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A zero-carbon, reliable, and affordable energy future in Indonesia

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Abstract - We present an investigation of the Indonesian energy decarbonization pathway, mainly using solar photovoltaics. We performed an hourly energy balance analysis using ten years of meteorological data for a hypothetical solar-dominated system combined with pumped hydro storage. Our work shows that Indonesia could achieve 100% renewable electricity at a low cost. The levelized cost of electricity was found to be in the range of US$80 - 102/Megawatt-hour.

Introduction

Indonesia has the world's 4th largest population of 278 million people [1] with 335 million projected in 2050 [2]. Indonesia's 1 Megawatt-hour (MWh) per capita per year electricity consumption is anticipated to eventually approach Singapore's current consumption of 9 MWh per capita [3,4]. Further, as Indonesia electrifies most energy functions - domestic, transport, heating, and industry, electricity demand could increase to 10-20 MWh per capita. Because of its high population and projected rapid growth in energy consumption, Indonesia's energy future could have a significant impact on global greenhouse emissions. Indonesia's energy is primarily generated from fossil energy. Gas and coal account for 88% of the electricity mix [5].

As the tenth largest worldwide greenhouse gas emitter, Indonesia's current carbon emissions of 2.3 tonnes of CO2-equivalent per person [6] will drastically increase if it continues to rely on fossil fuels to meet its energy needs. Transitioning to clean energy is crucial for Indonesia to fulfill its international climate commitment of net zero emission by 2060 [7]. Solar PV is cost competitive with fossil, nuclear, hydro, and other renewable generation technologies. Solar PV constituted more than half of new global generation capacity in 2022 [8]. Solar energy is vastly available in Indonesia [9,10]. Indonesian solar resources have low seasonal variations (Figure 1). This study explores high renewable electricity scenarios for Indonesia, with the goal of achieving zero carbon emissions in the energy sector.

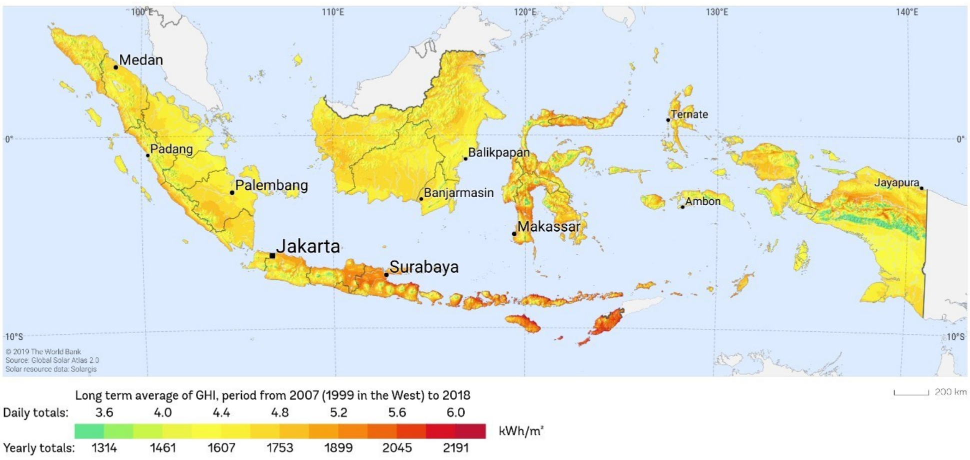


Figure 1. Global horizontal irradiation of Indonesia [11]

Methodology

We modelled Indonesia's future electricity system using hourly resolution of supply and demand. The demand increases tenfold as Indonesia moves towards 100% renewable energy. Solar PV supplies most energy. Existing hydro, legacy fossil fuel plants, and pumped hydro energy storage which potential is huge in Indonesia [12], provide most of the balancing of supply and demand. We applied the modelling tool introduced by Lu et al. [13] which provides high-resolution, chronological modelling of energy supply-demand balance. The model uses time series demand and meteorological data to simulate the hourly energy balance in each service area. The model optimizes generation and storage capacities for each region and derives the least-cost solution that meets specified resource, reliability, and energy constraints. The cost assumptions are summarized in Table 1 with a real discount rate of 5% is used for all technologies. We also explored independent regional interconnection and the potential for an “Indonesia super grid” (Figure 2).

Table 1. Cost assumptions are in US dollars.

Technology	Capital cost	Fixed O&M cost	Variable O&M cost	Lifetime (years)	Purchase price
PV	$530/kW	$10/kW p.a.	-	25	
Hydro	-	-	-	-	$57/MWh
Geothermal	-	-	-	-	$70/ MWh
Coal	-	-	-	-	$70/ MWh
Pumped hydro	$500/kWp + $50/kWh	$10/kW p.a.	-	50	-
HVDC	$200/MW-km + $200,000/MW-pair	-	-	50 for transmission lines; 30 for converter stations	-
HVAC	$1000/MW-km	-	-	40	-

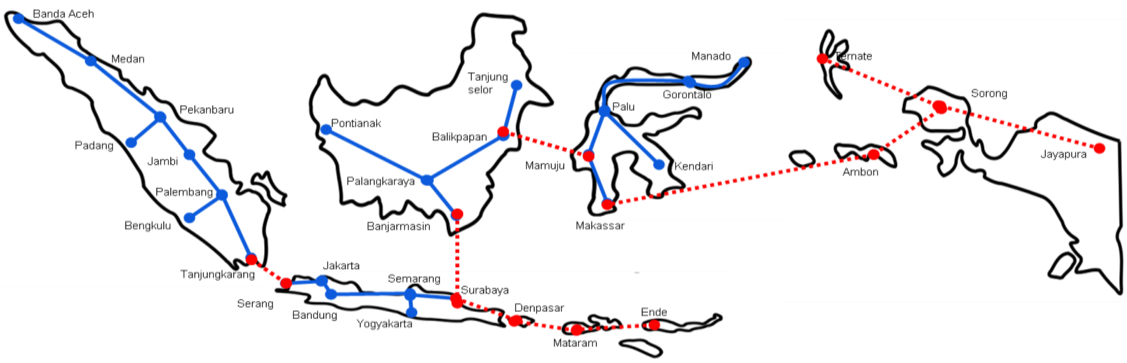


Figure 2. Indonesia super grid (all regions interconnected)

Results

The modelled levelized cost of electricity (LCOE) of an Indonesian Supergrid is $95/MWh (Figure 3 and Figure 4). This is larger than the modelled population weighted LCOE average of $90/MWh (Figure 2). Thus, strong interconnection of all 5 regions is not favoured by the model. However, the difference in LCOE is quite small – only 5%. An “Indonesian Supergrid” that connects all five regions was modelled. It has the benefit that required storage are reduced because local weather and demand can be smoothed out across the regions. However, the high transmission cost (adding undersea HVDC transmission cables) must be tolerated. The estimation of LCOE in this study ($90/MWh for the 10 MWh population weighted of independent regions scenario) is lower than in previous studies. Lu et al [13] estimated $114/MWh for the equivalent Indonesia scenario. Reyseliani et al suggested LCOE of $113/MWh [14]. Current generation cost in Indonesia is suggested to be $98/MWh [15]. However, the current generation cost depends largely on government subsidies and/or capped coal prices for power generation.

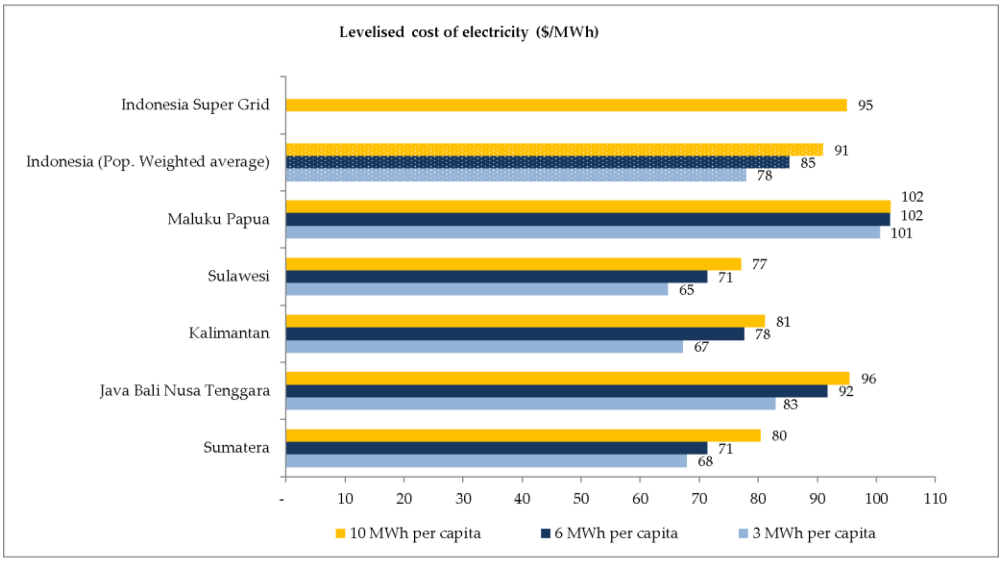
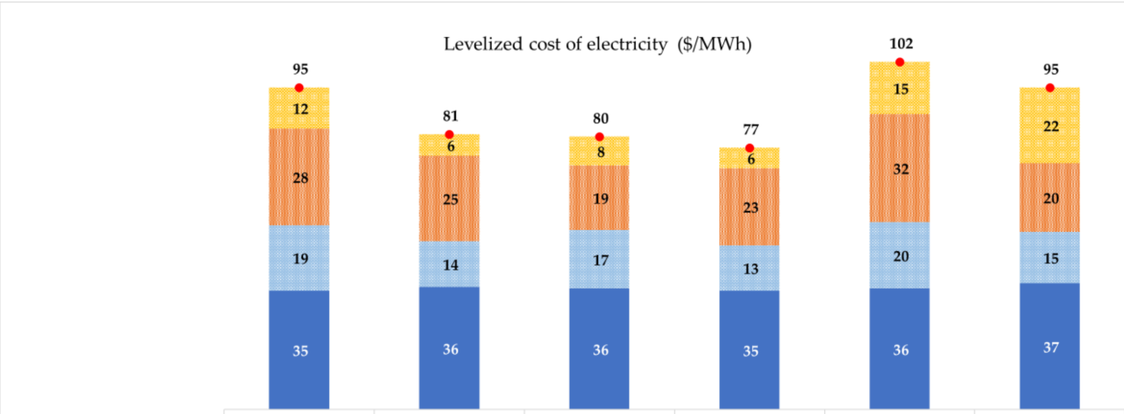


Figure 3. Levelized cost of electricity of 3 MWh per capita, 6 MWh per capita, and 10 MWh per capita consumption scenarios.



	Java Bali Nusra	Kalimantan	Sumatera	Sulawesi	Maluku Papua	Indonesia Supergrid
LCOE Transmission	12	6	8	6	15	22
LCOE Storage	28	25	19	23	32	20
LCOE Spillage & Loss	19	14	17	13	20	15
LCOE Generation	35	36	36	35	36	37
LCOE	95	81	80	77	102	95
Population (million people)	207	20	73	25	10	335

Figure 4. Levelized cost of electricity for 10 MWh per capita scenario (100% renewable)

The current low-cost coal generation might not be retained in the future. Furthermore, Indonesia has started implementing a carbon tax for fossil power generation. The LCOE values reported from this study represent upper bounds for the costs of 100% renewable electricity in Indonesia, because only mature, off-the-shelf technologies with known costs are included and future cost reduction or technology development will only lead to lower costs than those estimated in this study. Following increases in electricity system demand, storage needs grow in terms of both power (GW) and energy (GWh). For the 10 MWh per capita scenario, 1129 GW and 15,457 GWh of total electrical storage are needed across 5 distinct regions. Required storage drops to 1031 GW and 10,291 GWh when all regions are integrated into an Indonesian Supergrid. The reason for this is that strong transmission smooths out local weather and demand, at the cost of increased expenditure on transmission. We discovered that the average amount of time for storage is 14 hours across all cases we looked at, ranging from 9 to 17 hours. For the supergrid scenario, 10 hours of storage are needed. This confirms the estimation in previous work [12] that with its low variability of solar resources, Indonesia will require only overnight rather than weeks or months of energy storage.

Conclusion

This work shows that Indonesia could rely on solar PV combined with off-river PHES for clean energy transition. The fossil fuel dependency in the current Indonesian electricity system can be replaced with an affordable, reliable, and zero emission electricity in different stages of economic development. The growing electricity demand can be supplied by renewables while existing fossil fuels are phasing out gradually. In the future, this work can be expanded further to examine electrification of transport, heat and industry in Indonesia and its impact on the electricity system once these energy sectors are mature enough for a reliable estimation of the scales of these sectors to be presented.

Acknowledgement

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