising WEP. The plans for these provinces shall be aimed at equipping the grid to accept intermittent electricity from WPPs.

Wind energy IPPs

- As mentioned above, IPPs shall engage regional governments to conduct on-site resource assessments and feasibility study at promising WPP sites. Furthermore, IPPs should also engage in more bottom-up project initiatives by initiating cooperation with the provincial governments and PLN regional offices.
- Through AEAI, IPPs shall continue to lobby the Government, the Parliament, and regional governments for policies favoring wind energy development.

8.8. Limitations of the study

Although this study sheds some light on the technical and economic potential of wind energy in Indonesia given the prevailing institutional setting, the author acknowledges several limitations from each part. In the next subsections, limitations of the techno-economic analysis and the institutional analysis are presented consecutively.

8.8.1. Limitations of the techno-economic analysis

The techno-economic analysis of this study entails several limitations to be aware of. The first one is regarding the model's input data. As explained in Section 4.1, the model uses a 'simplified' wind speed data. Grouping and assigning onshore and offshore WPP sites to the 54 wind profiles may lead to underestimation and overestimation of hourly wind speeds and AEP. Furthermore, there are different levels of robustness among the wind profiles. For instance, region 5 is completely covered with wind speed data points, whereas there are much less data points in region 7 (see Figure 9). Consequently, the resulting LCOE figures are likely to be distorted to a certain extent. Ideally, on-site measurements of wind speed for at least one year are deemed exemplary in this field (Ea Energy Analyses et al., 2017). Such measurement may be possible in regional- or local-level studies. For a national-scale study, obtaining unique *hourly wind speed* and *mean wind speed* data for each WPP site is possible given sufficient computational resource (hardware and software) to collect and process the data. Additionally, the study utilizes open-source GIS data from OpenStreetMap for site selection. Hence, the data may not be complete because OpenStreetMap relies on users' voluntary contribution (McKenna et al., 2021).

The second limitation pertains to the employed site selection procedure. The procedure assumes no political and socio-cultural tensions emanating from the embedded institutions (e.g. local wisdom). Embedded institutions can fuel resistance towards WPP construction at sites which are considered eligible in this study. Given the variety of cultures and perspectives among Indonesians (as exemplified in Section 8.5), a regional-level study would be appropriate to incorporate these institutions. Furthermore, the siting procedure for offshore WPP disregards other maritime use, such as oil rigs and shipping routes. Applying these additional constraints may further detract the technical and economic WEP.

The third limitation stems from the adopted wind farm design. In the model, two approaches (point-grid and square-grid) are employed to give upper and lower estimates of eligible WPP sites and the computed potentials. However, both approaches ignore the possibility of merging neighboring sites to obtain the *adjusted WPP area*. Moreover, this study assumes a fixed WPP arrangement that disallows a more optimal placement of each turbine within the eligible areas. Such optimization may be possible if the analysis is conducted using a finer resolution (e.g. using 1-km^2 square grids). Another consequence of the adopted WPP design is the fixed WPP capacity. This study calculates technical and economic potential solely based on 50-MW onshore WPP and 400-MW offshore WPP. In other words, smaller and larger onshore and offshore WPP sizes are neglected. Realistically, sites which are deemed ineligible for WPP based on their size can still be used for wind power generation (see Section 8.3). In addition, this research excludes WEP of areas with *average wind speed* lower than 4 m/s. Small-scale wind turbines can still be employed at these regions. In fact, small-scale turbines may be subjected to less restrictive site selection constraints: their smaller dimension and noise level might be less intrusive to the nearby population. Incorporating small-scale turbines in the model can thus lead to a higher WEP estimate.

Fourth, the cost assumptions in this study may lead to an overestimation or underestimation of expenses due to four reasons. The first one pertains to the assumedly constant *turbine and others cost* for all sites. In reality, the cost can be different from one site to another, especially considering the various state of infrastructure development in Indonesia. Underdeveloped, rural onshore sites may require additional expenses for building physical access such as roads. Moreover, there may be supplementary cost for electricity infrastructure upgrade at the connection points in order to safeguard the infrastructure's operational integrity. The second reason arises from the employment of a single-version investment cost instead of a range of cost. Although this limitation is partly addressed by the sensitivity analysis (see Section 8.4), utilizing a range of cost for the techno-economic analysis can provide additional insights on the sensitivity of economic WEP and its spatial distribution. The third reason concerns the distance-independent assumption for offshore WPP OPEX. Implementing a distance-dependent OPEX may be challenging because the distance shall be measured from shores of islands with adequate human resources and tools/machines to conduct the maintenance activities. Finally, the fourth reason relates to the possible transmission cost underestimation due to the straight-line transmission cables being modelled. In reality, longer transmission distances are likely to be employed because of some 'obstacles' (e.g. land and maritime use) that the cables need to work around.

Fifth, this study overlooks system integration costs stemming from wind energy's intermittency when assessing the economic WEP. These costs are highlighted in the validation interviews: B. Elemans (personal communication, June 25, 2021) asserted the necessity of deploying expensive batteries to deal with the intermittent electricity supply. There is also a lack of clarity on who will bear the cost of adding the battery system. Furthermore, A. Tampubolon & H. Puspitarini (personal communication, June 29, 2021) pointed to the importance of grid development in order to equip local grids with the capability to accept the intermittent power. Both system development measures entail extra costs which are not taken into account in this study. Intuitively, adding these costs to LCOE is expected to lessen the economic WEP.

The final limitation is related to the analysis of natural disaster proneness impact on WEP. This study only scrutinizes the impact on onshore WEP, whereas the impact on offshore WEP remains unaddressed. Offshore natural disasters, such as tropical cyclones, hurricanes, and submarine earthquakes, shall be considered in future assessments. Furthermore, the interpretation of onshore natural disaster analysis is lacking an insight from the IPPs' perspective, namely, to understand the decision rule IPPs' employ in wind energy investment given the site's disaster-proneness.

In conclusion, this research merely gives a broad indication of possible WPP sites having technical and economic potential. A more detailed inspection at the regional or local level is required to accurately compute LCOE and in turn, to precisely determine the potentials on-site.

8.8.2. Limitations of the institutional analysis

The institutional analysis also entails some limitations which may be overcome in future studies. First, the input data is mostly collected through a literature review of scientific and government documents, reports, and news. While a lot of information can be gathered from these sources, they may not provide enough insight on the actors' views and vested interests. These sources depict the 'formal' side of governance, actions, and interactions between actors. Meanwhile, the practical, 'informal' side is not scrutinized in this study. This is signified by the missing actors (i.e. MMAF, AEAI, Bappenas, and foreign governments) from the stakeholder analysis, as acknowledged from the expert interviews. Moreover, the 'informal' side is also exemplified by the political influence of fossil-fuel incumbents, and the possible intertwined role of politicians and entrepreneur in the energy sector. Furthermore, the validation interviews do not evenly cover stakeholders from all sides: the interviews only involve representatives from think-tanks and RE consultant (private sector). Insights from the governmental actors, e.g. the ministries and PLN, are missing from this research. Hence, future studies can include interviews of more private and governmental actors to increase the findings' completeness and reliability.

The second limitation arises from the adopted scope of this research. Electricity pricing, generation infrastructure planning, property rights, and governance of contracts are selected as the institutional components being scrutinized for reasons presented in Chapter 6. In the literature, there are more problematic components being cited as barriers to RE development. For instance, issues related to local content restrictions, land acquisition, taxation, and grid codes and management are not discussed in this study. Moreover, this study excludes an analysis of L1 and L4 institutions. Studying both levels should be feasible if the research adopts a regional-level case study approach. Inclusion of all four levels allows for the identification of both top-down and bottom-up relationships between the institutions. Accordingly, more comprehensive insights can be derived.

Finally, the proposed institutional recommendations merely prescribe initial ideas for changes to be made. The proposal needs detailed institutional design and evaluation. The design shall operationalize the proposed ideas into executable actions that each actor must do in order to overcome the institutional barriers. In turn, the design should be subjected to an evaluation based on several criteria, such as effectiveness, flexibility, practicability, efficiency, and system conformity (Enzensberger et al., 2002).

This chapter has presented a discussion on the results and methodology of this study. Moreover, it has provided a reflection on the scientific and societal relevance. Finally, this chapter has conveyed the limitations of Part I and Part II of this research, which may serve as the basis for future studies. The next chapter will present the conclusion and future research recommendations.

Chapter 9. Conclusion

In this chapter, concluding answers to the research questions are presented in Section 9.1. This is followed by future research recommendations in Section 9.2.

9.1. Revisiting the research questions

9.1.1. Answering sub-research question 1

What is the technical and economic potential of onshore and offshore wind energy in Indonesia?

The computed onshore wind technical potential, as described by the average power output (APO), ranges from 17.6 to 30.9 GW. Moreover, offshore wind technical potential amounts to 470.6 – 595.6 GW. Summing the two components gives the total technical potential of 488.2 – 626.5 GW. In terms of annual energy production, the total technical potential is as large as 15 to 19 times Indonesia's electricity demand in 2019, or 1.9 – 2.5 times the projected demand in 2050. Based on its spatial distribution, the technical potential is more prevalent in the eastern part of Indonesia compared to the western part.

The economic potential is firstly characterized by the levelized cost of energy (LCOE). It is found that minimum LCOE of onshore wind ranges from 6.1 to 8.7 USD ct/kWh. In the western part of Indonesia, there are only a few onshore wind power plant (WPP) sites with LCOE < 10 USD ct/kWh. These sites are mainly located in Java and Sumatera Island; there are none in Kalimantan and Bali Island. There are more sites with LCOE < 10 USD ct/kWh in the eastern part of Indonesia. Provinces containing these sites include Nusa Tenggara Barat, Nusa Tenggara, Sulawesi Selatan, Sulawesi Tengah, Maluku, and Papua. Comparing to the current pricing scheme, economic APO of onshore wind amounts to 0.5 – 2.5 GW, or equivalent to 2.9 – 8.0% of the onshore wind technical potential. Economically feasible onshore WPP sites are mainly situated in Nusa Tenggara Barat, Nusa Tenggara Timur, Sulawesi Selatan, Maluku, and Papua. On the other hand, the minimum LCOE of offshore wind is 13.4 – 13.5 USD ct/kWh. Sites with LCOE < 20 USD ct/kWh are only located in Papua, Maluku, and Jawa Barat. Moreover, the economic APO of offshore wind is 5.9 – 8.0 GW, or equivalent to 1.3 – 1.4% of the offshore wind technical potential. In the case of offshore wind, economically feasible WPP sites are only located in Papua.

Examining the sites' natural disaster proneness suggests the significance of earthquake and landslide, among the four types of natural disaster studied (i.e. earthquake, landslide, tsunami, and volcano), to onshore WEP determination. Assuming that IPPs will not construct a WPP at areas highly prone to earthquakes, the onshore technical and economic potential is thus curtailed by up to 16% and 31%, respectively. On the other hand, removal of sites being highly prone to landslide subtracts the onshore technical and economic potential by up to 4% and 8%, respectively.

9.1.2. Answering sub-research question 2

Considering the current institutional setting, what are the institutional barriers hampering Indonesia's wind energy development?

The institutional barriers in electricity pricing (L2) are twofold. Firstly, there is an uncertainty in terms of pricing regulations which in turn deters IPPs' and investors' interest in developing WPPs in Indonesia. These regulations change frequently without sufficient stakeholder consultation. Secondly, the current pricing is too low to make RE projects, including wind energy projects, economically viable. This issue stems from the problematic price cap, which is pegged to *Biaya Pokok Penyediaan* (BPP or the cost of power generation for electricity provision). BPP calculation disincentivizes investment at low-BPP islands. Moreover, negative externalities of fossil-fuel power generation are not taken into account in the calculation; hence, this creates an uneven playing field for RE.

In terms of power generation infrastructure planning (L2), an institutional barrier arises from the small amount of WPP capacity being planned by PLN, the state-owned electricity enterprise, in their ten-year planning. As observed in the current national and regional electricity plans, most of the future RE technology deployment involves hydropower and geothermal energy. Meanwhile, wind energy is anticipated to only have a peripheral role power generation. Another issue stems from the inconsistent planning of PLN as significant changes to the planned WPP capacity occur year-by-year. This hampers performance evaluation of PLN in meeting the plans and adds to the institutional uncertainty for Independent Power Producers (IPPs). Analyzing the regional-level plans of the five most promising provinces based on economic wind energy potential (WEP; as identified in Part I of this study) indicates a priority being placed in the construction of baseload plants. Consequently, intermittent RE is only allocated a small portion in these plans. To conclude, WEP at these provinces remains largely unexploited in the coming years.

Based on the analysis on property rights allocation (L2), the institutional barriers to wind energy development are related to PLN-IPP cooperation scheme and project ownership. However, both of these barriers have been addressed by recent legislations. In 2020, the mandatory *Build, Own, Operate, and Transfer* (BOOT) scheme for wind energy projects was replaced by a *Build, Own, and Operate* (BOO) scheme. BOOT scheme was deemed detrimental to the projects' finances by IPPs since it introduces additional contracting costs and uncertainty. Enforcement of BOO scheme is expected to benefit the IPPs in obtaining their return of investment, since no ownership transfer is mandatory at the end of the concession period. Furthermore, the project ownership issue is also addressed in 2021 with the presumed removal of foreign ownership restrictions.

Institutional barriers in governance of contracts (L3) are divided into two parts: before and after the Power Purchase Agreement (PPA) signing. In the former part, the negotiation between PLN and the IPP is seen as a barrier because of the prolonged and difficult process. This barrier can be attributed to a poor governance structure, which is characterized by the intricate position of PLN. By negotiating PPAs with IPPs (PLN's competitors in power generation), PLN faces a conflict of interest and may behave strategically to maintain its market share. Additionally, PLN's dependence on government subsidy leads to possible cost-saving measures that decrease the possibility of reaching an agreement with IPPs on the PPA tariff. Adding to the poor governance structure is the missing PPA standard for intermittent RE. On the other hand, post-PPA signing institutional barriers include poor law and contract enforcement, the lack of coordination and leadership among the governments at different levels, and the lack of funding available for RE projects because of the inhospitable institutional environment for RE investment.

These institutional barriers are validated by interviewing four experts from the private sector (RE consultant) and think-tanks focusing on the energy transition. The respondents generally agree with the identified barriers. However, they also cited two additional barriers, i.e. PLN's revenue model and local content restrictions. Additionally, they underlined the largely deficient grid infrastructure to cope with intermittent power from WPPs as a technological barrier.

9.1.3. Answering sub-research question 3

How can the institutional setting be improved to proliferate wind energy development in Indonesia?

Three institutional recommendations are drawn based on the aforementioned barriers and the stakeholders' attributes. The first one entails a change to the RE-based electricity pricing scheme. The Government is recommended to establish a masterplan which encompasses a staged implementation of economic policy instruments. Feed-in tariff (FiT) is deemed the most appropriate scheme in the near future, as it provides long-term cash flow certainty for investors and transparency to the PPA establishment. However, FiT needs to be capped with a capacity quota to avoid overinvestment. Once the quota is fulfilled, FiT can be replaced with reverse auctions, so that cost-competitiveness of wind energy can be truly reflected. Importantly, the masterplan shall be implemented using a regional approach, i.e. by starting at provinces with promising economic WEP.

The second recommendation is aimed at addressing the financial issues. New sources of funds shall be provided to continuously support the Government's subsidy to PLN. These sources include the reallocated budget for subsidizing fossil-fuel enterprises and revenues from ETS and carbon pricing. Furthermore, it is advised to promote local participation and ownership in wind energy projects. This takes form in participation incentives for the people or enterprises located near the WPP site. Accordingly, these changes can alleviate the issue of limited funding for WPP deployment.

The final recommendation pertains to changing the governance structure in the electricity sector. This study proposes the establishment of an independent regulatory body that acts as a referee in validating electricity infrastructure development plans, monitoring the plans' fulfillment, and ensuring a sufficient level of political inclusion throughout the planning process. The regulator is also authorized to scrutinize and oversee the design and implementation of electricity pricing schemes. Essentially, the regulator acts as a referee that fairly evaluates the performance of PLN and MEMR in RE development.

Based on the validation interviews, the experts largely agree with the proposed recommendations. Nevertheless, the experts noted that the recommendations' implementation may be impeded by the economic capability and the embedded values of the Indonesian people.

9.1.4. Answering the main research question

What is the economic potential of wind energy across Indonesia and within its provinces, and how can its development be promoted given the prevailing institutions?

Answers to the sub-research questions can already sufficiently answer the main research question. Nevertheless, the answer in this subsection takes a broader perspective and attempts to summarize the previous answers. The techno-economic analysis results show that Indonesia has a considerable amount of technical WEP. The potential is particularly apparent in the eastern provinces of Indonesia, including Sulawesi Selatan, Papua, and Maluku. Moreover, there are plenty of offshore wind resources to be exploited within the Indonesian marine territory. Unfortunately, the technical potential is not supported by favorable cost figures of wind energy technology in Indonesia: being a niche market, wind power generation involves high investment costs which lead to high LCOE and in turn, to a low cost-competitiveness of wind energy. Furthermore, the employed electricity pricing scheme creates an inhospitable investment climate for wind energy. This is exemplified by the small share of economic APO in the total APO. For instance, the appreciable technical WEP in Java and Kalimantan Island corresponds to zero economic potential. Meanwhile, only a small portion of the abundant technical WEP in the aforementioned eastern provinces is economically feasible under the current institutional regime. The economic potential is even lower if natural disaster-prone sites are excluded from consideration.

Looking at the calculated potentials and the prevailing institutions, it is obvious that significant institutional changes need to be made to proliferate wind energy development in Indonesia. Among the three institutional recommendations, alteration to the pricing scheme shall be considered as a priority in the short term. In this respect, Indonesia is moving in the right direction as the Government is currently designing the new scheme. Formation of an independent regulatory body should also be prioritized and started immediately considering how long such formation can take: political processes involving the complexly-interrelated stakeholders and the enactment of new institutions will take time under Indonesia's democratic regime. This is not to say that the financial issue should be addressed only at the end. Instead, all of these changes shall be implemented in parallel. By introducing these changes, wind energy development can slowly start and subsequently induce cost reductions as more WPPs are being deployed. Importantly, enabling these institutional changes entails more than just altering the institutional environment (L2) and governance (L3): there must be a shift of norms and values (L1) of the stakeholders, especially the politicians, in interpreting electricity 'affordability'. Without this shift, RE will only continue to compete with fossil-fuels in an unlevel playing field.

New institutional barriers, other than what this study has identified, is expected to emerge as these changes are implemented. Nonetheless, the barriers shall be circumvented by further institutional adjustments, which call for an active lobbying from pro-RE coalition of actors in the future. Furthermore, it is worth remembering that this study entails methodological and scoping limitations. Hence, as indicated by the validation interviews, there are additional institutional and non-institutional barriers to be solved involving a wider range of stakeholders than those being considered in this study.

9.2. Recommendations for future research

Besides the recommendations for actors in Section 8.7, this study recommends two research avenues to be explored. Firstly, future research can address the limitations of both the techno-economic and institutional analysis to obtain more sophisticated results. A similar national-scale WEP analysis can be performed by utilizing a refined wind speed data which accurately reflects the wind resources at site. The analysis can also adopt flexible WPP capacities so that the potential of smaller-scale and distributed wind power generation can be evaluated. Additionally, a refinement of cost assumptions in the techno-economic analysis is also recommended in future studies. This can be done by incorporating investment cost ranges, distance-dependent cost functions, and a locational cost-factor/multiplier to represent the varying state of infrastructure development across Indonesia. Meanwhile, system integration cost can be quantified by using alternative economic metrics for power generation technologies, such as System LCOE, Levelized Avoided Cost of Electricity, and Value-adjusted LCOE (Doluweera, 2020). In turn, the analysis can be coupled with an institutional assessment that incorporate first-hand insights from the stakeholders. These insights can be derived by interviewing representatives of each actor depicted in the stakeholder map (see Figure 34). Input data improvements in both analyses can deliver higher-quality knowledge to be fed into institutional design studies.

Secondly, further studies can build upon this study's results in three ways. The first way is to conduct a similar study at the regional level, such as in provinces with promising economic WEP. In the techno-economic portion of the study, WPP site selection can be precisely determined by looking at regional spatial plans and possibly by conducting a site visit to empirically obtain localized information on the area's suitability. Moreover, wind farm design can be made more flexible, namely, customized to meet the eligible sites' characteristics. The WPP model can be further equipped with current and future electricity demand levels, as well as the availability of transmission and distribution lines within the region. Regarding the institutional analysis, institutions at all four layers of WLIF should be scrutinized, including the local norms and values (L1). IADF can also be employed to supplement the findings from WLIF analysis by looking at the interaction of actors within the local action arena.

The second way pertains to an ex-ante analysis on the proposed institutional changes. The analysis involves identifying the necessary preconditions to support the changes, such as by reforming formal regulations (L2) and gradually steering a shift of the stakeholders' norms and values (L1). In addition, an impact assessment shall also be conducted to quantitatively investigate the changes' effectiveness in attaining a targeted installed WPP capacity, as well as the entailed social, economic, and environmental impacts. Obtaining the stakeholders' views on these changes will be highly valuable for the analysis. Results of the ex-ante analysis shall be used to refine the selection of policy parameters and in turn, produce draft regulations to facilitate these changes.

The third way is to adopt a forward-looking, design approach in formulating detailed proposals of institutional reform and a roadmap of WPP deployment throughout Indonesia. For this approach, the research can include innovation and transitions theories, e.g. Functions of Innovation Systems of van Alphen et al. (2008) and Multi-Level Perspective of Geels (2002), to create such roadmap. As explained in Section 6.2.1, the latter theory allows the integration of institutional analysis with a multi-layer transitions approach to analyze and foster wind energy technological transition.

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Appendix

A. Literature review on wind energy potential studies

Table 24. An overview table of wind energy potential academic publications reviewed and their corresponding attributes (continued to the next page)

Author (year)	**Geographical scope (Location of study)**	**Site**	**Application (Total capacity)**	**Wind speed data source**	**Potential indicators**						
					Theor.	**Technical**				**Economic**	
					WPD	**APO**	**CF**	**AEP**	**Other**	**LCOE**	**Other**
Rumbayan & Nagasaka (2011)	Regional (Bali; Balikpapan, East Kalimantan; Surabaya, East Java; and Jayapura, Papua)	Onshore	-	National Oceanic and Atmospheric Administration (NOAA)	✓	-	-	-	-	-	-
Widhiyanuriyawan et al. (2011)	National	Offshore	-	NASA QuikSCAT satellite	✓	-	-	-	-	-	-
Hiendro et al. (2013)	Regional (Temajuk Village, West Kalimantan)	Onshore	Hybrid system (1 kW)	-	✓	✓	✓	✓	-	✓	✓
Gernaat et al. (2014)	Global	Offshore	Utility-scale wind farm (-)	National Renewable Energy Laboratory (NREL)	-	-	-	-	✓	✓	-
Ismail et al. (2014)	Regional (Purworejo, Central Java)	Onshore	Utility-scale wind farm (>76.5 MW)	Actual measurement on site	-	-	-	✓	-	-	✓
Martosaputro & Murti (2014)	Regional (Lebak, Banten; Nusa Penida, Bali; Bantul, SR Yogyakarta; Baron Beach, SR Yogyakarta; Purworejo, Central Java; Garut, West Java; Sukabumi, West Java; Oelbubuk, East Nusa Tenggara; Jeneponto, South Sulawesi; Sidrap, South Sulawesi; and Selayar, South Sulawesi)	Onshore	-	National Institute of Aeronautics and Space (LAPAN); and Wind Hybrid Power Generation (WHyPGen)	✓	-	-	-	-	-	-
Sari & Kusumaningrum (2014)	Regional (Yogyakarta, SR Yogyakarta; and Semarang, Central Java)	Onshore	Building-integrated turbine (< 2.5 kW)	-	✓	-	-	-	-	-	-
Deng et al. (2015)	Global	Onshore & offshore	-	Computational and Information Systems Laboratory (CISL)	-	-	-	✓	-	-	-
Ismail et al. (2015)	Regional (Purworejo, Central Java)	Onshore	Wind farm (126 MW)	Actual measurement on site	-	-	-	-	-	-	✓
Mahmuddin (2015)	Regional (Sulawesi and Maluku)	Offshore	Mobile floating structure	NASA QuikSCAT satellite	✓	✓	✓	-	-	-	-

Author (year)	***Geographical scope (Location of study)***	***Site***	***Application (Total capacity)***	***Wind speed data source***	***Potential indicators***						
					Theor.	***Technical***				***Economic***	
					WPD	***APO***	***CF***	***AEP***	***Other***	***LCOE***	***Other***
			(2 MW)								
Mahmuddin et al. (2015)	Regional (Sulawesi and Maluku)	Offshore	-	NASA QuikSCAT satellite	✓	-	-	-	-	-	-
Patriawan & Hartanti (2016)	Regional (South Bone Bay, Sulawesi; and Aru Islands, Papua)	Onshore	Stationery Airborne Wind Energy System (4 kW)	NASA QuikSCAT satellite	-	✓	-	-	-	-	-
Tjahjana et al. (2016)	Regional (Pandansimo Beach, SR Yogyakarta)	Onshore	Single turbine (0.1 – 2 MW)	Actual measurement on site	✓	✓	✓	✓	✓	-	-
Hardianto et al. (2017)	Regional (Puger Beach, Jember)	Onshore	Wind farm (1 & 2 MW)	Actual measurement on site	✓	✓	-	-	-	-	-
Premono et al. (2017)	Regional (Semarang, Central Java)	Onshore	Single turbine (20 – 900 kW)	Meteorological, Climatological, and Geophysical Agency (BMKG)	✓	-	✓	✓	✓	-	-
Kusumo et al. (2018)	Regional (Islands of Sumatera, Java, Kalimantan, West Nusa Tenggara, Sulawesi, and Papua)	Onshore	Wind farm (20 & 50 MW)	NASA MERRA satellite	-	-	✓	✓	-	✓	-
Tjahjana et al. (2018)	Regional (Surakarta, Central Java)	Onshore	Building-integrated turbine (-)	Adi Soemarmo Air Force Base	✓	-	-	✓	-	-	-
Bestari & Arifin (2019)	Regional (Sorowako, South Sulawesi)	Onshore	-	PT Vale Indonesia	✓	-	-	-	-	-	-
Bosch et al. (2019)	Global	Offshore	-	NASA MERRA-2 and Global Wind Atlas (Danish Technical University).	-	✓	✓	✓	-	✓	-
Daratha et al. (2019)	Regional (Enggano Island, Bengkulu)	Onshore	-	Actual measurement on site	✓	-	-	-	-	-	-
Putro et al. (2019)	Regional (Krui, Lampung)	Onshore	-	Actual measurement on site	✓	-	-	-	-	-	-
Satwika et al. (2019)	Regional (Locations in Bali: Sanglah, Ngurah Rai, Jembrana, and Karangasem)	Onshore	-	Meteorological, Climatological, and Geophysical Agency (BMKG)	✓	-	-	-	-	-	-
Hidayat et al. (2020)	Regional (Malang, East Java)	Onshore	Hybrid system (6 kW)	-	-	-	-	-	-	✓	✓
Ismail et al. (2020)	Regional (Lebak, Banten; Bantul, SR Yogyakarta; Baron Beach, SR Yogyakarta; Garut, West Java;	Onshore	-	Literature of Martosaputro & Murti (2014)	-	-	✓	✓	-	-	✓

Author (year)	Geographical scope (Location of study)	Site	Application (Total capacity)	Wind speed data source	Potential indicators						
					Theor.	Technical				Economic	
					WPD	APO	CF	AEP	Other	LCOE	Other
	Sukabumi, West Java; Jeneponto, South Sulawesi; and Sidrap, South Sulawesi)										

Table 25. An overview table of governmental and NGO-based publications reviewed on wind energy potential and their corresponding attributes

Author (year)	Geographical scope (Location of study)	Site	Application (Total capacity)	Wind speed data source	Potential indicators						
					Theor.	Technical				Economic	
					WPD	APO	CF	AEP	Other	LCOE	Other
Sah & Wijayatunga (2017) (Asian Development Bank)	Regional (Bali)	Onshore	-	National Oceanic and Atmospheric Administration (NOAA)	-	-	-	✓	-	-	-
Ea Energy Analyses & Danish Energy Agency (2019)	Regional (South Kalimantan)	Onshore	Wind farm (150 - 600 MW)	windPROSPECTING (by EMD International A/S)	-	-	✓	✓	-	✓	-
KPMG et al. (2019)	Regional (Lombok, West Nusa Tenggara)	Onshore	Wind farm (50 MW)	windPROSPECTING (by EMD International A/S)	-	-	-	-	-	-	✓
Lee et al. (2019) (National Renewable Energy Laboratory)	Supranational (ASEAN: Southeast Asia)	Onshore	Wind farm (3 MW/km^2)	Global Wind Atlas (Danish Technical University)	-	-	✓	-	-	✓	-

B. CAPEX values used in wind energy economic potential studies

Table 26. CAPEX values of onshore wind power plants used in economic WEP studies

Author	*CAPEX (USD2020/kW)*	*Country of application*	*Remarks*
Sliz-Szkliniarz & Vogt (2011)	1,632 – 2,611	Poland	
Brown et al. (2016)	1,758 – 1,945	USA	
NEC (2017)	1,901	Indonesia	Estimate by PLN System Planning Division (includes equipment and installation)
	1,521 – 1,630	Indonesia	Estimate by Vestas (Asian Pacific) (includes equipment and installation)
	1,630	Indonesia	Conclusion by NEC (includes equipment and installation)
Moné et al. (2017)	1,842	USA	
IRENA (2018)	2,544	ASEAN	Approximated for 2016
Lee et al. (2019)	2,074	Indonesia	
KPMG et al. (2019)	1,534 – 2,046	Indonesia	
NEC (2021)	1,534	Indonesia	Conclusion by NEC (includes equipment and installation)

Table 27. CAPEX values of offshore wind power plants used in economic WEP studies

Author	*CAPEX (USD2020/kW)*	*Country of application*	*Remarks*
Moné et al. (2017)	5,030	USA	
	7,245	USA	
NEC (2017)	3,803	Indonesia	Conclusion by NEC (includes equipment and installation)
Schallenberg-Rodríguez & Montesdeoca (2018)	3,685 – 5,527	-	For fixed offshore structures (CAPEX range based on literature review)
	4,606 – 9,457	-	For floating offshore structures (CAPEX range based on literature review)
Noonan et al. (2018)	4,393	Japan	
Bosch et al. (2019)	7,580	Indonesia	Average CAPEX for seabed depth < 25 m (Part of global study)
	8,611	Indonesia	Average CAPEX for seabed depth 25 - 55 m (Part of global study)
	8,706	Indonesia	Average CAPEX for seabed depth 55 – 1,000 m (Part of global study)
NEC (2021)	3,580	Indonesia	Conclusion by NEC (includes equipment and installation)

C. Map of connection points

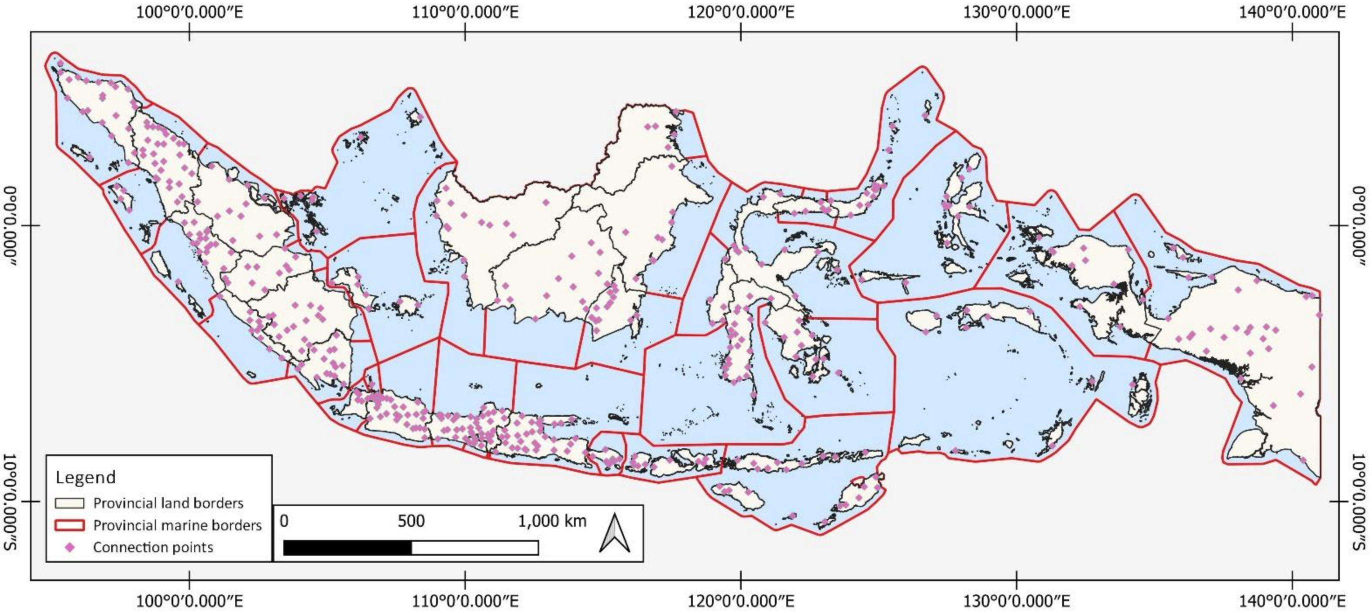

Figure 42. A map of connection points used in this study; these points include national capital, provincial capital, regency capital, and Kota

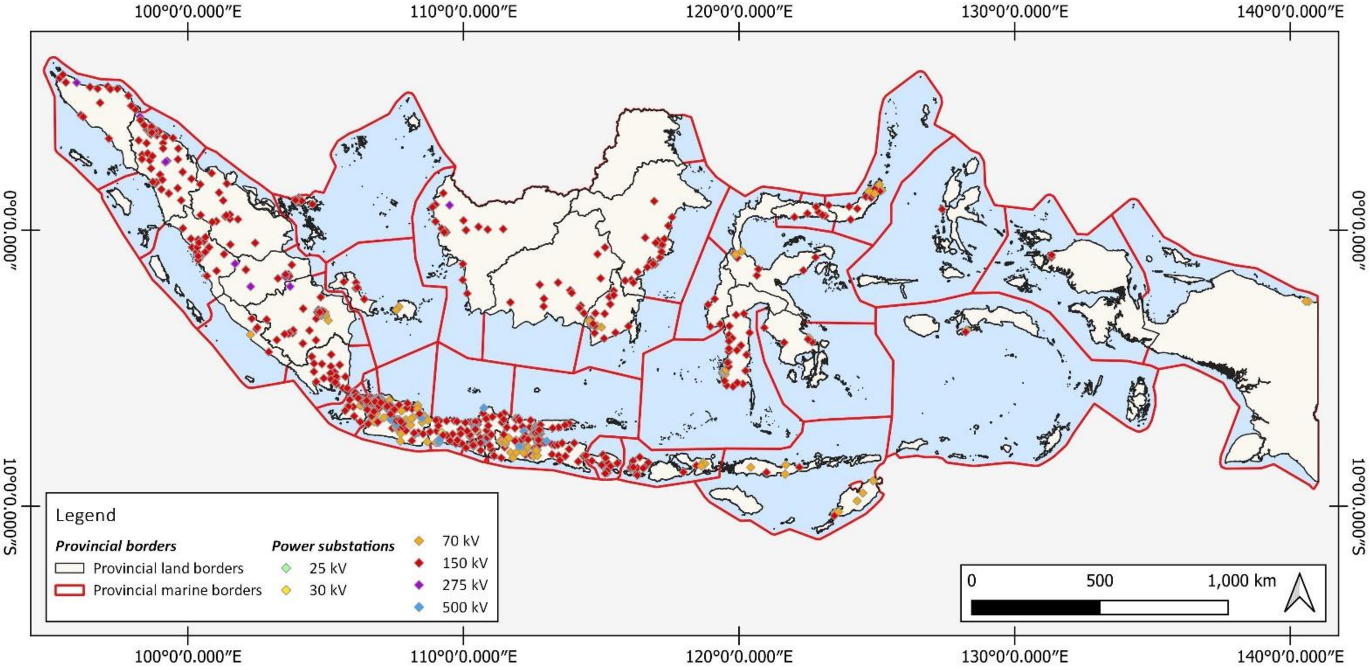

Figure 43. A map of power substations in Indonesia (derived from MEMR Geoportal)

D. Provincial distribution of wind energy technical and economic potential

Table 28. Distribution of technical and economic potential by province as derived using point-grid approach

No	Province	Technical Potential (GW)			Economic Potential (GW)		
		Onshore	Offshore	Total	Onshore	Offshore	Total
1	Aceh	0.17	4.54	4.71	0.05	0.00	0.05
2	Bali	0.03	0.98	1.01	0.00	0.00	0.00
3	Banten	0.31	2.33	2.64	0.00	0.00	0.00
4	Bengkulu	0.07	7.04	7.11	0.00	0.00	0.00
5	Daerah Istimewa Yogyakarta	0.10	2.26	2.36	0.00	0.00	0.00
6	Daerah Khusus Ibukota Jakarta	0.00	0.00	0.00	0.00	0.00	0.00
7	Gorontalo	0.25	0.21	0.45	0.04	0.00	0.04
8	Jambi	0.15	1.62	1.77	0.00	0.00	0.00
9	Jawa Barat	1.01	14.60	15.60	0.00	0.00	0.00
10	Jawa Tengah	1.24	23.91	25.15	0.00	0.00	0.00
11	Jawa Timur	1.64	41.90	43.54	0.00	0.00	0.00
12	Kalimantan Barat	1.30	21.62	22.92	0.00	0.00	0.00
13	Kalimantan Selatan	0.54	11.62	12.17	0.00	0.00	0.00
14	Kalimantan Tengah	1.59	21.67	23.27	0.00	0.00	0.00
15	Kalimantan Timur	0.42	1.11	1.54	0.00	0.00	0.00
16	Kalimantan Utara	0.05	0.00	0.05	0.00	0.00	0.00
17	Kepulauan Bangka Belitung	0.66	33.50	34.16	0.00	0.00	0.00
18	Kepulauan Riau	0.29	87.88	88.17	0.02	0.00	0.02
19	Lampung	0.33	3.98	4.31	0.00	0.00	0.00
20	Maluku	4.32	134.73	139.05	0.71	0.00	0.71
21	Maluku Utara	0.22	1.35	1.57	0.00	0.00	0.00
22	Nusa Tenggara Barat	0.74	2.45	3.19	0.12	0.00	0.12
23	Nusa Tenggara Timur	3.39	8.77	12.16	1.15	0.00	1.15
24	Papua	5.52	108.43	113.95	0.11	8.03	8.14
25	Papua Barat	0.59	8.96	9.54	0.00	0.00	0.00
26	Riau	0.20	0.97	1.18	0.00	0.00	0.00
27	Sulawesi Barat	0.06	1.35	1.41	0.00	0.00	0.00
28	Sulawesi Selatan	2.32	37.53	39.85	0.24	0.00	0.24
29	Sulawesi Tengah	0.67	1.35	2.03	0.04	0.00	0.04
30	Sulawesi Tenggara	0.23	0.40	0.63	0.00	0.00	0.00
31	Sulawesi Utara	0.45	4.99	5.44	0.00	0.00	0.00
32	Sumatera Barat	0.16	0.19	0.35	0.00	0.00	0.00
33	Sumatera Selatan	1.38	2.33	3.71	0.00	0.00	0.00
34	Sumatera Utara	0.51	0.00	0.51	0.00	0.00	0.00
	Total	30.92	594.58	625.50	2.48	8.03	10.51

Table 29. Distribution of technical and economic potential by province as derived using square-grid approach

No	Province	Technical Potential (GW)			Economic Potential (GW)		
		Onshore	Offshore	Total	Onshore	Offshore	Total
1	Aceh	0.07	0.90	0.97	0.00	0.00	0.00
2	Bali	0.00	0.49	0.49	0.00	0.00	0.00
3	Banten	0.08	0.24	0.32	0.00	0.00	0.00
4	Bengkulu	0.03	3.95	3.98	0.00	0.00	0.00
5	Daerah Istimewa Yogyakarta	0.00	0.92	0.92	0.00	0.00	0.00
6	Daerah Khusus Ibukota Jakarta	0.00	0.00	0.00	0.00	0.00	0.00
7	Gorontalo	0.15	0.00	0.15	0.00	0.00	0.00
8	Jambi	0.08	1.19	1.27	0.00	0.00	0.00
9	Jawa Barat	0.13	10.73	10.86	0.00	0.00	0.00
10	Jawa Tengah	0.25	21.40	21.65	0.00	0.00	0.00
11	Jawa Timur	0.25	32.95	33.20	0.00	0.00	0.00
12	Kalimantan Barat	1.01	18.29	19.31	0.00	0.00	0.00
13	Kalimantan Selatan	0.28	10.84	11.12	0.00	0.00	0.00
14	Kalimantan Tengah	1.18	20.83	22.02	0.00	0.00	0.00
15	Kalimantan Timur	0.06	0.22	0.28	0.00	0.00	0.00
16	Kalimantan Utara	0.00	0.00	0.00	0.00	0.00	0.00
17	Kepulauan Bangka Belitung	0.47	28.53	29.00	0.00	0.00	0.00
18	Kepulauan Riau	0.05	70.98	71.03	0.00	0.00	0.00
19	Lampung	0.14	1.82	1.96	0.00	0.00	0.00
20	Maluku	2.90	107.03	109.92	0.07	0.00	0.07
21	Maluku Utara	0.00	0.28	0.28	0.00	0.00	0.00
22	Nusa Tenggara Barat	0.35	0.12	0.47	0.00	0.00	0.00
23	Nusa Tenggara Timur	1.77	4.66	6.43	0.44	0.00	0.44
24	Papua	5.09	97.59	102.68	0.00	5.90	5.90
25	Papua Barat	0.20	4.52	4.73	0.00	0.00	0.00
26	Riau	0.06	0.10	0.16	0.00	0.00	0.00
27	Sulawesi Barat	0.00	0.84	0.84	0.00	0.00	0.00
28	Sulawesi Selatan	1.33	28.58	29.92	0.00	0.00	0.00
29	Sulawesi Tengah	0.45	0.34	0.78	0.00	0.00	0.00
30	Sulawesi Tenggara	0.04	0.00	0.04	0.00	0.00	0.00
31	Sulawesi Utara	0.12	0.73	0.85	0.00	0.00	0.00
32	Sumatera Barat	0.01	0.00	0.01	0.00	0.00	0.00
33	Sumatera Selatan	0.82	1.48	2.30	0.00	0.00	0.00
34	Sumatera Utara	0.27	0.00	0.27	0.00	0.00	0.00
	Total	17.64	470.56	488.20	0.51	5.90	6.41

E. Impact of other types of natural disaster proneness on WEP

Table 30. Volcano proneness impact on technical and economic wind energy potential

Proneness level	*Square-grid*		*Point-grid*	
	Technical potential (GW)	*Economic potential (GW)*	*Technical potential (GW)*	*Economic potential (GW)*
Outside volcano-prone zone	17.62	0.51	30.43	2.45
KRB I (low)	0.01	0	0.26	0
KRB II (medium)	0.01	0	0.11	0
KRB III (high)	0.01	0	0.12	0.03

Table 31. Tsunami proneness impact on technical and economic wind energy potential

Proneness level	*Square-grid*		*Point-grid*	
	Technical potential (GW)	*Economic potential (GW)*	*Technical potential (GW)*	*Economic potential (GW)*
Outside tsunami-prone zone	17.64	0.51	30.88	2.48
Medium	0	0	0.01	0
High	0	0	0.04	0

F. Validation interview questions

Introductory questions

- Could you please share the role and expertise of your company/organization in wind energy and electricity sector?
- How do you see the role being played by wind energy for power generation in Indonesia?
- What is your opinion on Indonesia's wind energy development as of now?

Theme 1: Validation of stakeholder analysis

- What is your opinion of this chart?
    - Do you agree with how the actors are laid out in the chart?
- How to make this chart more complete?

Theme 2: Validation of institutional barriers

- What is your view on these barriers?
    - To what extent do you agree with these barriers?
    - In your opinion, which barrier is more significant than the others?
    - Could you please tell me of other institutional or other barriers that might have been overlooked by this study?
- How do recent developments – such as bills and draft regulations, and the recently enacted Omnibus Law – influence (alleviate or exacerbate) these issues?

Theme 3: Validation of institutional recommendations

- Do you agree with these proposed changes?
    - Do you think these proposed changes will be effective in alleviating the barriers? And why?
    - If not, what can be added/modified to these recommendations?
- How could the proposed changes be implemented?
    - What are the necessary preconditions to facilitate the proposed changes?
- What are the possible issues that may arise if/when these recommendations are implemented?
- Do you have additional suggestions on institutional changes to overcome the barriers?

Closing questions

- How do you see Indonesia's wind energy development in the future?
- Is Indonesia moving in the right direction in terms of enabling wind energy development?

G. Validation interview summary

Interview 1: Brent Elemans (Pondera Consult)

Respondent profile

Brent Elemans is a Business Developer at Pondera Consult, a consultancy and engineering company for wind and solar PV development based in the Netherlands. Their services include studies on permitting for wind and solar farms, wind resource assessments, and project contracting/tendering. The company also acts as a developer in some countries including Indonesia.

Views on Indonesia’s wind energy sector

- Indonesia is not the best country for wind energy. There are some good locations for wind power generation, but they are limited. Looking at the major challenge Indonesia faces in the energy transition, wind should still play a role in future energy system.
- There is not always a best match between energy demand and supply at certain locations such as Papua. In the future, there is an opportunity of phasing-out diesel power plants by producing green hydrogen, e.g. in Papua, and then transporting the hydrogen to demand centers.
- There were high hopes for wind energy development in Indonesia when Sidrap and Tolo-1 WPP were established. PLN then started some tendering on wind energy projects such as in Tanah Laut. However, the tendering stopped during the COVID-19 pandemic. Since then, there is no new policy in wind energy. The actors seem to wait for the new Presidential Regulation on RE-based electricity tariff. The regulation should have been enacted a year ago, but it is yet to be legislated. Having a start-stop policy regime deters the motivation of private parties in RE. The rules of the game are not consistent and transparent. A steady policy is needed: an example is to implement a certain policy for 5 years, and then evaluate its performance. An integral approach should be taken to drive RE development.

Validation of stakeholder analysis

- The chart is extensive: it shows that there are many actors involved.
- Based on his experience in Sumba Island, PLN headquarters has the final say on the RUPTL. The regional government can make a request on the RUPTL content, however, eventually PLN headquarters makes the decision.
- According to the chart, DGNREEC has a dead end. DGE seems to have more decision-making authority in electricity. This may be a flaw in the system: there is a lack of influence from DGNREEC in the decision-making process. DGNREEC probably does not have enough power to push for RE development. Furthermore, it is not really clear what role they can play in the development.
- The difference between IPPs and investors are: IPPs take initiative for the development of new projects, and in turn, they invite financier/investors. Therefore, IPPs and investors work in that order.
- On the missing actors from the chart:
  - Foreign bodies (e.g. foreign governments and embassies) can have influence on the system: they can stimulate cooperation projects involving foreign companies through government-to-government relationship.
  - Ministry of Marine Affairs and Fisheries will probably be in charge of policymaking on offshore wind. There is currently no policy for offshore wind.

Validation of institutional barriers

- On electricity pricing: It is true that RE can meet the high demand in densely-populated islands such as Java and Sumatera. However, the low BPP at these islands does not favor RE development. The BPP-pegged scheme pushes RE development to the eastern part of Indonesia. The downsides of carbon emission, e.g. air pollution and health repercussions, are indeed not considered in the cost of energy production.

- On generation infrastructure planning:
    - RUPTL content is determined by both IPPs' proposals and the Government's initiatives. IPPs can influence the content by lobbying the Government, and thus, RUPTL is not only determined by a top-down approach.
    - There should be a market system in which the private sector can make initiatives. It should be more transparent than the current system. Currently, the system relies on competition: a project in RUPTL may not be awarded to the initiator.
    - Grid planning is something that cannot be overlooked in advancing RE. Grids adjacent to WPPs may not be sufficient to accept the large amount of generated electricity. This can eventually become a problem and a bottleneck in Indonesia. Connecting the islands through subsea cables entails an expensive cost, but it may be necessary for certain distances (e.g. Java – Bali).
- On property rights allocation:
    - Land acquisition is a challenging process in Indonesia. Land lease may be possible, but it may not be a part of the system just yet.
    - Ownership transfer at the end of concession period in BOOT cooperation scheme only allocates the risk to the developer, and not to PLN. Although BOOT is no longer mandatory, there are still concept PPAs that include this scheme. WPP can be bought by PLN at the end of project lifetime, but the price has to be set by considering future profits, and not only the cost of the WPP.
    - Restriction of foreign ownership is also a challenge for IPPs because it forces them to sell some shares of the project. However, the omnibus law is expected to alleviate this issue. The law is helpful for foreign investors.
- On governance in contracts:
    - Before PPA signing:
        - With the Presidential Regulation on electricity pricing coming up, PLN decided not to start any negotiations. Previously, having negotiations with PLN on the PPA tariff does not feel really 'honest' because of PLN's monopoly. Negotiating with the party having all the power is not really a 'negotiation', because PLN can set the price they want.
        - PLN's dependence on government subsidies is not a barrier for IPPs, but the dependence affects how PLN acts.
        - In a PPA negotiation, the conditions within PPA are negotiable in general. However, it is not transparent on which standard is being used to base the PPA draft.
    - After PPA signing:
        - If a PPA is established, it is questionable whether IPPs have the power to stand against PLN in enforcing the contract. This can soon result in a legal case if any problem arises. Good contract management can prevent this from happening. However, if IPPs are forced to accept PPA terms during the negotiation because of PLN's power, then it can create problems afterwards.
        - PPA would only be signed with a 'per-kWh' price that will make a project economically viable (a 'green' business case). Communications with financiers on business case parameters are done in parallel with the PPA negotiation. Therefore, this barrier is unlikely to happen after PPA signing. Instead, the barrier is actually in getting the PPA agreed and signed: it happens before PPA signing.
        - Financing for RE projects is not really limited because there are financing institutions providing this service, and even more in the coming years. For example, ADB used to finance gas-fired power plants in Indonesia, but they are no longer doing so. They

        become green investors. They have certain conditions that must be met so that the PPA can be signed, and the project can be funded.
        - Financing could become an issue if something changes in the business case, e.g. changing laws in import tax. This problem does not come from the PPA; PPA should be finance-proof.
- On additional barriers not included in the study:
    - Local content restriction is a barrier for wind energy development. Wind turbine is a tailor-made product imported from abroad. It is hard to have wind turbines with high quality and standards to be constructed in Indonesia, especially for the first steps. If there is more WPP deployment in Indonesia, then there might be an incentive for (wind turbine) tower manufacturers to construct their products in Indonesia. But for now, the high percentage of local content acts as a barrier. In the present state, only the concrete foundation can be made locally. However, this is only a small part of a wind energy project investment.
    - The intermittency of wind energy mandates a study on how the grid will accept the electricity. Stabilizing/smoothening the grid will require batteries, which is very expensive at this moment. However, the whole tariff system does not clarity on who is going to pay for the cost of batteries. Are they included in the PPA tariff? Including the cost in IPPs business case can make the case economically unattractive. In the Netherlands, the grid operator is responsible for providing the batteries. In Indonesia, it is not yet clear.
- The two additional barriers are separate from the barriers found in this study. The latter barriers need to be solved first before the additional barriers can be addressed. However, these additional barriers can be a bottleneck for future WPP deployment.

Validation of institutional recommendations

- All the recommendations can help to solve the barriers.
- There is a strong lobby from the coal sector in the policymaking on energy. Having a regulator as an independent referee may help to overcome this practice.
- There is a certain protectionism in Indonesia: on one hand, Indonesia needs foreign investors and IPPs for RE development. However, some regulations (e.g. local content restriction) do not make it easy for foreign parties to settle in Indonesia. Protectionism in policies is understandable, but policies should be well-balanced to entice foreign parties. Project takeovers from foreign IPPs by powerful companies with government-backing also happens in this sector. Therefore, this discourages foreign companies to come to Indonesia.
- In Indonesia, promotion of local ownership may be hindered by the economic capability of the people living nearby the WPP. It requires a long-term view to invest in a WPP, which might not be acceptable for the less-wealthy people. Policies should consider giving the people a compensation for the negative impacts of WPP (e.g. visual pollution). Moreover, the local content policy should include ‘investing’ in the local community, not just to oblige manufacturing locally. For instance, it can be done by establishing education centers about RE.
- Preconditions for enabling the recommendations:
    - There should be a willingness to evaluate and shuffle the current actor/stakeholder structure. Many ministries and bodies are involved in the RE sector as a result of time. Governance structure shall be changed: should there by a regulator? Can some bodies be combined?
    - Energy transition will cost a lot of money. What should become clear for the Government is that the downsides of keeping the status-quo, i.e. negative externalities of the current energy system. These externalities must be taken into account to understand the importance of

energy transition. The younger people interested in RE should be given an opportunity to have a say about the importance of such transition.

- Indonesia needs to become open to and keep up with RE innovations. They need the international companies to show novel technologies. For instance, Indonesia can become a front-runner in hydrogen technology because it is well-suited to the Indonesian context. Indonesia should give foreign companies an opportunity to practice the technology on their own risk. This also requires policymaking to drive technology implementation, instead of having the technology adjusted to the existing policies.

Interview 2: Martha Maulidia, PhD (IISD)

Respondent profile

Martha Maulidia is an independent researcher on climate and energy policy. She is affiliated with the Global Subsidies Initiative of International Institute for Sustainable Development (IISD) as an energy policy consultant. IISD is a think-tank based in Switzerland.

Views on Indonesia's wind energy sector

- Wind energy and other RE are expected to become increasingly integrated in Indonesia's power system. The current utilization of these energies is much less than their potentials.
- Recently, Indonesia is formulating a net-zero emission target. The focus in the energy sector is placed on electricity. With the phasing-out of coal, wind power generation is expected to be escalated in the future.
- As of now, there is a technical barrier of PLN: their infrastructure cannot absorb much electricity generated from intermittent RE. PLN sets a limit of maximum 10% of electricity being supplied from intermittent RE in their grids.
- Sidrap WPP and Tolo-1 WPP are examples of how the private sector succeeded in engaging high-level government officials, including the President. These projects involve all stakeholders, e.g. the President, the ministries, and the National Land Agency (to deal with land acquisition issues). There was cross-sectoral coordination among stakeholders in realizing the projects. However, it turned out that some stakeholders are bearing losses. For instance, PLN is experiencing losses due to the increased share of intermittent RE in the power supply. This needs to be mitigated in the future: while other parties are benefitting from these projects, some parties are left with the losses.
- There are positive implications of the omnibus law for the electricity sector, especially for IPPs. For instance, *Business Area* restriction for IPPs is loosened: they can generate power in one *Business Area* and in turn, transmit the power to another region at another *Business Area*.
- The potential negative repercussions of the omnibus law pertain to the environment and the society: investors who are benefitted by this law may not put enough consideration on environmental, social, and governance criteria.

Validation of stakeholder analysis

- The chart already comprehensively describes the actors and their relationships. It sufficiently depicts the government stakeholders. Adding other stakeholders may overcomplicate the chart.
- As shown by the chart, PLN is squeezed by the interests of the ministries. In reality, PLN reports to MSOE instead of MEMR. Moreover, PLN usually prioritizes MSOE's mandates. Therefore, a straight line (instead of a converging line) from MSOE to PLN can be displayed in the chart. (*Note: this suggestion has been implemented in the formal chart as reported in this study.)*

Validation of institutional barriers

- She agrees with the barriers identified in this study. Electricity pricing and infrastructure planning are especially relevant because they impede RE development in Indonesia.
- Electricity pricing policies are quite vague: even if the forthcoming Presidential Regulation draft on the pricing's amendment is legislated after being delayed for some time, the regulation may not solve all the problems in this sector.
- BPP-pegged pricing is indeed problematic. PLN has multiple roles as the single buyer of electricity. Even if RE is made a priority for power generation by law, PLN might not be able to overcome the barriers to RE development. This is due to an underlying issue concerning PLN's revenue model. PLN's revenue is sourced from the consumers' payment on electricity based on a government-determined

price. However, the price is lower than the cost of power generation and the amount of payment to IPPs. This price difference creates a more fundamental issue than the electricity pricing itself.

- There are two important aspects related to PLN's revenue model:
    - Electricity law: In the past, an electricity law reform which introduces liberalization was annulled by the Supreme Court.
    - Political tenets: Indonesian politicians share the objective of providing as-cheap-as-possible electricity for the people. In this context, 'cheap' has a different meaning than 'affordable'. The politicians need to review their understanding of energy affordability: it does not mean the cheapest price per se, but it should consider negative externalities of power generation.
- Some people argue that PLN can still make their business processes more efficient. However, she argues that both the Government and PLN need to improve their governance in this sector.
- The circulating Presidential Regulation draft states that the Government will compensate PLN for the price difference. Nevertheless, there is a clause which stipulates that the compensation is subject to the Government's financial situation. This clause is not agreed by PLN since it would further exacerbate the company's financial health.
- Out of the four identified barriers, electricity pricing is the most significant barrier. The pricing issue is closely tied to PLN's revenue model. Having a rationed budget does not allow PLN to make new investments, which are expected to increase PLN's business efficiency.
- PLN and MEMR are not the only parties being responsible for infrastructure planning. The planning involves a wider range of stakeholders. For example, Bappenas (the Ministry of National Development Planning) is involved at the national level.
- In reality, the planning is highly centralized and dominated by PLN, who is also mandated by law to execute the task. Consequently, infrastructure plans are not delegated to the regional-level governments. In turn, this practice hampers RE development. RE is known for the small-scale and distributed power generation. Regionalization in planning can benefit the development of distributed RE-based power generation.
- After signing a PPA, PLN is locked in a take-or-pay contract. This is a barrier not only for RE, but also power generation using other energy sources. This type of contract is aimed at enticing private sector investment. However, with the recent drop of electricity demand, a take-or-pay contract puts a burden on PLN's finances. Thus, utility companies worldwide are arguably avoiding this long-term contract for now and in the near future. Furthermore, recently signed PPAs are renegotiated by PLN.
- PPA standard for RE in general (not only intermittent RE) is still awaited by the stakeholders. Studies are being conducted to design and standardize a PPA that can support RE development without imposing a huge burden on PLN's and the state's finances. Introducing the standard may be an opportunity to provide an alternative to the take-or-pay scheme. The alternative scheme entails a multi-level FiT: different FiT levels are employed throughout the different periods within the project lifetime. Such scheme can benefit PLN and IPPs simultaneously.

Validation of institutional recommendations

- In general, the proposed masterplan resembles the Presidential Regulation draft on electricity pricing. The draft regulation is not yet enacted because PLN objects the conditional clause on receiving a compensation from the Government. Furthermore, the masterplan would be an interesting topic for further research, e.g. on the respective duration of FiT and reverse auction implementation.
- Based on her research, there is a mixed response from the stakeholders on the establishment of the regulatory body. Around 50% of the stakeholders view that introducing the regulator will not be effective in increasing RE market share in Indonesia. The remaining 50%, however, think otherwise.

Those who perceive the regulator as an ineffective solution points to the importance of firstly solving the fundamental barriers, such as PLN's revenue model.

- In reality, MEMR must consult with PLN when devising policies and making decisions in the electricity sector. Moreover, PLN's recommendations are usually taken as the final decision of MEMR, since the policy cannot be implemented without PLN's cooperation. Having an independent regulator may solve this issue.
- On creating new funding sources for subsidizing PLN:
    - Indonesian politics do not favor 'earmarking' in the budgetary practices. The Government's subsidy allocation is restructured over time (e.g. electricity price adjustments for consumers and removal of liquified-petroleum gas subsidy). However, the problem is that the reallocated funds cannot be easily earmarked to support RE development.
    - A Presidential Regulation on carbon pricing is anticipated to provide a strong support for ETS' implementation. The regulation is still under review by the Government.
- Promoting local ownership supports the founding of a sustainable model of RE development.
- On preconditions for the proposed recommendations' implementation:
    - Establishing the masterplan would require the legislation of the forthcoming Presidential Regulation. The masterplan can be an implementing regulation of the Presidential Regulation.
    - The proposal to introduce the regulator have been studied by international development banks. Learning for the experience of Australia, having the regulator can pave way for electricity sector liberalization in the future.
    - Earmarking would be a challenge for reallocating fossil-fuel subsidies. Moreover, by pledging to have a net-zero emission in the future, PLN can gain more access to funding sources with more beneficial terms. Meanwhile, carbon pricing (ETS and carbon tax) depends on the content of the forthcoming Presidential Regulation.

Interview 3: Agus Tampubolon & Dr. Handriyanti Puspitarini (IESR)

Respondent profile

Agus Tampubolon is the Project Manager of Clean, Affordable and Secure Energy (CASE) at IESR. CASE is a cooperation program between four Southeast Asian countries aimed at driving the transition towards a clean, affordable, and secure energy provision.

Handriyanti Puspitarini is a senior researcher at IESR with an expertise in RE optimization. Her research is on the mapping of RE potentials in Indonesia, including solar, wind, hydropower, and biomass.

IESR is a think-tank based in Indonesia which concentrates on the energy sector, specifically RE. The organization advocates the energy transition from fossil-fuel-fired power generation to RE-based power generation.

Views on Indonesia's wind energy sector

- Wind energy potential in Indonesia is not as large as the potential of solar and hydropower. The latter two energy sources have a huge potential because of Indonesia lies across the equator. Another consequence of being located on the equator is the presence of converging winds blowing from the south and from the north. Hence, there is a high variation of wind resource in Indonesia: wind resources are high during the dry season and low during the rainy season. In turn, this high variation results in the generally low wind energy potential in Indonesia.

Validation of stakeholder analysis

- The chart is already comprehensive.
- To invest in wind energy in Indonesia, IPPs have to report to the Ministry of Investment/BKPM. There are several conditions for investing in wind energy. One of them is the approval from DGE of MEMR, to indicate that the electricity system can accept wind-based electricity. Thus, there might be a relationship between DGE and the Ministry of Investment.
- This chart focuses more on government stakeholders with the addition of PLN, IPPs, and investors. However, there is an actor that might be missing is the Indonesian Wind Energy Association (*Asosiasi Energi Angin Indonesia* or AEAI). With wind energy IPPs as its members, AEAI has an important role in promoting wind energy development.
- Regional governments have a crucial role in providing licenses.
- MF has several directorates that manage the administration of the subsidy to PLN.
- Through the ownership, MSOE determines key performance indicators (KPI) of PLN directors.
- If a long-term view is adopted, Bappenas should be included in the chart. Bappenas devises a national medium-term plan which acts as a framework for the ministries to formulate their respective work plans.

Validation of institutional barriers

- Based on a recent discussion with PLN, IESR learned that the Java-Bali electricity system has an overcapacity of power generation. Hence, PLN would not accept the integration of a new power plant into the system because they are obliged to pay as per PPA although the plant cannot be run at high levels of capacity factor. In other words, PLN would operate the new plant with a loss. Unfortunately, there are still several long-term contracts (PPAs) which have been signed before the overcapacity occurred. These contracts are part of the *35 GW Electricity Development Program*.
- The issue with BOOT cooperation scheme has indeed been resolved by the regulation in 2020. Moreover, if foreign ownership restrictions are removed by the omnibus law, it would be beneficial for future RE development.

- There is no PPA standard in a contract format for all RE sources. Based on interviews with financiers, one of the issues with financing IPPs for RE projects is the disparity of PPA standards observed across IPPs. As far as he is concerned, PLN does not provide a standard for PPA. Consequently, financiers proposed the Government to formulate such standard.
- On other barriers hampering wind energy development:
    - Grid stability and readiness to accept intermittent electricity from WPP becomes an issue for wind energy development in Indonesia. The grid cannot receive surplus energy from WPPs. For instance, a WPP in Nusa Penida, Bali only operated for two years because of the lack of a feasibility study before the project was commissioned. Thus, the electricity production from the WPP is below stakeholders' expectations during the planning phase.
    - For regions where overcapacity does not occur, such as Sulawesi Selatan, the problem lies in stabilizing the electricity system with the flow of intermittent electricity. For example, commissioning of the WPP in Jeneponto (Tolo-1 WPP) was postponed because PLN was waiting for the commissioning of Poso hydropower plant. The hydropower plant is important to address the load swing stemming from Tolo-1 WPP. Moreover, the PPA for Tolo-1 WPP does not include any provisions on battery energy storage. To conclude, the system's capability to accept intermittent electricity becomes important for future WPP deployment. Importantly, not many electricity systems in Indonesia have this capability. The Java-Bali system has this capability; however, the state of overcapacity hinders intermittent power plant integration into the system.
    - Local content is an issue for solar energy projects. This can also be an issue for wind energy projects.

Validation of institutional recommendations

- On the masterplan:
    - The plan needs to include a clearly-defined capacity quota for wind energy, such as done in the solar auctions. This provides transparency for investors.
    - Having the consecutive implementation of FiT and reverse auction is indeed necessary. However, what is also needed is the determination of locations with wind energy potential, as is done by this study. This will help the investors to engage in wind energy projects.
    - The plan can also be complemented by a masterplan for other RE sources which can balance wind energy's intermittency. Thus, the energy system plan for provinces with promising wind energy potential can be focused on wind energy development, while still being synchronized with the plan to develop supporting (grid-stabilizing) power plants.
- On the regulatory body:
    - The actor that should be responsible for ensuring progress in the transition to RE is NEC. The authority of NEC can be equipped to act as the regulator. For example, NEC can monitor the progress of WPP deployment based on the initially-made plans. Conceiving a new regulatory body may be redundant given the presence of NEC. It is thus better to optimize the role of existing bodies in this sector, including PLN.
- On the new funding sources for subsidizing PLN:
    - This proposal is aligned with IESR's studies. However, IESR proposed the creation of an RE fund, instead of subsidizing PLN. For instance, IESR proposed to make coal export tax revenue as the source of RE fund.
    - The fund is channeled to IPPs (instead of PLN) as a loan with a competitive interest rate. By lowering the interest rate, the electricity selling price to PLN can be reduced.
- On other recommendations:

   - As of now, private sector involvement is focused on power production. However, another major issue in Indonesia pertains to electricity transmission. To his knowledge, foreign/private sector investment on electricity transmission is governed more strictly compared to on the electricity generation. Investment of electricity transmission has to be done via PLN. Given the pivotal role of the transmission infrastructure in the future energy system, a study can be conducted on how to loosen the restrictions for the investment.