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Review

# Review of Renewable Energy Potentials in Indonesia and Their Contribution to a 100% Renewable Electricity System

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**Abstract:** Indonesia has an increasing electricity demand that is mostly met with fossil fuels. Although Indonesia plans to ramp up Renewable Energy Technologies (RET), implementation has been slow. This is unfortunate, as the RET potential in Indonesia might be higher than currently assumed given the archipelago's size. However, there is no literature overview of RET potentials in Indonesia and to what extent they can meet current and future electricity demand coverage. This paper reviews contemporary literature on the potential of nine RET in Indonesia and analyses their impact in terms of area and demand coverage. The study concludes that Indonesia hosts massive amounts of renewable energy resources on both land and sea. The potentials in the academic and industrial literature tend to be considerably larger than the ones from the Indonesian Energy Ministry on which current energy policies are based. Moreover, these potentials could enable a 100% renewables electricity system and meet future demand with limited impact on land availability. Nonetheless, the review showed that the research topic is still under-researched with three detected knowledge gaps, namely the lack of (i) economic RET potentials, (ii) research on the integrated spatial potential mapping of several RET and (iii) empirical data on natural resources. Lastly, this study provides research and policy recommendations to promote RET in Indonesia.

**Keywords:** renewable energy; potential; Indonesia; literature review; 100% renewables; scenario



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## 1. Introduction

Indonesia is a strongly growing country and could become the world's 4th largest economy by 2050 [1]. This development is reflected by Indonesia's rapidly increasing electricity demand of more than 6% p.a. since 2000 [2,3]. Until now, the archipelago mostly depends on its abundant domestic resources of coal and natural gas to meet this demand [4]. Nevertheless, Indonesia has committed to the energy transition via the national energy plan (Rencana Umum Energi Nasional—RUEN) and targets a share of Renewable Energy Technologies (RET) in the energy mix of 23% and 31% by 2025 and 2050, respectively [5].

Large hydropower, geothermal and biomass are already substantial parts of Indonesia's electricity mix with 17.3% in 2018 [4]. In contrast, the shares of alternatives like solar photovoltaics (PV) and wind power are considerably lower, while ocean energy has not been implemented at all. The reasons for the stagnant development of the latter technologies are manifold, including lack of experience, limited grid flexibility to balance intermittent power production [6–9] as well as opaque and incomplete pricing schemes, investment-repelling regulation and complicated, time-consuming licensing processes [5]. Notwithstanding, the implementation of RET might benefit from a more comprehensive and accurate overview of their potential in Indonesia. With such an overview, it would be possible to assess how much current and future electricity demand could be covered with RET. Moreover, energy scenarios like a 100% renewable electricity system and its requirements like land area could be deduced. With these insights, it would be possible to evaluate whether current RET implementation goals are in line with the potentials and

whether adjustments are needed. To our knowledge, such an overview does not exist yet in literature. Therefore, this paper aims to address the following research question:

What is the state of contemporary literature on RET potentials for electricity production in Indonesia and to what extent could these potentials meet current and future electricity demands?

To answer the research question, existing academic, industrial, and governmental literature on the potentials of nine RET in Indonesia is reviewed. The focus is set on the provincial and national level and distinctions are made between the theoretical, technical, practical, and economic potential as shown in Table 1. Moreover, this study critically analyses what is necessary to activate these potentials in terms of required land areas, and indicates the impact of the potentials on current and future electricity demand. Light is also shed on how implementation proceeded compared to the plans expressed in the RUEN.

The scientific contribution of this work is not only to provide an overview of existing literature on RET potentials in Indonesia but also to critically put them into perspective in terms of impact and realisation requirements. Moreover, this study aims to raise awareness to researchers, policymakers, and investors about Indonesia as a country that not only hosts a diverse set of renewable resources but also has a large and rising energy demand to match these resources. By discovering current knowledge gaps in the literature, future research directed towards these gaps might contribute to knowledge on both Indonesia's energy transition and climate change mitigation with benefits beyond national borders. Therefore, the results also have significant policy relevance.

The paper is organised as follows. Section 2 elaborates on the methods to search and select literature as well as defining the boundaries of the review. Section 3 presents the results of the literature review, followed by a critical discussion in Section 4. The paper ends with a conclusion and recommendations in Sections 5 and 6, respectively.

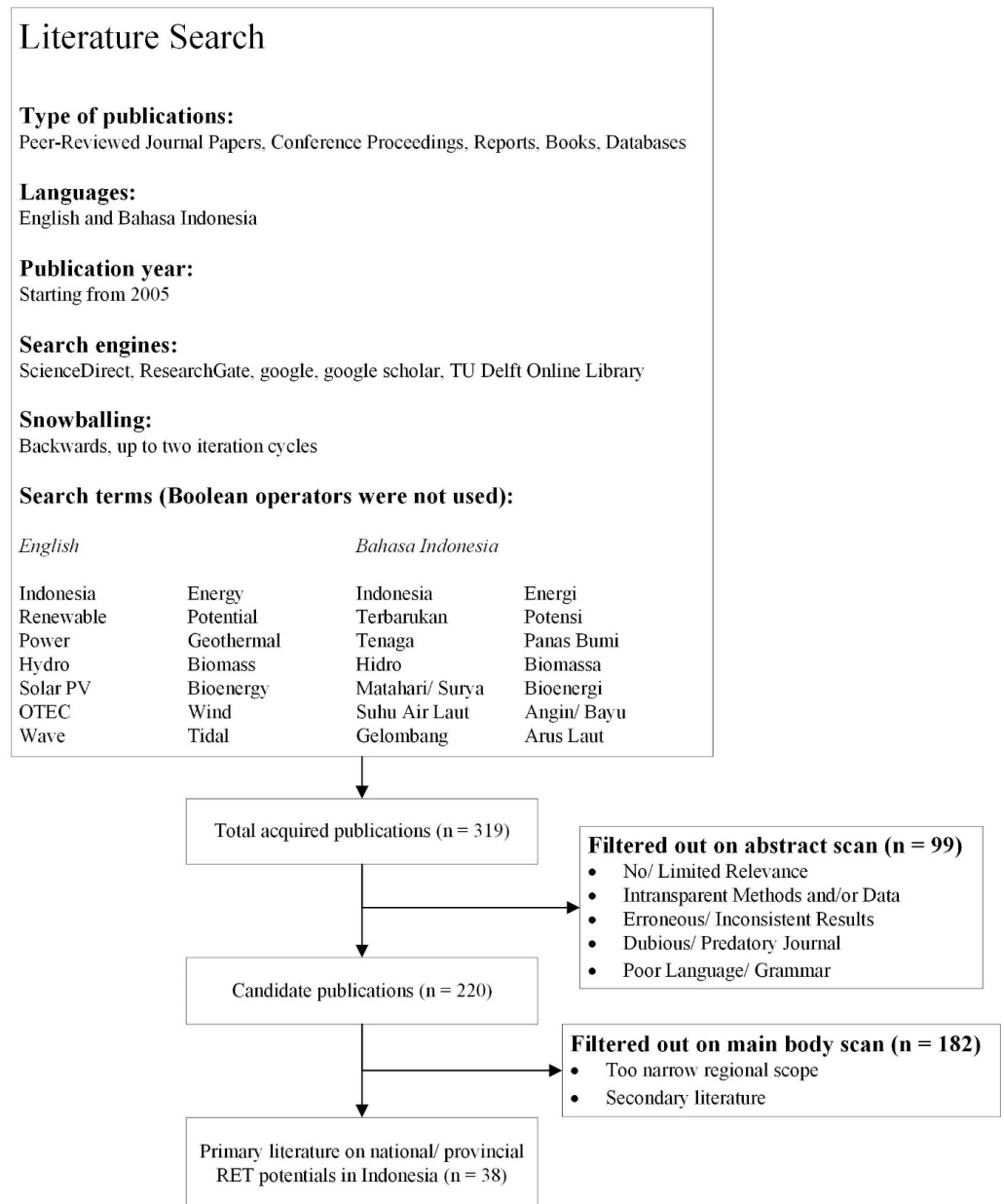
## 2. Materials and Methods

An overview of the literature review is depicted in Figure 1. Backwards snowballing was used to trace primary literature with a maximum of two iteration cycles. Regarding language and grammar, studies were left out if the main message of the reviewed publication could not be unequivocally reconstructed. In case a study was filtered out on abstract scan, it was still fully read if its content was helpful to convey the storyline of this paper. Thus, the elaborations in the following sections are not only based on the 38 extracted studies in Figure 1. Out of the 38 reviewed studies, 4 come from the Ministry of Energy and Natural Resources (Kementerian Energi dan Sumber Daya Mineral—ESDM), 5 from industrial sources and 29 from academic literature. 22 publications focus on the national, 6 on the global level, and 5 studies each on the provincial and inter-provincial, regional level. Regarding the technologies, 7 studies each were about a set of RET and solar PV, 6 studies were about biomass, 5 studies each were about wave energy and tidal current and 2 studies each were about hydropower, OTEC, offshore wind and geothermal. 34 studies are in English, 4 in Indonesian (Bahasa Indonesia).

Figure 1 shows that 182 studies were filtered out due to being secondary literature or too regional scope. This study aims to draw insights from potential studies that can be scaled to the global or at least provincial level. Local case studies might not be scalable to such an extent, especially for locally sensitive technologies like wind power, which is why they are excluded here. Nonetheless, it is acknowledged that localised RET research is highly important, as decentralised RET can be a gateway for community empowerment and local socio-economic development [10,11].

The nine reviewed technologies comprise geothermal, large and small hydropower, biomass, solar PV, wind power as well as tidal power, wave energy and Ocean Thermal Energy Conversion (OTEC). In literature, the potential of these technologies is studied on different levels based on different definitions as Table 1 shows. To maintain consistency, this study uses the definitions found in academic and industrial literature, as these are broken down more distinctly compared to those of the ESDM. The ministry's potentials

are adjusted where necessary to make them comparable. ESDM's technical and practical potentials are summarised as technical potentials and the acceptable potential becomes the practical potential. ESDM's theoretical and economic potentials are assumed to remain unchanged. The values drawn from the Global Energy Resource Database by Royal Dutch Shell are based on "[... ] an estimate of the *realistic*, or constrained, technical potential, which accounts for technical as well as non-technical limitations [...]" [12] (p. 240). Hence, the realistic potentials listed in the database are labelled as practical potentials here.



**Figure 1.** Methods used for the systematic literature review on RET potentials in Indonesia.

In this paper, the potentials found in literature are shown in their original physical units and converted to  $\text{GW}_e$  to make them comparable. In the case of units of energy, the potential is converted to  $\text{GW}_e$  using average generation efficiencies (electricity output divided by primary energy input) and capacity factors (generated electricity divided by installed capacity and 8760 h/year) of Indonesian power plants based on the statistics provided by ESDM [2].

Unless stated otherwise, this literature review focuses on RET for electricity production, while other applications such as heat, cold and transportation are excluded. Moreover,

the state of the art of individual technologies and power plants is not reviewed as such works already exist as pointed out in the respective sub-sections. The review of energy statistics is limited to the context of RET since general statistics for the whole Indonesian energy system were covered recently [6,9,13,14].

**Table 1.** Different definitions of potentials found in literature.

	Academic and Industrial Literature [15–17] (Terminology Used in This Study)	Reports by ESDM [18]
Theoretical Potential	Potential restricted by physical limits (e.g., Carnot efficiency for thermal power plants, Betz limit for wind turbines, etc.)	Potential based on field data via a modelling system
Technical Potential	Potential restricted by technical limits (e.g., geo- and oceanographic restrictions, electrical and mechanical efficiencies, etc.)	Identified potential that can be implemented at a certain location
Practical Potential	Potential restricted by non-technical limits (e.g., protection zones and tourist areas)	Identified potential that can be implemented at a certain location based on long-term data
Acceptable Potential	-	Potential that considers demand, infrastructure, and communal approval
Economic Potential	Potential with unit costs equal to or lower than benchmark (e.g., wholesale electricity price)	Potential that can be actually utilised

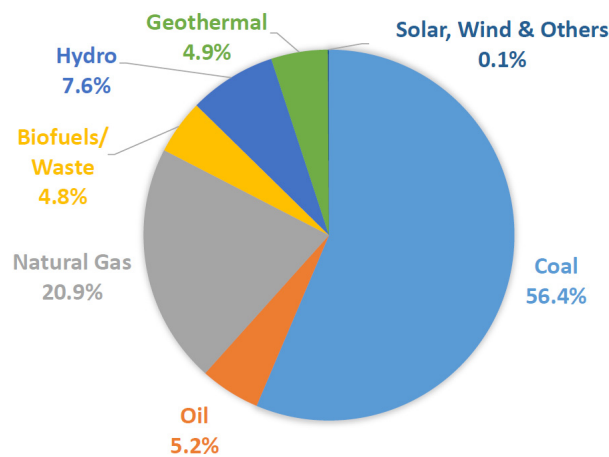
### 3. Results

#### 3.1. RET in Indonesia and Development Plans

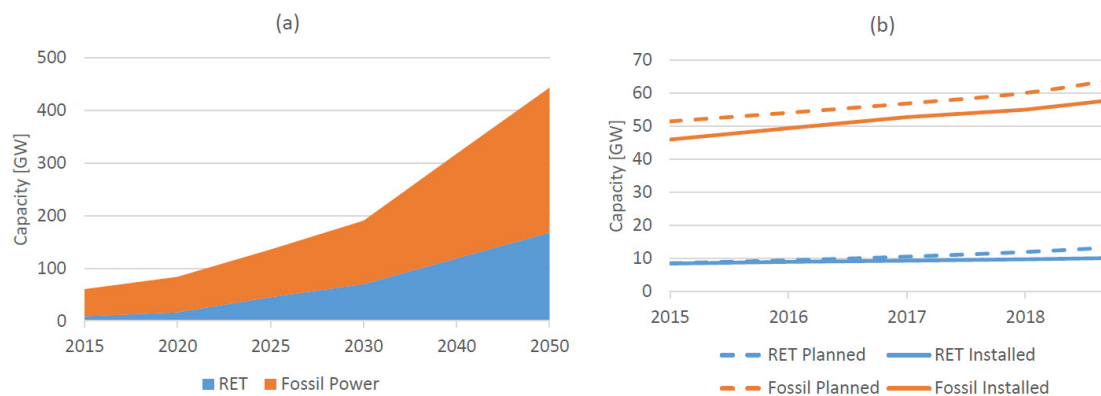
In 2018, Indonesia's share of RET in the electricity mix was 17.4% as shown in Figure 2. The Levelized Cost of Electricity (LCOE) of renewables and their competitiveness against fossil-fuelled generators in Indonesia are shown in Table 2. What the most prominent RET in Indonesia, namely large hydropower, geothermal and biomass, have in common is their non-intermittent power production. In contrast, fluctuating RET like solar PV and wind power are still at an early stage of implementation in Indonesia [2]. But this might change with the government's current capacity development targets. Indonesia plans to ramp up the total installed capacity from 65 GW in 2018 to 443 GW until 2050, 168 GW of which from RET, as shown in Figure 3a. Moreover, Indonesia's electricity demand is expected to rise from 258 TWh in 2018 [4] to 2046 TWh in 2050 [5,19]. Despite the ambition to develop RET in the Indonesian electricity system, the dominance of fossil fuels would not end with the RUEN but get stronger as illustrated in Figure 3a. So far, both fossil and renewable capacity are not implemented as planned in the RUEN as seen in Figure 3b, at least in absolute terms. In relative terms, fossil capacity was developed at the planned annual rate of roughly 6%, while RET only grew by 5% per year instead of the planned 9%. This suggests that implementation targets might generally be set too high and that the development of fossil capacity proceeds smoother compared to renewable capacity.

**Table 2.** The levelized cost of electricity of renewables and fossil-fuelled generators in Indonesia. Values for OTEC based on [20], values for all other technologies based on [21].

Technology	Levelized Cost of Electricity [US¢/kWh]
Open-Cycle Gas Turbine	9.2–12.94
Combined-Cycle Gas Turbine	6.69–8.93
Coal Mine Mouth	5.01–7.31
Coal Sub Critical	6.11–8.41
Coal Super Critical	5.77–8.05
Coal Ultra Super Critical	5.83–8.38
Onshore Wind	7.39–16.1
Utility Scale Solar	5.84–10.28
Geothermal	4.56–8.7
Biomass	4.68–11.4
Ocean Thermal Energy Conversion (Commercial Large-scale plant after 30 years of modelled upscaling.)	6.2–16.8



**Figure 2.** Total electricity supply of Indonesia in 2018 [4].



**Figure 3.** (a) Planned installed capacity based on RUEN [5] and (b) installed vs. planned capacity of fossil and RET until 2019 [2,5].

The following sub-sections show the results of the literature review on RET potentials in Indonesia and the impact of these potentials on demand coverage and area usage if possible. Furthermore, the current developments and barriers of each technology are discussed as well as their roles in the RUEN. Based on these insights, it might be possible to explain why RET implementation does not progress as planned.

### 3.2. Geothermal

Geothermal power plants produce electricity by extracting the heat generated and stored within the Earth at depths of around 1 km and below. According to current estimates, Indonesia hosts around 40% of global geothermal resources due to its location on the ring of fire, an area known for seismic and volcanic activity [22,23]. As of 2019, Indonesia deployed 2.1 GW<sub>e</sub> or 9% of estimated geothermal resources which produced 14 TWh<sub>e</sub>. With such a capacity, the country ranks 2nd in global geothermal implementation behind the USA [24].

Estimates on geothermal potentials in Indonesia mainly come from the Geology Agency of ESDM. In contrast to other RET, geothermal potentials are clustered in two categories, namely resources and reserves. Resources are rough estimations of geothermal heat, which might be exploitable if technical and economic prerequisites are met. Reserves on the other hand only include technically and economically recoverable heat based on geoscience survey tools and empirical data like reservoir temperature and size [25]. The Geology Agency aggregates resources and reserves to get a total [2]. Resources can become reserves if they can be extracted economically and vice versa, reserves can become resources again if detrimental economic developments render their extraction unprofitable.



In 2019, geothermal resources and reserves were 9.3 GW<sub>th</sub> and 14.6 GW<sub>th</sub> [2], respectively. Outside ESDM's work, only one academic study was found that estimated Indonesia's geothermal potential. However, that study did not calculate potentials but proposed a new accounting methodology based on ESDM's values [25]. Additionally, recent literature comprises literature reviews of the geothermal industry in Indonesia [22,23,26,27]. From the industrial side, Royal Dutch Shell [28] indicates practical resources of 1009 PJ<sub>e</sub> per year or 42 GW<sub>e</sub> if a capacity factor of 76% is assumed [2]. With such resources, Indonesia's electricity demand in 2018 [4] and 2050 [5,19] could be covered to 108% and 14%, respectively.

Until 2050, an installed geothermal capacity of 17.5 GW<sub>e</sub> is planned, which is 4% of the total planned RET capacity [5]. For an additional capacity of 15.4 GW<sub>e</sub>, more than 300 new plants would have to be built with an average capacity of 50 MW<sub>e</sub> [2]. This exceeds the current thermal reserves, which implies that some part of the resources must become reserves. To which extent this is possible depends on economic developments and technical availability, as not all thermal resources are suitable for electricity generation [25]. As of now, the installed capacity in 2019 is 15% lower than projected in the RUEN [2]. Current challenges include complications in obtaining land permits, inadequate electricity tariffs, opposition from local communities, limited data availability as well as long lead times of 7–8 years on average amongst others [29].

### 3.3. Hydropower

Hydropower plants convert the energy of moving water into electricity. Depending on the system size, there is large and small hydropower. Although an accepted consensus of 10 MW has emerged as an upper limit for small hydropower, there is no formal definition, leading to regionally variable thresholds [30]. Some works aggregate the potential of both technologies, including Hoes et al. [31] calculating a theoretical potential of 241 GW and Royal Dutch Shell [28] with a practical potential of 205 PJ per year or 15 GW, if a capacity factor of 43% is assumed [2]. In the following, the two technologies are reviewed separately.

#### 3.3.1. Large Hydropower

ESDM currently estimates a theoretical large hydropower potential of 75 GW [32,33], a value obtained in 1983 [34]. From this potential, 30% and 29% are situated in Papua and Kalimantan, respectively [18]. The only reviewed industrial study estimates a practical potential of 26 GW and includes restrictions like protected areas, tourism zones, reservoir size and resettlement of residents [35]. In 2019, roughly 5.6 GW or 7.5% of the theoretical potential was installed resulting in an electricity production of around 21 TWh. Malaysian hydropower is the only type of electricity that is imported to Indonesia. Including 1.7 TWh of these imports, large hydropower's contribution to the total electricity supply was 7.6% in 2019 [2].

Large hydropower will be an integral part of the Indonesian energy transition according to the RUEN. Until 2050, an additional capacity of 32.5 GW is planned, which is higher than the technical and practical potentials mentioned above. With a resulting capacity of 38 GW in 2050, large hydropower would form 8.6% of total installed capacity, making it the second largest renewable generator in Indonesia in terms of capacity after solar PV [5]. Moreover, 38 GW of large hydropower could cover 55% and 7% of Indonesia's electricity demand in 2018 [4] and 2050 [5,19], respectively. In 2019, implementation exceeded plans by 2% [2].

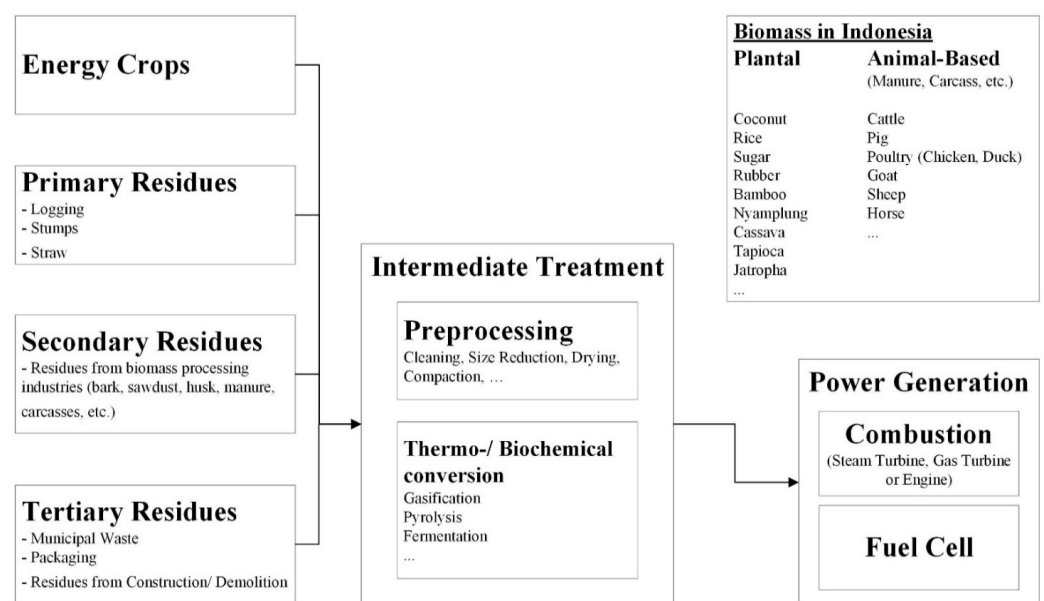
#### 3.3.2. Small Hydropower

Currently, ESDM estimates a theoretical small hydropower potential of around 19.4 GW [18,36]. The highest share of that potential is in East and Central Kalimantan with 18% and 17%, respectively [33]. In 2019, the installed capacity was around 418 MW or 2% of the theoretical potential [2]. In academic literature, small hydropower enjoys more attention than its large counterpart with individual case studies [37–40], a review [41] and a climate change impact study [42].

The rapid upscaling of small hydropower is endorsed in Indonesia due to low costs, local expertise and reliable power production, amongst others [43]. An installed capacity of 7 GW until 2050 is targeted in the RUEN, most of which are in Sumatera, Kalimantan, Java and East Nusa Tenggara [5]. With 7 GW of small hydropower, 10% and 1% of Indonesia's electricity demand in 2018 [4] and 2050 [5,19] could be covered, respectively. However, implementation lagged by roughly 44% in 2019 [2]. Small hydropower is considered key for rural electrification and community empowerment, while reported barriers include lack of foreign investment, access to finance, as well as limited infrastructure [29].

### 3.4. Biomass

In the field of energy, biomass encompasses all renewable plant- and animal-based materials for power and heat production. Figure 4 summarises the different types of biomass available in Indonesia and the options for power generation.



**Figure 4.** Biomass in Indonesia and options for power production (based on [44–49]).

The potential of biomass in Indonesia is studied widely by both governmental and academic research. Table 3 shows current literature on biomass potentials in both their original physical units as well as in terms of thermal energy and electrical capacity. ESDM estimated the potential of biofuels, residues from industrial agriculture and biogas for power generation. Elaborations on the methods and assumptions regarding the conversion from thermal to electrical energy could not be found. Currently, ESDM estimates a theoretical biomass potential of 32.7 GW<sub>e</sub> [36], with most of the resources being located in Sumatera, the Java-Madura-Bali region and Kalimantan with roughly 48%, 28% and 16%, respectively. Palm oil, as well as rice husk, take the largest shares of the potential with 39% and 30%, respectively [18]. Out of the 32.7 GW<sub>e</sub>, municipal waste and biogas from manure comprise potentials of 2.1 GW<sub>e</sub> and 0.5 GW<sub>e</sub>, respectively [18,32].

In academic literature, national theoretical and technical potentials were assessed for solid biomass [45,47,50], biogas [46,51] and bio-methanol for fuel cells [44]. A critical aspect of the sustainability of biomass is its origin. As mentioned above, biomass for energy conversion is primarily produced in palm oil plantations which often renders the local environment a degraded wasteland [52]. Therefore, an increased use of unsustainable biomass for electricity generation might exacerbate deforestation and undermine efforts to make Indonesia's energy system more environmentally friendly. One way to establish sustainable biomass supply chains is the renewed use of degraded land to cultivate plants like bamboo and nyamplung with additional benefits like soil recovery and non-interference with food production [47,50,53]. From a bottom-up perspective, challenges with this option are un-



certain land tenure and local ownership as well conflicting interests between investors and local communities [54]. Although potentials in literature can vary considerably, it can be noted that the biomass potential tends to be the highest for energy crops, amongst others cultivated on degraded land. They could theoretically cover up to 28% of Indonesia's final energy demand and 32% of electricity demand in 2050 [5]. Compared to energy crops, the potential of biomass residues is less high, which is in line with the findings of ESDM.

**Table 3.** Biomass potentials in Indonesia. \* (Co-)firing in steam plants with efficiency and capacity factor of 34.0% and 74.8% respectively. \*\* Combustion in gas plants with efficiency and capacity factor of 38.4% and 18.8%, respectively [2,4]. \*\*\* Density and heat value of methanol 792 kg/m<sup>3</sup> and 22.7 MJ/kg, respectively.

Ref.	Type of Biomass	Origin of Biomass	Type of Potential	Original Unit(s)	Potential	
					Thermal Energy [PJ <sub>th</sub> ]	Capacity [GW <sub>e</sub> ]
			Solid Biomass			
[32]	Primary & Secondary	Agriculture	Theoretical	28.0 GW <sub>e</sub>	1940 *	28.0
[45]	Primary & Secondary	Industrial forestry	Technical	132.2 PJ <sub>th</sub>	132.2	1.9 *
[47]	Energy Crops	Degraded land	Theoretical	1105 PJ <sub>th</sub>	1105	15.9 *
[50]	Energy Crops	Degraded land	Theoretical	5000–7000 PJ <sub>th</sub>	5000–7000	71.9–100.7 *
[28]	Energy Crops, Primary & Secondary	Industrial forestry and agriculture	Practical	1225 PJ <sub>th</sub>	1225	17.6 *
			Biogas			
[32]	Secondary	Manure	Theoretical	535 MW <sub>e</sub>	8.3 **	0.5
[46]	Secondary	Livestock farming	Theoretical Technical	9597.4 Mm <sup>3</sup> /year 1.7 × 10 <sup>10</sup> kWh <sub>e</sub> /year	159.4 **	10.3 **
			Waste-to-Energy			
[18]	Tertiary	Agriculture	Theoretical	2.1 GW <sub>e</sub>	145.7 *	2.1
[51]	Tertiary	Households, industry, etc.	Theoretical Technical	2992 GWh <sub>th</sub> /year 1172 GWh <sub>e</sub> /year 343 MW <sub>e</sub>	10.8	0.3
			Bio-Methanol			
[44]	Primary & Secondary	Natural and industrial forestry	Technical	40–169 × 10 <sup>9</sup> L 42–176 Wh <sub>e</sub> /year 10–42 GW <sub>e</sub>	730–3040 ***	10–42

Recently, the use of biomass for power generation was increased significantly from 0.3% of total generation in 2017 [55] to 4.8% in 2018 [4]. Parts of that share come from the co-firing of biomass in coal plants, which is perceived as one of the cheaper options to promote the energy transition [48]. First tests have already been conducted by ESDM with positive results [56]. However, its feasibility for small-scale, rural application still needs to be addressed [54]. Moreover, there might be lock-in effects for coal-based power generation, as current co-firing plants are designed for a biomass rate of only 10–15% [57]. In the RUEN, a ramp-up to 26 GW until 2050 is projected, which would encompass 15.5% of the total planned renewable capacity [5]. As of 2019, implementation lags by 15% [2] due to barriers like insufficient tariffs, the resistance of local communities as well as lack of stakeholder coordination [29].

### 3.5. Solar PV

Solar energy can be converted to electricity in numerous ways, e.g., with PV modules on which this section will focus. ESDM estimates a theoretical solar PV potential of 3551 GW<sub>p</sub> [58] with forest areas and 1360 GW<sub>p</sub> [5,18] without forest areas, respectively. The theoretical potential is then multiplied with a uniform efficiency of 15%, resulting in a technical potential of 533 GW<sub>p</sub> [58] with forest areas and 208 GW<sub>p</sub> [5,18,33] without forest areas. Although ESDM only mentions forest areas as an exclusion criterion, their solar PV potential map indicates that conservation areas on land and sea are considered as

well [5]. The largest shares of the photovoltaic power potentials are situated in the West and the North of the country, especially in Sumatera with 32% and Kalimantan with 25%, respectively [18].

However, if forest and conservation areas are the only exclusion criteria, the technical potentials are rather small as shown in Table 4. Assuming an installed capacity of  $150 \text{ W}_p/\text{m}^2$  and using current statistics on total land, forest, water, and conservation areas, the technical solar PV potential would be  $99 \text{ TW}_p$  if the entire eligible area would be covered with solar panels. Only 0.21% of eligible land area and 0.07% of total land area would be needed for  $208 \text{ GW}_p$  which seems conservative. For instance, roughly 0.1% of Germany's total land area was already covered with solar PV in 2019. (Based on installed capacity of  $49 \text{ GW}_p$  [59], power production of  $150 \text{ W}/\text{m}^2$ , and total land area of  $357,386 \text{ km}^2$ .) It could be that ESDM used further exclusion criteria, but these were not confirmed by the reviewed material. Nonetheless, solar PV's prospect of becoming Indonesia's key energy technology is apparent even with ESDM's values. Assuming an annual solar electricity production of  $1377 \text{ kWh}/\text{kW}_p$  [60], the electricity production from  $208 \text{ GW}_p$  would be enough to cover 111% of Indonesia's electricity demand in 2018 [4] and 14% of the projected demand in 2050 [5,19].

**Table 4.** The technical potential of solar PV based on ESDM [5,18,33] and own estimations for maximum land coverage excluding forest, water, and conservation areas.

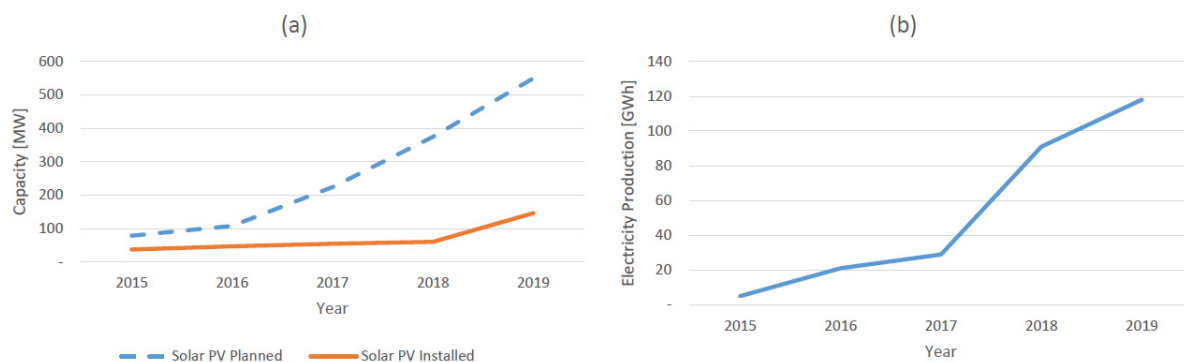
Region	BPS [61]	ESDM	Own Estimation	
	Land Area (Excl. Forest, Water, and Conservation Area) [ $\text{km}^2$ ]	Tech. Potential [ $\text{GW}_p$ ]	Total Area Coverage for ESDM Potentials [%]	Tech. Potential with Land Area [ $\text{GW}_p$ ]
Sumatera	251,603	69	0.070	37,740
Java	96,312	32	0.032	14,447
Bali, East & West Nusa Tenggara	43,870	19	0.019	6581
Kalimantan	176,921	53	0.053	26,538
Sulawesi	53,422	23	0.023	8013
Maluku & North Maluku	14,547	5	0.005	2182
Papua & West Papua	20,991	8	0.008	3149
Total	657,666	208	0.21	98,650

The potentials found in academic and industrial work are much higher than the ones from ESDM and are summarised in Table 5. The Institute for Essential Services Reform (IESR) [62] found a technical potential of  $20 \text{ TW}_p$  while excluding protected and forest areas, water bodies, wetlands, airports, harbours and areas with slopes higher than  $10^\circ$ . With further exclusion criteria like agricultural and settlement areas, a practical potential of  $3.4 \text{ TW}_p$  was calculated, which would cover Indonesia's electricity demand in 2018 [4] 18 times and the projected demand in 2050 twice [5,19]. For such a capacity, 3.4% of Indonesia's suitable land area is necessary. Another industrial estimation on practical solar PV potentials comes from the Royal Dutch Shell Database [28] with  $6569 \text{ PJ}$  or  $1.3 \text{ TW}_p$ .

Solar PV is planned to be the most dominant technology in terms of installed capacity with  $45 \text{ GW}_p$  in 2050, which would be 10.1% of total and 26.8% of renewable capacity. For this, the roofs of up to 30% of government buildings and up to 25% of developed residential housing should be occupied by solar PV. Another plan is the development of a vertically integrated, domestic PV industry [5]. However, solar PV struggles to gain traction in Indonesia today and implementation trails behind by over 73% [2], as shown in Figure 5a.

**Table 5.** Overview of academic and industrial solar PV potential research.

Ref.	Publication Type	Regional Scope	Potential			
			Theoretical	Technical	Practical	Economic
[62]	Report	National	-	20,000	3400	-
[28]	Database	National	-	-	1300	-
[63]	Journal Paper	On-Grid National	-	1100	27	0.4
[64]	Journal Paper	Off-Grid National	-	-	0.8	-
[65]	Journal Paper	National	-	3200 (on-grid) 45,900 (off-grid)	73.3 (on-grid) 0.4 (off-grid)	-
[66]	Journal Paper	West Kalimantan	-	148	-	-
[67]	Journal Paper	West Kalimantan	-	2.0	-	-
[68,69]	Report	Bali	-	80	-	-

**Figure 5.** (a) Planned vs. installed solar PV capacity. (b) Electricity production from solar PV [2,5].

A closer look into ESDM's statistics reveals that the problems mostly come from grid-connected systems. Although off-grid PV systems only comprise 28% of the total installed capacity of 146 MW<sub>p</sub> in 2019, they produced 54% of the total solar electricity production. Based on Figure 5, an average capacity factor as low as 2% underlines the operational problems of some solar PV systems documented in the literature [7,8]. Then again, statistical errors might also be responsible for the low factor, given that Figure 5a,b are not always aligned. On a positive note, solar PV already contributes to the electrification of rural communities. As part of a government programme, over 360,000 solar-powered lamps have been distributed across Indonesian communities [18,70]. These and other efforts seem to pay off and the recorded performance of the off-grid solar system should be an encouragement to promote even more solar systems in Indonesia both on- and off-grid. To do so, several barriers must be tackled, which for solar PV include complications in land ownership, unattractive tariffs and policy support, lack of local experience [29] as well as active resistance from the state-owned utility company Perusahaan Listrik Negara (PLN) [8].

### 3.6. Wind Power

The kinetic energy of moving air can be converted to electricity using wind turbines. ESDM estimated a theoretical and technical onshore wind potential with and without forest and conservation areas. At locations with average wind speeds above 6 m/s, 1 MW wind turbines were assumed with an area requirement of 1 km<sup>2</sup> per turbine. At locations with wind speeds between 4 and 6 m/s, 100 kW turbines with an area requirement of 0.25 km<sup>2</sup> were assumed [71]. The wind speeds were mapped at heights between 30–50 m at 120 locations [18]. Offshore locations were excluded in ESDM's assessments and the differences between potentials were not elaborated. The theoretical and technical potentials of onshore wind are 113.5 GW and 30.8 GW [71] with and 60.6 GW and 18.1 GW [5,18] without forest and conservation areas. Assuming a capacity factor of 36% [2], the latter technical potential would be enough to cover 22% of Indonesia's electricity demand in

2018 [4] and 3% of the projected demand in 2050 [5,19]. Most of the theoretical potential is in Java and East Nusa Tenggara with 38% and 17%, respectively. More comprehensive wind measurements and analyses are recommended to refine the potential [33]. As with solar PV, ESDM's wind potentials might be too conservative for three reasons. First, it is again not clear whether forest and conservation areas were the only spatial restriction areas on land, given that 18 GW of wind power would merely require 2.7% of Indonesia's total land area. Second, the assumed capacity densities might be too pessimistic, as current practice and studies suggest a density of 7 MW/km<sup>2</sup> [12]. Third, the omission of offshore wind removes a vast and otherwise eligible area for wind power deployment. Although there are good reasons to omit offshore wind in some areas, for example interfering shipping routes and high risk of natural catastrophes, no explanation for the exclusion could be found in ESDM's reports.

Rethinking the exclusion of offshore wind might be worthwhile, as academic and industrial sources suggest a far higher offshore than onshore wind potential. Bosch et al. [72] conducted a global offshore wind analysis and calculated a practical potential of 3.0 TW and 8318 TWh in Indonesia, using Economic Exclusive Zones (EEZ), conservation areas, vicinity of marine cables and water depth as exclusion criteria. This potential could cover Indonesia's electricity demand in 2018 [4] 36 times and the projected demand in 2050 [5,19] four times. To implement such a capacity, roughly 8% of the 5,568,600 km<sup>2</sup> [73] of the total available sea area of Indonesia would be required. In the database of Royal Dutch Shell [28], the practical on- and offshore wind resources are 69 and 14,174 PJ, or 6 and 1248 GW with a capacity factor of 36% [2], respectively. In the underlying study of the database [12], floating wind turbines were included up to a water depth of 1000 m. This opens up a new dimension of potential as mounted offshore turbines cannot be implemented at such depths today.

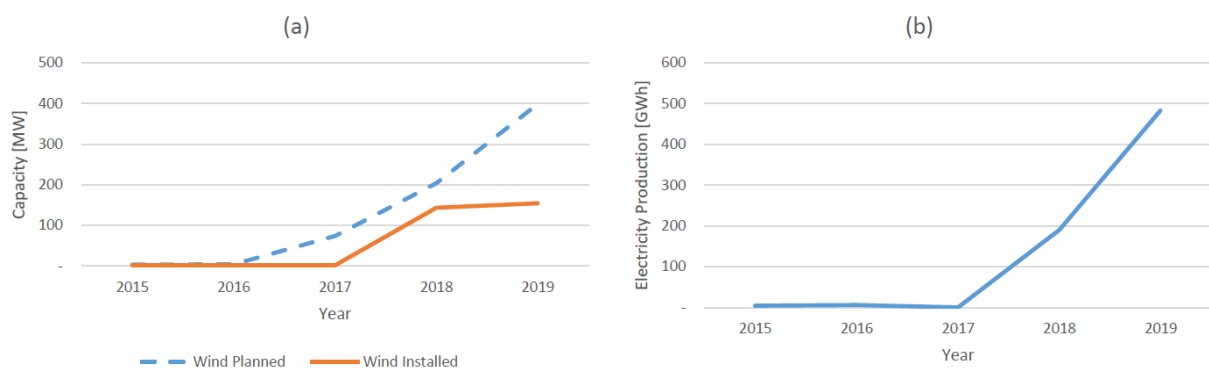
Gernaat et al. [74] estimate a technical offshore potential of 53 EJ, which translates to a capacity of 4668 GW or 260 times ESDM's potential. It is unclear why this potential is so high, given that the water depth and distance to shore were restricted to 80 m and 139 km, respectively, while the other two studies [28,72] above include depths of 1000 m for floating wind turbines and a distance to shore of more than 200 km. There might be differences in input data and limited accuracy due to low-resolution data. In contrast to Deng et al. [12] and Bosch et al. [72], who use wind speed data with a resolution of 19 km and 5 km, respectively, Gernaat et al. [74] do not mention the data resolution, so their estimation could not be checked. No other academic study on the national or provincial potential of wind power was found to validate these numbers. Instead, both international [75–77] and Indonesian [78–80] research tends to focus more on local case studies. Even if Gernaat et al.'s [74] potential would be technically possible, the practical hurdles are very high given that 11% of Indonesia's available sea area would be needed for such a capacity.

Until 2050, 28 GW of wind power are planned to be installed, but Figure 6a shows that implementation lagged by roughly 60% in 2019, notwithstanding a significant growth of electricity production from wind power since 2017 as Figure 6b illustrates [5]. In 2019, 154 MW or 0.25% of ESDM's technical potential were tapped. But as with solar PV, the unaligned development of capacity and electricity production in Figure 6a,b indicate that there might be statistical errors. Current barriers are unattractive tariffs as well as a lack of stakeholder coordination and experience [29]. Besides increasing the quantity and quality of wind resource assessments and feasibility studies, the RUEN calls for the development of wind turbines in isolated regions, outermost islands and at the country borders [5], which might imply wind power's vital role for future rural electrification.

### 3.7. Ocean Energy

Ocean energy is the least developed RET in Indonesia and no commercial plants are operating yet. However, being the largest archipelago worldwide, Indonesia has exceptional potentials to use the energy stored in the ocean, namely through the motion of tides

and waves or the thermal energy of the water. In recent reports of ESDM and the RUEN, the collective theoretical and technical potentials of ocean energy are estimated as 288 GW and 18–72 GW, respectively, though without elaboration on methods, assumptions and distinction between individual technologies [33]. The further assessment and refinement of ocean energy technologies are explicitly encouraged, and their upscaling is currently projected to start in 2025 with a target capacity in 2050 of 6.1 GW [5]. Besides ESDM, the Indonesian Ocean Energy Association (Asosiasi Energi Laut Indonesia—ASELI) assessed the potentials of individual ocean technologies. However, despite being frequently cited in other papers [16,81–83], the underlying study or seminar protocols could not be found. The internet presence of ASELI was not accessible anymore in December 2020. Thus, the primary study from ASELI could unfortunately not be reviewed.



**Figure 6.** (a) Planned vs. installed wind capacity. (b) Electricity production from wind power [2,5].

### 3.7.1. OTEC

OTEC generates electricity using the temperature difference between warm surface and cold deep-sea water. As a tropical archipelago, Indonesia is a very interesting country for OTEC [84–86]. Recently, the practical and economic potential of moored OTEC in Indonesia has been estimated with and without upscaling and technological learning. There, a practical potential of 102 GW<sub>e</sub> is estimated, which would span over 14% of the available marine area. Without upscaling and technological learning, the economic potential is refined to 0–2.0 GW<sub>e</sub> [87] and increases to 6–41 GW<sub>e</sub> if these two important mechanisms are included [20,88]. OTEC could cover up to 22% of Indonesia’s electricity demand in 2050 [5,19]. Besides that, a nominal 100 MW<sub>nom</sub> plant at 20 °C seawater temperature difference could produce around 1200 GWh of electricity annually [89] due to real average temperature differences far higher than 20 °C of up to 25.4 °C [90].

### 3.7.2. Tidal Power

The movement of water caused by the gravitational forces between the Earth, Moon and Sun can be exploited for electricity generation. The only estimation of tidal energy’s theoretical potential in Indonesia originates from an IRENA report [91] in collaboration with ESDM and comprises 18 GW, which would be 6% of the total theoretical ocean energy potential above. Besides that, academic research focuses on local power densities [92–94] and regional potentials [95–99] of tidal current power, while studies on alternatives like tidal barrages could not be found. Among existing literature, the most researched sites are the straits in Bali, Lombok, Larantuka and Alas. In Alas, the technical potential could be as high as 2.3 GW, while Larantuka and Bali could have technical potentials between 0.2–0.3 GW and 0.5–1.0 GW, respectively [95,96]. These low potentials might be explained by suboptimal local tide properties and moderate flow velocities [98]. To the knowledge of the authors, no academic or industrial work has shed light on national tidal power potentials in Indonesia yet.



### 3.7.3. Wave Energy Conversion

Wave energy converters produce electricity from the kinetic energy of waves. Within the global wave energy research network, many concepts have been studied over the last decades. Many of these designs are limitedly comparable due to technical differences [100] and uncertain design parameters [101]. For Indonesia, the oscillating wave column emerged as the most frequently studied technology and the potential of wave converters have been assessed as parts of global studies [102,103] as well as country-specifically on a national [83,101], provincial [104], cross-provincial [105,106] and local levels [107,108]. In the field of wave energy, the specific potential is usually expressed in the unit of kW/m, which represents the power per wave crest width [100]. In Indonesia, South Java is considered to have promising wave energy resources of up to 30 kW/m [101–103]. Other interesting areas are the Arafuru Sea [83], South Sumatera coastline [106] and South Kuta Bali [109]. An aggregated potential in kW is only available for individual sites [83,104], but not aggregated over provincial or national boundaries.

### 3.8. Potential Overview and 100% RET Scenario

The national RET potentials found in literature are summarised in Table 6. Solar PV and offshore wind power have the highest technical potential in Indonesia with a capacity of 20 TW<sub>p</sub> and 4.7 TW and electricity production of 27,540 TWh and 14,722 TWh, respectively. This would be enough to cover the demand in 2018 and 2050 more than 163 and 20 times, respectively. However, these two technologies are also amongst the least developed ones in the Indonesian electricity system and less than 1% of each potential is currently tapped. Compared to more established RET like geothermal and large hydropower, less established RET like solar PV, wind power and small hydropower were implemented slower than projected in the RUEN. Table 6 summarises the potentials for both ESDM and other sources. It shows that ESDM's potentials do not go beyond the technical level and although definitions for an acceptable and economic potential exist, no publication could be found that reports these potentials for any RET.

Table 7 shows how a 100% RET electricity scenario in 2050 could be shaped with the reviewed potentials. Until 2050, large hydropower, geothermal and biomass can still be considerably scaled up. On a national level, they could comprise 6–14% of the electricity mix. Most of the electricity would have to be supplied with solar PV and wind power with a combined share of 66%. The area requirements for the necessary capacity would be limited, as only 0.5% of the marine area would be necessary for offshore wind farms, and only 0.5% of the suitable land area of solar PV parks. The conceptual feasibility of a 100% RE system is in line with recent studies on Indonesia [110–112], although there are differences in the roles of RET and land use. Compared to IESR's recent deep decarbonisation report [113], the major difference to our projection is that solar PV's role is more prominent in their work with a share of 88% in 2050. With the reviewed potentials, such a share could have been reproduced here as well, but we decided to diversify the electricity mix over a broader set of RET with 33% of solar PV, 33% of wind energy and 33% of other RET. Compared to Simaremare et al. [110], Günther [111], and Günther & Eichinger [112], our land use shares are much smaller which can be explained by differences in regional scope. All of the three studies look into the Java-Bali region, while our scenario spans across the entire country. This shows that most RET in our scenario would not be in the economic heart of Indonesia in the Java-Bali region but the economically less developed East. Therefore, large investments in transmission infrastructure are probably required to transport the electricity produced in the East to the demand centres in the West. Moreover, creating a RET hub in East Indonesia could boost socio-economic development there and empower local communities with clean, decentralised electricity. A significant share of baseload could be provided by OTEC without interfering with land use, which is an interesting insight. Although not included in Table 7, other ocean energies like wave and tidal energy could contribute locally as well. Note that our 100% RET scenario is just a rough projection and comes with several limitations. Besides the aforementioned necessary transmission



capacity from the East to the West, the scenario does not consider the necessary storage capacity to cope with the short-term and seasonal fluctuations of solar and wind power production. Moreover, OTEC would have to be scaled up with an annual growth rate of 28% until 2050 [20,88]. The necessary growth rates for solar PV and offshore wind should be even higher. Moreover, the economic feasibility of this projection will require more attention in future research. Nonetheless, the scenario shows that current energy transition plans could be reshaped towards more ambitious targets.

**Table 6.** Potential of RET in Indonesia. For references, see respective sections.

Technology		National Potential [GW <sub>e</sub> ]								Installed Capacity 2019 [GW <sub>e</sub> ]	Planned until 2050 [GW <sub>e</sub> ]	Demand Coverage in 2050 [%] (Pract. Potential)	
		Theoretical		Technical		Practical		Economic					
		ESDM (Theo)	Rest	ESDM (Tech + Pract)	Rest	ESDM (Accep)	Rest	ESDM (Eco)	Rest				
Hydro	Large	75	241	-	-	-	26	15	-	-	5.6	38	3
	Small	19		-	-	-	-	-	-	0.4	7		
Biomass	Solid	28	16–101	-	2	-	18	-	-	-	-	6	
	Waste	2.1	-	-	0.3	-	-	-	-	-	1.8	26	-
	Methanol	-	-	-	10–42	-	-	-	-	-	-	-	-
	Biogas	0.5	-	-	10	-	-	-	-	-	-	-	-
Solar PV		1360–3551	-	208–533	1100–19,835	-	28–3397	-	0.4	0.15	45	2–229	
Wind		61–114	-	18–72	4668	-	1254–2976	-	-	0.15	28	193–406	
Ocean	OTEC	-	-	-	-	-	102	-	6–41	-	-	40	
	Tidal	288	-	18–72	-	-	-	-	-	-	6.1	-	
	Wave	-	-	-	-	-	-	-	-	-	-	-	
				Resources			Reserves		Proven				
				Speculative	Hypothetical	Possible	Probable		3				
Geothermal	ESDM	6 GW <sub>th</sub>	-	3 GW <sub>th</sub>	10 GW <sub>th</sub>	-	2 GW <sub>th</sub>	-	3	2.1	17.5	-	
	Rest	-	-	-	-	-	42 GW <sub>e</sub>	-	-	-	-	14	

**Table 7.** 100% RET scenario until 2050 based on the reviewed potentials.

100% RET System in 2050 (with Electricity Demand of 2,046,000 GWh [5,19])						
RET	Potential (Type) [GWe]	Potential Electricity Production [GWh/Year]	Share of Practical Potential [%]	Deployed Capacity [GWe]	Annual Electricity Production [GWh/Year]	Share of Electricity Generation [%]
Geothermal	42 (pract)	279,619	100%	42	279,619	14%
Large Hydro	38 (RUEN)	143,138	100%	38	143,138	7%
Small Hydro	7 (RUEN)	26,368	100%	7	26,368	1%
Biomass	18 (pract)	115,324	100%	18	115,324	6%
Solar PV	3397 (pract)	4,677,669	14%	491	676,306	33%
Wind Energy	2976 (pract)	8,318,237	7%	214	676,306	33%
OTEC	102 (pract)	339,045	16%	16	128,940	6%
Total	6580	13,899,400	-	826	2,046,000	100%

## 4. Discussion

### 4.1. Limitations

Although the methods described in Section 2 yielded more than 300 publications, it cannot be guaranteed that all available literature was retrieved. The use of additional search engines, terms and techniques could have resulted in an even more comprehensive collection. Moreover, there can be a subjective bias in the classification of potentials, especially in the cases where studies did not specify the type of potential or definitions differed substantially across studies. Therefore, the differences in potentials throughout studies might stem from the underlying differences in assumptions. This was especially apparent for the reports from ESDM, where methods are not always elaborated or scattered across multiple reports. The potential definitions in Table 1 are not consistently used, which could be because different departments within ESDM use different definitions. Therefore, there are uncertainties involved about the potentials from ESDM, which this study can

only point out, but not resolve. These limitations aside, this paper still provides the most comprehensive overview of the general state of research on Indonesia's RET potentials so far.

#### 4.2. Knowledge Gaps

Three knowledge gaps can be identified. A first knowledge gap comprises the limited work on RET potentials in Indonesia beyond the technical level. Most potentials reviewed in this paper originate from reports by ESDM, which do not always elaborate on the used data, methods, and assumptions. Most academic literature covers localised case studies with limited applicability to provincial and national levels. Many of these case studies were excluded from this review due to conceptual and methodological inconsistencies. If national potentials are mentioned in journal papers, they are generally directly adopted from ESDM [9,13,14,46,114]. This is reasonable as the potentials from ESDM are not only useful for review papers and energy policy planning but also provide a foundation for energy scenarios in academic research [13,14,115]. However, this paper provides reasons to assume that ESDM's potentials are too conservative and therefore current strategies like the RUEN. Although potentials can vary considerably across academic publications, they tend to be significantly higher compared to ESDM's potentials. If these academic estimations hold, Indonesia's potential to implement RET might be much larger than currently assumed. Alternative development strategies might capture these updated potentials more adequately than the RUEN enabling more progressive implementation targets. But to consolidate these arguments, more in-depth research is required.

The second knowledge gap builds upon the first one, as there is not only limited work on the potential of individual technologies but also on how these potentials relate to each other. Outside the field of ocean energy, no study was found that assesses the potential of several RET in Indonesia simultaneously. If the applicability of RET across Indonesia was mapped, it was either done for individual technologies [87] and in the case of solar PV and wind power [63,64] solely onshore, thus excluding alternatives like floating PV and offshore wind. For ocean energy, collective potential maps exist [16,116], but they are qualitative and do not offer insights into their technical and economic performance. As a result, current literature does not offer a map of the collective potential of several RET across Indonesia and the interaction between individual technologies.

The third knowledge gap refers to the lack of thorough data on natural resources such as wind and ocean data. As mentioned in two biomass studies, datasets on the same metric could differ significantly between sources, thus affecting the results based on the choice of the dataset [44,117]. Regarding wind power, both ESDM and academia agree that thorough field data is needed for more refined potentials, although the costs of acquisition are a hurdle [5,114,118,119]. This might explain why current research focuses more on local case studies since these cases can be studied more cost-effectively via simulations [76,79] or local on-site measurements [78,80]. These complications also apply to ocean energy research, as there are only a few data observation stations [101] and research is currently predominantly performed locally. None of the reviewed wind and ocean energy studies used simulated resource data from reanalysis models like HYCOM or NASA MERRA-2 as a proxy for measured field data.

## 5. Conclusions

In this paper, contemporary literature was reviewed to show what the potential of Renewable Energy Technologies (RET) in Indonesia is and how they could contribute to meeting current and future electricity demand in 2050. This study concludes that Indonesia hosts massive renewable energy resources spread over a wide range of different technologies on land and sea. Moreover, a 100% RET system could be technically feasible to meet Indonesia's future electricity demand. However, the research field is still underdeveloped and could benefit from more attention, potentially targeting the three knowledge gaps discovered in this study. First, there is limited work on RET potentials beyond the technical

level with most existing knowledge originating from the Indonesian Energy Ministry and its subdivisions. These potentials might be too conservative based on the methodological assumptions. Second, existing studies mostly assess individual technologies and do not offer insights on the aggregated potential of multiple technologies and their distribution across the country. Third, there is a lack of thorough empirical data on natural resources such as wind and ocean data, due to which contemporary literature focuses more on local case and feasibility studies with little applicability to larger regional scopes.

The implementation of most RET, especially of unestablished ones like small hydropower, solar PV, and wind power, has proceeded slower than planned in the RUEN. This and the lack of academic and industrial research oppose the potential that RET might possess in Indonesia. Potentials from non-governmental studies tend to be much higher than the ones from ESDM. For example, the technical potential of wind power might be 260 times higher than currently projected in the national energy plan. If these projections hold, Indonesia has the luxury to choose between multiple options to promote the energy transition beyond what is already planned in the RUEN. However, due to the limited body of academic and industrial studies, more research is required to make more solid estimations of these potentials.

The assessment of RET potentials in Indonesia is a promising and worthwhile pursuit. Indonesia is a strongly growing country with the outlook of becoming one of the largest economies in the world; a development that might precipitate an equally robust growth in electricity demand. At the same time, the recent exhaustion of domestic oil resources in Indonesia shows that fossil fuels are finite [9], with the currently abundant resources of coal and natural gas being no exception. Therefore, the archipelago has splendid prerequisites to move away from fossil fuels towards a more sustainable energy system with beneficial effects beyond national borders.

## 6. Recommendations

Based on the literature review and three knowledge gaps found in this study, the following research and policy recommendations are proposed. The research recommendations are not ordered by relevance, but by the knowledge gaps in Section 4.2.

### 1. Assessment of RET Potentials Beyond the Technical Level

As shown in Table 6, there is only limited work on potentials beyond the technical level for virtually all reviewed technologies. To consolidate the potentials found in literature, more research on the potentials under practical and economic constraints is needed. For example, Langer et al. [87] assessed the economic potential of OTEC considering marine protected areas, water depth, connection points from sea to shore and the local electricity tariff. The methodology proposed there might be adapted for other RET, as recently done for wind power as a master thesis project at TU Delft [120].

### 2. Aggregation and Spatial Mapping of Potentials of Several RET

The potentials of individual technologies do not provide insights into how these technologies interact with each other. For instance, OTEC plants could be complemented with floating solar energy modules [121,122], but not with offshore wind turbines due to potential harmful interference of the offshore structures. Therefore, it might be helpful to pursue an integrated approach and to map the potential of several technologies across Indonesia. If multiple non-combinable technologies overlap at one location, the one with the higher potential could be preferred. Such work could connect the existing work on individual technologies, e.g., visualising the potential of wave energy conversion in South Java, while highlighting solar PV potentials in East Nusa Tenggara.

### 3. Utilisation of Simulation and Forecast Models for an Initial Potential Estimation

In literature, the collection of thorough field data is mentioned to refine the potential analyses. This might not be necessary and instead, the collection of field data could be limited to high-potential areas based on grounded estimations. For example, a preliminary

assessment with data from sources like HYCOM and the Global Wind Atlas could reveal interesting areas for further investigation. For example, Namrole on Buru Island emerged as an economically interesting location for OTEC based on simulated data from HYCOM [87]. Thus, field data could be collected there to validate the simulation data, methods, and potential of OTEC.

#### 4. *Re-shape provincial and national targets for RET implementation until 2050*

A key insight of this study is that the potential of RET in Indonesia is far higher than currently assumed by ESDM. However, current energy policies are built around ESDM's work, so the RUEN does not consider these increased potentials or even leaves out entire technologies like offshore wind. Therefore, this study recommends to re-assess current energy transition strategies to consider the potential of RET more appropriately. An important step towards this was PLN's recent pledge to become carbon neutral by 2060 [123]. To achieve this ambitious goal, the role of solar PV and offshore wind should become far more prominent as well as storage technologies to deal with short-term fluctuations in power supply. The integrated potential map discussed above and the scenarios derived from it could serve as the conceptual baseline of an updated energy transition strategy.

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#### Abbreviations

Abbreviation	Meaning
ASELI	Asosiasi Energi Laut Indonesia (Indonesian Ocean Energy Association)
EEZ	Exclusive Economic Zones
ESDM	Kementerian Energi dan Sumber Daya Mineral (Ministry of Energy and Mineral Resources)
IESR	Institute for Essential Services Reform
LCOE	Levelized Cost of Electricity
OTEC	Ocean Thermal Energy Conversion
PLN	Perusahaan Listrik Negara (State Electricity Company)
PV	Photovoltaic
RUEN	Rencana Umum Energi Nasional (National Energy Plan)

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