Generation Expansion Planning with a Renewable Energy Target and Interconnection Option: A Case Study of the Sulawesi Region, Indonesia

Sarjiya[1]*, Lesnanto Multa Putranto[1], Tumiran[1], Rizki Firmansyah Setya Budi[1], Dwi Novitasari[1], and Deendarlianto[2]

Key Messages

- The Indonesian government has set a renewable energy target of 31% by 2050
- The Sulawesi region consists of two isolated power systems, i.e., the Northern and Southern Sulawesi systems
- It is more economical to achieve the renewable energy target by interconnecting the two isolated systems
- Interconnecting the two isolated systems incurs a generation cost of 8.36 cents USD/kWh
- Implementing the targets provides an emission reduction in 2050 of 34.91% compared to the business-as-usual

***Sulawesi:** The fastest economic growth island in Eastern Indonesia (6.43%) and a special economic zone for Eastern Indonesia. Future industry sectors: agriculture, forestry, nickel mining and processing, and tourism*

Introduction

As part of the global action to deal with climate change, Indonesia committed to reducing its greenhouse gas (GHG) emissions at the COP21 in Paris in 2015 [1]. Law of the Republic of Indonesia number 16/2016 states that Indonesia will decrease its GHGs by a minimum of 29% compared to business-as-usual (BAU) and 41% with international support by 2030 [2]. The electricity sector is the second highest contributor to CO_2 emissions in Indonesia [3]. Therefore reducing CO_2 emissions in the electricity sector is crucial for supporting the nation's GHG reduction commitment. Indonesia has set a target of 23% for new and renewable energy (NRE) use in 2025 and 31% in 2050 in the national energy mix [4, 5] to reduce CO_2 emissions. However, Indonesia did not meet the yearly NRE target in the electricity sector from 2015–2019 [6].

As an archipelagic country, Indonesia faces many challenges in meeting its NRE target, e.g., unconnected electricity systems and renewable energy locations that are scattered and far from the load centre. One of the power systems facing these challenges is the Sulawesi electricity grid system. This system, one of four major systems in Indonesia, is in an area of high growth and is a strategic economic region in eastern Indonesia. The Sulawesi system faces two challenges in achieving the renewable energy (RE) target. The first is it contains two unconnected isolated electricity systems, i.e., the Northern and Southern Sulawesi Power Systems [7]. The second relates to RE resources, including hydropower, wind power, and geothermal, which are scattered on both the northern and southern sides of the island. Therefore, how to arrive at the best scenario for generation expansion planning by considering RE resources and the interconnection option between these two electricity systems needs consideration.

This policy briefing aims to identify the Sulawesi region's optimum renewable energy development pathways, including the interconnection option. Furthermore, a CO_2 emission reduction scheme is analysed as part of the optimum pathway analysis. An open-source generation expansion planning (GEP) model with two scenarios (isolated and interconnected scenarios) is developed to achieve the research aim. Each of these scenarios is then subdivided into business as usual (BAU) and RE target. The BAU represents a GEP with business-as-usual conditions in which no further efforts to achieve the RE target are made. In comparison, the RE target represents a GEP used to achieve the RE target.

The GEP model is created based on an open-source energy modelling system (OSeMOSYS) platform. The optimum solution is obtained using an economic objective function by considering an energy balance, reserve margin, and RE target. Finally, the comparative analysis is carried out to obtain the optimum pathway.

The optimum development pathways

To identify the optimum pathways, several scenarios are created which represent the combination of possible pathways, as shown in **Table 1.**

Implementing the RE target in Sulawesi's GEP changes the energy mix. In the business-as-usual (BAU) scenario, Northern Sulawesi's energy mix in 2050 consists of 74.2% coal, 21.4% gas, and 4.4% RE. On the other hand, the BAU energy mix in Southern Sulawesi in 2050 consists of 79.5% coal, 10.1% gas, and 10.4% RE and the BAU energy mix in the Interconnected Sulawesi in 2050 consists of 78.3% coal, 12.5% gas, and 9.2% RE.

For the RE target scenario, the energy mix in each electricity system changes as follows. Northern Sulawesi's energy mix in 2050 consists of 43.6% coal, 25% gas, and 31.4% RE and the energy mix in Southern Sulawesi in 2050 consists of 44.4% coal, 24.6% gas, and 31% RE.

Implementing the RE target in each isolated power system increases the generation cost and decreases CO2 emissions. Northern and Southern Sulawesi's generation cost increases 6.6% to 8.91 cents USD/kWh and 4.6% to 8.33 cents USD/kWh, respectively. Meanwhile, the average generation cost of Northern and Southern Sulawesi becomes 8.47 cents USD/kWh. The CO2 emissions of Northern and Southern Sulawesi in 2050 decrease 35.27% to 10.55 million tons of CO2 and 35.85% to 39.06 million tons of CO2, respectively.

Table 1. Scenario descriptions

Scenario	Analyzed electricity system	RE target	Interconnection option	Costs considered	Optimization description
Northern Sulawesi BAU	Isolated Northern Sulawesi	No	No	Generation cost	Least cost optimization
Northern Sulawesi RE target	Isolated Northern Sulawesi	31 % by 2050	No	Generation cost	Least cost optimization considering RE target
Southern Sulawesi BAU	Isolated Southern Sulawesi	No	No	Generation cost	Least cost optimization
Southern Sulawesi RE target	Isolated Southern Sulawesi	31 % by 2050	No	Generation cost	Least cost optimization considering RE target
Interconnected Sulawesi BAU	Isolated Northern and Southern Sulawesi	No	Yes	Generation and interconnector costs	Least cost optimization considering interconnection option
Interconnected Sulawesi RE target	Isolated Northern and Southern Sulawesi	31 % by 2050	Yes	Generation and interconnector costs	Least cost optimization considering interconnection option and RE target

In comparison, the results of implementing the RE target in the interconnection scenario are as follows. The energy mix in 2050 consists of 45% coal, 24% gas, and 31% RE. The generation cost in the interconnected scenario by implementing the RE target is 8.36 cents USD/kWh.

Implementing the RE target in the interconnected Sulawesi scenario increases the generation cost and decreases CO_2 emission compared to the interconnected Sulawesi BAU scenario. The generation cost increases 4.5% from 8 cents USD/kWh to 8.36 cents USD/kWh and the CO_2 emissions in 2050 decrease 34.91% from 77.02 million tons of CO_2 to 50.12 million tons of CO_2.

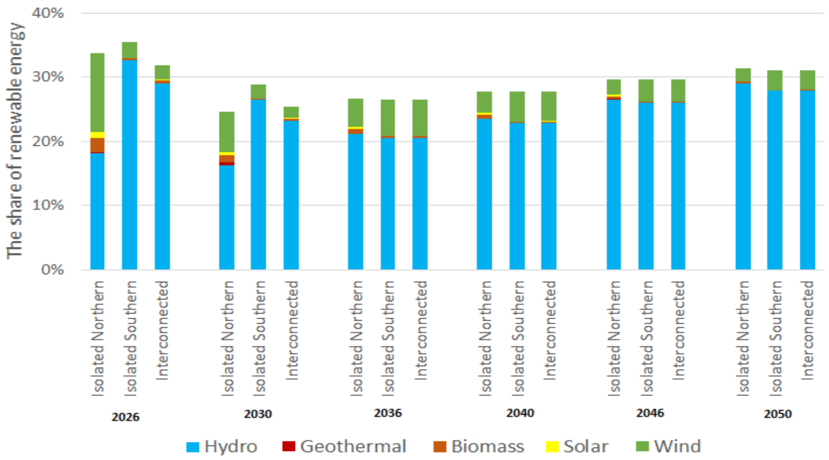

Figure 1. Renewable energy share for each scenario

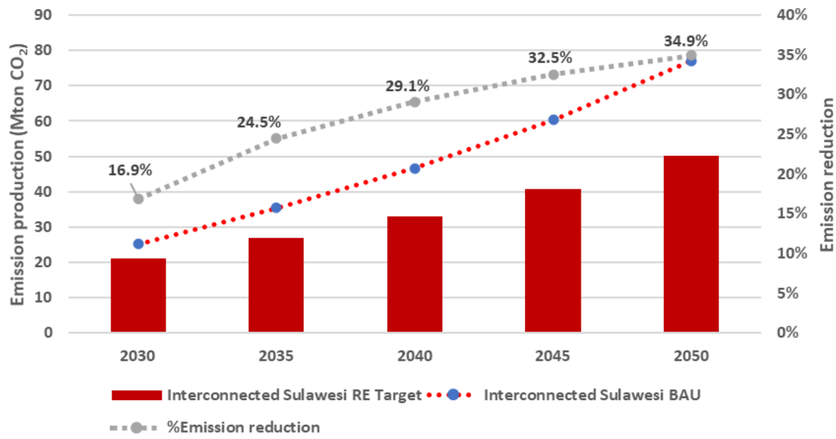

Figure 2. The emission production on the interconnected Sulawesi BAU and RE target scenario, and its emission reduction

Concluding remarks

The RE share in each scenario is different, as shown in **Figure 1** as it depends on the potential resources in each system. The enormous amount of hydropower energy available dominates RE utilization in the Southern system, whereas for the isolated Northern Sulawesi system, hydro, wind, and geothermal energy are utilized to achieve the target. However, this composition changes when the two isolated systems are interconnected. Hydro energy is the most used RE in the Sulawesi interconnection system. This is because there are enormous hydro resources available which are more economical to develop.

A comparison of the isolated and interconnection scenarios shows that the interconnection scenario is the optimum renewable energy development pathway in Sulawesi. Using the interconnection option ensures a lower generation cost with an emission reduction which is very close to the isolated scenario. The interconnection scenario reduces the total cost by 139.8 million USD compared to the total cost in both isolated scenarios.

The interconnection scenario results in an emission reduction in 2050 of 34.91% compared to the scenario without the RE target (BAU), as shown in **Figure 2.** In addition, interconnecting both isolated electricity systems increases the system flexibility. This is crucial for handling renewable energy intermittency.

Implementing the RE target increases the generation cost compared to the BAU. These results indicate that the implementation of RE targets requires policies that can force the utility to invest in renewable energy power plants or can make investing in renewable energy power plants attractive. However, existing policies in renewable energy do not represent those required policies. The existing policies are the national energy policy (NEP) and power purchase agreement (PPA).

The NEP only states the RE target without providing a detailed pathway and the required efforts. Meanwhile, the PPA regulates the renewable energy price as a maximum of 85% from the power system generation cost. This price is a barrier to renewable energy investment. Therefore, stronger policies are required to support investment in renewable energy sources

Recommendations

Based on the optimum development pathway analysis, the following recommendations can be made for the case study of the Sulawesi Region in Indonesia:

- The government should prioritize investment in the interconnection between the Northern and Southern electricity systems to achieve the renewable energy target.
- The government should prioritize investment in renewable energy sources – particularly hydro, wind, and solar.
- Stronger policies are required to support investment in renewable energy sources – particularly hydro, wind, and solar.

References

[1] Government of Indonesia. First Nationally Determined Contribution Republic of Indonesia. 2016.

[2] Masripatin N, Rachmawaty E, Suryanti Y, Styawan H, Farid M, Iskandar N. NDC Impmenetation Strategy (Strategi Implementasi NDC). Jakarta: 2017.

[3] Ritchie H, Roser M. CO_2 and Greenhouse Gas Emissions. Our World Data 2020:1. https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions%0Ahttps://ourworldindata.org/co2-and-other-greenhouse-gas-emissions#licence%0Ahttps://ourworldindata.org/co2-and-other-greenhouse-gas-emissions.

[4] President of Republic Indonesia. Republic of Indonesia Government Regulation No.22/2017 concerning National Energy Planning (Peraturan Presiden Republik Indonesia Nomor 22 Tahun 2017 tentang Rencana Umum Energi Nasional). Indonesia: 2017.

[5] President of Republic Indonesia. Republic of Indonesia Government Regulation No 79/2014 concerning National Energy Policy (Peraturan Pemerintah Republik Indonesia No 79/2014 tentang Kebijakan Energi Nasional) 2014.

[6] National Energy Council. Performance Report (Laporan Kinerja). 2019.

[7] PT PLN. Electricity Supply Business Plan of PT. PLN (PERSERO) 2019-2028 (Rencana Usaha Penyediaan Tenaga Listrik PT. PLN (PERSERO) 2019-2028). Jakarta: PT. PLN; 2019.

Notes

Climate Compatible Growth (CCG) programme: CCG is funded by the UK's Foreign Development and Commonwealth Office (FCDO) to support investment in sustainable energy and transport systems to meet development priorities in the Global South.

Acknowledgements

The authors would like to thank the Deputi Bidang Penguatan Riset dan Pengembangan, Kementerian Riset dan Teknologi/Badan Riset dan Inovasi Nasional, Indonesia for supporting this work through the Penelitian Dasar Unggulan Perguruan Tinggi (PDUPT) [grant number 1719/UN1/DITLIT/DIT-LIT/PT/2021].

Author Information

Affiliations

[1] Department of Electrical and Information Engineering, Universitas Gadjah Mada

2 Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada

All authors: Center for Energy Studies, Universitas Gadjah Mada

**corresponding author*

Email: sarjiya@ugm.ac.id