

PAPER • OPEN ACCESS

Decarbonizing the electricity system in Sumatra region using nuclear and renewable energy based power generation

To cite this article: Ika Wahyu Setya Andani *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **753** 012011

View the [article online](#) for updates and enhancements.

You may also like

- [Early transformation of the Chinese power sector to avoid additional coal lock-in](#)
Huan Wang, Wenying Chen, Christoph Bertram *et al.*
- [The effects of climate change mitigation strategies on the energy system of Africa and its associated water footprint](#)
Ioannis Pappis, Vignesh Sridharan, Mark Howells *et al.*
- [Overview of Hysteresis Current Controller Application in Renewable Energy Based Power Systems](#)
A. M. Shiddiq Yunus, Sri Swasti and Purwito



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Decarbonizing the electricity system in Sumatra region using nuclear and renewable energy based power generation

Ika Wahyu Setya Andani^{1*}, Agus Sugiyono², Khusnul Khotimah¹, Boanerges Desryanto Siregar³

¹ Center for Nuclear Standardization and Quality Unit, National Nuclear Energy Agency Science and Technology Park, South Tangerang City, Banten, Indonesia

² Center for Assessment of Process Industry and Energy, Agency for the Assessment and Application of Technology, 720 Building, Science and Technology Park, South Tangerang City, Banten, Indonesia

³ Directorate General of Electricity, Ministry of Energy and Mineral Resources, Jl. H.R. Rasuna Said, Blok X 2, Kav. 7-8, East Kuningan, South Jakarta, DKI Jakarta 12950, Indonesia

*Email: ikawa@batan.go.id

Abstract. The Indonesian national energy policy mandates that the new and renewable energy in 2025 reaches a share of 23% and in 2050 rises a share of 31% in the primary energy mix. The energy mix by types is further detailed in the national energy plan (RUEN). Since Indonesia is committed to participating in efforts to mitigate global climate change, the energy sector is expected to contribute to the greenhouse gas (GHG) reduction target of up to 29% (unconditional) and 41% (conditional) under Business as Usual (BAU) by 2030. The use of nuclear power and renewable energy-based power generations can reduce GHG emissions in the electricity sector. Sumatra region is a potential region for the development of renewable energy. In this study, various options were made to reduce GHG emissions by utilizing nuclear power and renewable energy-based power generations. Assuming that electricity planning in the Sumatra region, as stated in the Electricity Supply Business Plan (RUPTL) from PLN as a Business as Usual (BaU) scenario, then an alternative scenario can be made by replacing coal power generation using low-carbon power generation. Hydropower, geothermal, and nuclear power generations are prospective options as they have large capacity per unit. At the same time, the utilization of other renewable energy sources still face some challenges due to the intermittent generation. The east coast regions of Sumatra that do not have the potential hydropower and geothermal sources, suit for nuclear power generation.

Keywords: decarbonization, GHG emission, nuclear power, renewable energy

1. Introduction

The achievement of the Indonesian New and Renewable Energy (NRE) mix in the national energy policy is still low compared to the government's target, as stated in Government Regulation No 79/2014 concerning the National Energy Policy (KEN). Based on KEN, the share target of NRE in the national primary energy mix in 2025 is 23% and increases to 31% in 2050. The utilization of NRE until 2018 is still 9% of the total national energy mix due to several obstacles faced [1]. The main obstacles are related to the economy, long-term financing, and infrastructure land acquisition constraints. Besides, the generating cost of NRE is still higher than that of fossil energy [2]. Therefore,



it is not yet competitive in the domestic market. There are still many renewable energy resources that have not been utilized, and this has prompted the government to initiate actions by optimizing the use of renewable energy in the National Energy General Plan (RUEN) and the Regional Energy General Plan (RUED). Development planning is carried out by taking into account the local culture and local NRE potency following the objectives of national energy management to be fair, sustainable, and environmentally friendly [3].

The Indonesian government, through the State Electricity Company (PLN), describes the development of electricity generation to supply electricity demand a more efficient, well-planned, and environmentally friendly manner in the Electricity Supply Business Plan (RUPTL). The RUPTL also includes planning for utilizing NRE and developing NRE projects while still considering the economy, supply-demand, and the readiness status of environmentally friendly power generation technology [4]. This in line with Indonesia's involvement in reducing greenhouse gas (GHG) emissions, as stated in the Paris Agreement. The agreement aims to keep the increase in global average temperature to well below 2°C above pre-industrial levels, and to pursue efforts to limit the increase to 1.5°C. The Paris Agreement is also the basis for implementing climate change control at the international level becomes universal and must be implemented internally by the country itself. Indonesia has pledged to reduce its GHG emission by 29% through its efforts and 41% with international support for the Business as Usual (BaU) scenario by 2030 [5]. Thus, it is necessary to divide the duties of each ministry and institution, both central and local government, with involvement as actors who play a role in the implementation of the Paris Agreement.

Many developed and developing countries continue to strive to increase the use of low carbon technology. The GPI study [6] discusses the decarbonization of the electricity sector in the Midcontinent Region of the United States of America by 2050 with various low carbon technology options. The use of energy-efficient technology and renewable energy plays a significant role in reducing GHG emissions. Besides that, the technology of utilizing natural gas by capturing carbon is also an important choice. National Development Planning Agency [7] has conducted studies related to the economic benefits of low carbon development. With this new paradigm, the development will benefit all parties and become a win-win solution for the Indonesian economy, society, and the local and global environment. Siagian et al. [8] discussed the decarbonization of the energy sector using three scenarios, i.e., the use of renewable energy technology, carbon capture and storage (CCS), and economic structural change. Technically decarbonization can be achieved by applying of three pillars, i.e., energy efficiency, electrification for end-users, and the use of renewable energy in the electricity sector.

This paper will discuss decarbonization for electricity in Sumatra. The electricity interconnection in the Sumatra region is the second-largest after the Java-Bali electricity interconnection. The utilization of NRE for power plants in Sumatra currently reaches 29% of total generation. The Sumatra region has considerable hydropower and geothermal potential compared to other islands in Indonesia. The potential for renewable energy needs to be optimized for the use of electricity generation in the context of decarbonizing the Sumatra electricity system. In addition to hydropower and geothermal power plant, options for nuclear, biomass, biogas, solar PV, wind, and ocean power plant for decarbonization are also evaluated by comparing the indicator of reducing CO₂ emission in the Sumatra electricity system.

2. Methodology

2.1. Projection of Electricity Demand-Supply

The methodology used to analyse decarbonization is to create an energy model to forecast long-term electricity demand-supply. Electricity demand is projected using an econometric method based on historical data on electricity demand as well as the assumptions on population and gross regional domestic product (GRDP) growth. It is projected that electricity supply can meet electricity demand with various power generation technology options. Various parameters are considered in the

calculation of electricity generation, including installed capacity, availability factor, thermal efficiency and economic lifetime. In the Business as Usual (BaU) scenario, the power generation technology used is in accordance with the current trend. In the decarbonization scenarios, various power generation options are used to reduce CO₂ emissions. The calculation of CO₂ emissions uses a Tier 1 emission factor from the IPCC [9]. The analysis was carried out by comparing CO₂ emissions between the BAU scenario and the decarbonization scenario.

2.2. Current Sumatra Electricity System

The power plants in the Sumatra region are managed by the PLN Main Unit for North Sumatra Generation and the PLN Main Unit for Southern Sumatra Generation, except for a few plants in an isolated system managed by the Regional PLN Main Unit. The 275 kV Extra High Voltage Transmission Line (SUTET), which is the backbone of electricity distribution throughout the Sumatra region, was completed in September 2019 [10]. This transmission connects electricity supply from the Southern Sumatra to the Northern Sumatra System, which stretches from Lahat to Pangkalan Susu along 2,936 kms and is expected to increase the reliability of the Sumatra electricity system.

2.2.1. Renewable Energy Potential. As the second-largest island in Indonesia, Sumatra has enormous renewable energy potential. The potentials range from hydropower, geothermal, wind, biomass, biogas, ocean to solar energy. The most enormous potential comes from solar energy at 68,749 MW, and the smallest comes from biogas at 422 MW, as shown in Table 1 [11]. The potential that has been utilized quite a lot is geothermal, large-scale hydropower, and small and medium-scale hydropower. At the same time, the utilization of biomass, biogas, and solar PV is still relatively small.

Table 1 Renewable energy potential in the Sumatra region

No.	Power Plant	Potency (MW)
1	Geothermal	7,387
2	Large scale hydropower	15,579
3	Small and medium scale hydropower	5,734
4	Biomass	15,166
5	Biogas	422
6	Solar PV	68,749
7	Wind	6,260
8	Ocean	8,300
Total		127,596

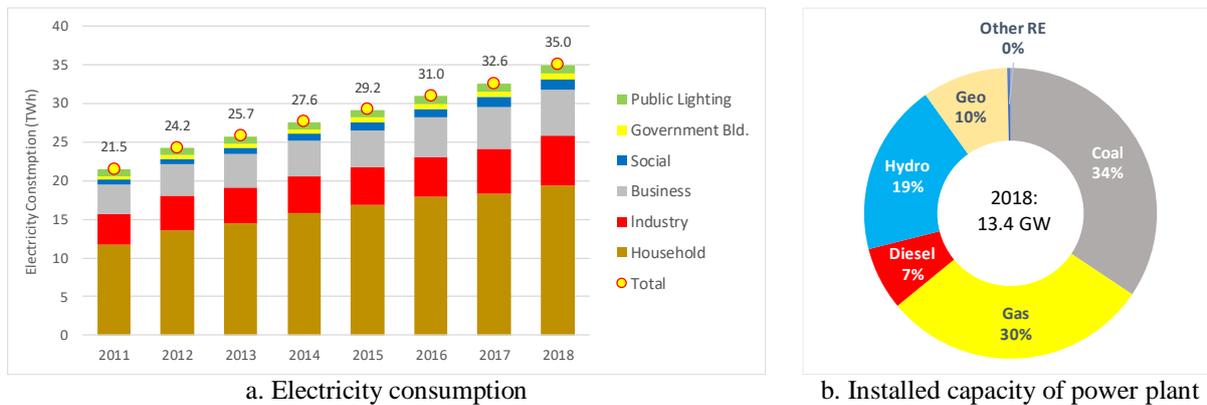
Note: - Calculated based on RUEN and NRE&EC Statistics (2016)
 - Geothermal potential that is considered as a reserve
 - Ocean energy potential that is considered is practical potential

In general, renewable energy development uses the resource base principle. The power plant must be located near the energy sources considering that most of the potential for renewable energy cannot be traded elsewhere, except for biomass. PLN has also considered the potential use of nuclear energy, especially when fossil energy reserves are running low. National Nuclear Energy Agency (BATAN), as the initiator of the development of nuclear energy power plants, has conducted studies and research, which is quite intense even though regulations from the government have not provided directions for the development of nuclear power plants in Indonesia [4].

2.2.2. Demand and Supply of Electricity. The demand for electricity in the Sumatra region in 2018 was 35 TWh or an increase of 7.5% from the previous year (See Figure 1). The greatest electricity demand is used in the household sector 55%, followed by the industrial sector (18%) and the business sector (17%). During the 2011-2018 period, the household sector continued to dominate electricity use, which means that most electricity was still for consumption purposes, not for industrialization development. Along with the government's program to build Special Economic Zones (KEK), PLN is

expected to be able to meet the electricity demand in the area; therefore the electricity demand for the industrial sector can be increased. PLN is considered capable of fulfilling electricity demand in the KEK area directly by building power plants and transmission lines to the area or transferring captive power.

The PLN Sumatra region currently has the power plant with an installed capacity of 13.4 GW or with a rated capacity of 6.7 GW to meet existing electricity demand. Most of the power plants are in the form of a coal-fired power plant, whose share reaches 34%, followed by gas-fired/gas combined cycle power plant by 30%, hydropower (including large-scale and mini/micro) with a share of 19%, geothermal power plant 10%, and diesel/gas engine power plant by 7%. Several biomass power plants has been built but are still experiencing operational problems. In the future, development of a coal-fired power plants is predicted to remain dominant. The coal power plant will be built as a class capacity of 300 MW and 600 MW which already uses supercritical/ultra-supercritical technology. The coal-fired power plant is prioritized to be built at the mine mouth because there are abundant coal sources in Sumatra. Gas-fired/gas combined cycle power plant is still being developed to carry the peak and medium load (load follower) with capacities ranging from 100 to 800 MW [4].



Source: Calculated from [4][12][13]

Figure 1 Current condition of electricity in the Sumatra region

3. Results and Discussions

Decarbonization is analyzed for the period 2025-2050 by replacing the planned fossil fuel-based power plants with renewable energy-based power plants. For this purpose, it is necessary to make projections of demand and supply of electricity for that period. PLN has made detailed projections of electricity demand and supply by province from 2019-2028. This projection will become the basis for calculations and projections after 2028 using data and literature studies from various sources. Population growth for the long term refers to the Bappenas study [14], while the electricity demand is projected based on the results of the DEN study [15] and Sugiyono et al. study [16]. Based on this data and literature study, the assumptions of population and economic growth can be summarized to make projections of growth in electricity demand in the 2018-2050 period, as shown in Table 2.

Table 2 Assumption of population, economy, and electricity demand growth

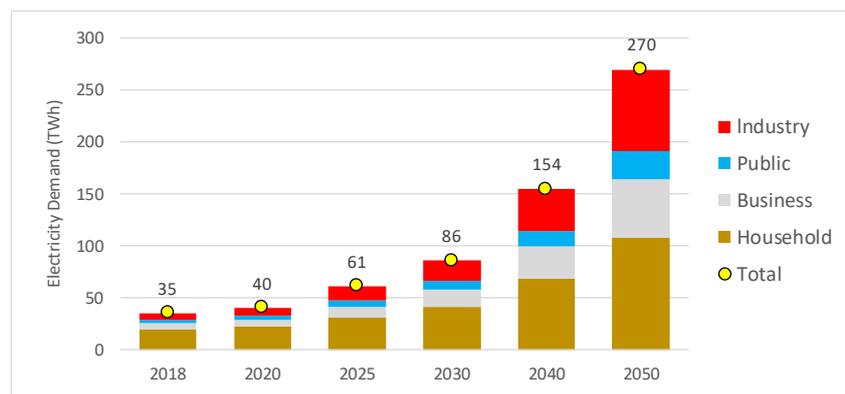
Description	Unit	2018	2020	2025	2030	2040	2050
GRDP	Trillion Rp.	2,229	2,483	3,412	4,794	8,803	15,611
GRDP growth	%	5.6	5.5	6.6	6.9	6.0	5.6
Population	Million	57.8	59.7	63.3	66.3	70.9	73.5
Population growth	%	1.4	1.3	1.1	0.9	0.5	0.3
Electricity demand growth	%	7.5	7.6	6.9	6.7	5.9	5.5

Note: - Gross Regional Domestic Product (GRDP) at 2010 constant market
 - GRDP and population at 2018 based on BPS data [17]

The decarbonization analysis uses two main scenarios: the Business as Usual (BaU) scenario and the decarbonization (DeC) scenario. The BaU scenario estimates electricity demand based on historical growth trends by utilizing energy technology that is already economical nowadays. The DeC scenario is based on demand projection as in the BaU scenario, while the electricity supply projection refers to optimizing the use of renewable energy-based power plants. The potential for renewable energy will be utilized starting in 2025 and increasing gradually so that the total potential will be utilized in 2050. The utilization of nuclear power plant starts in 2030 because it considers the construction time of plant, which is relatively longer than other power plants. The two scenarios are then compared with CO₂ emissions to determine the potential for decarbonization of the electricity system in Sumatra.

3.1. Business as usual scenario

The projection of electricity demand for the BaU scenario is shown in Figure 2. Electricity demand in the Sumatra region will increase from 35 TWh in 2018 to 270 TWh in 2050 or increase by an average of 6.6% per year. The growth in electricity demand in the short term can be higher than in the long term due to the government's program to improve energy access and the quality of life of the people. In line with industrialization efforts, energy demand in the industrial sector has grown by an average of 8.2% per year, which is higher than in the other sectors.



Note: Public sector including social, government buildings and public lighting

Figure 2 Projection of electricity demand in the Sumatra region

The electricity demand is supplied by various type of power plants, both those based on fossil energy (such as; coal-fired, gas-fired, gas combined cycle, diesel, and gas engine power plant), as well as those based on renewable energy (such as; large hydropower, small/medium hydropower, geothermal, and biomass). The projection of electricity supply is calculated based on electricity demand and taken into account important factors such as; rated capacity, load factor, power plant efficiency, and transmission/distribution losses. The generation of electricity with various energy sources is shown in Figure 3.

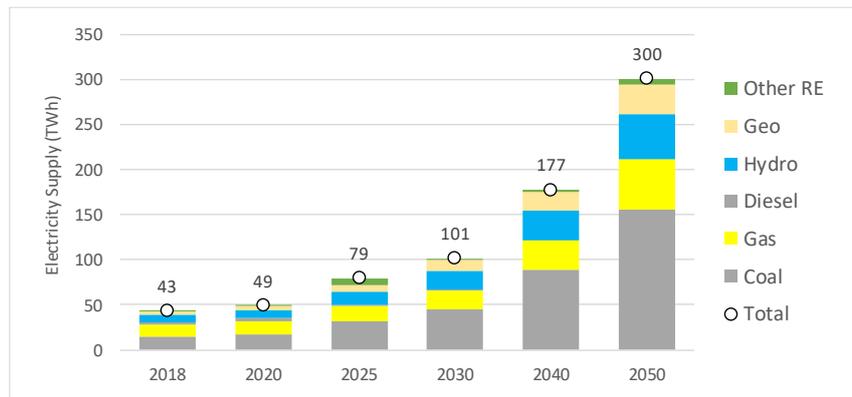


Figure 3 Projection of electricity generation in the Sumatra region

Electricity generation will grow from 43 TWh in 2018 to 300 TWh in 2050 or increase by an average of 6.3% per year during this period. Coal power plants is seen to continue to be dominant in supplying electricity demand with an increasing share from 35% (2018) and to 52% (2050). Following government policy, diesel power plants that are using oil fuel are gradually being reduced because not economical. Meanwhile, other renewable energy power plants increased rapidly by an average of 12.3% per year, but the share remained small during this period.

Fossil fuel-based power plants will produce CO₂ emissions, while renewable and nuclear energy-based power plants are considered to have no emissions. The fossil fuel for power plants under consideration is coal, natural gas, and diesel oil. Emission factors for each type of fuel are the coal of 0.5720, natural gas of 0.3339, and diesel oil of 0.4411 ton CO₂/BOE. The projection of CO₂ emissions from power plants in the Sumatra region is shown in Figure 4. CO₂ emissions increase from 26 million tonnes of CO₂ in 2018 and increase to 163 million tonnes of CO₂ in 2050. CO₂ emissions from power plants are mainly from coal use.

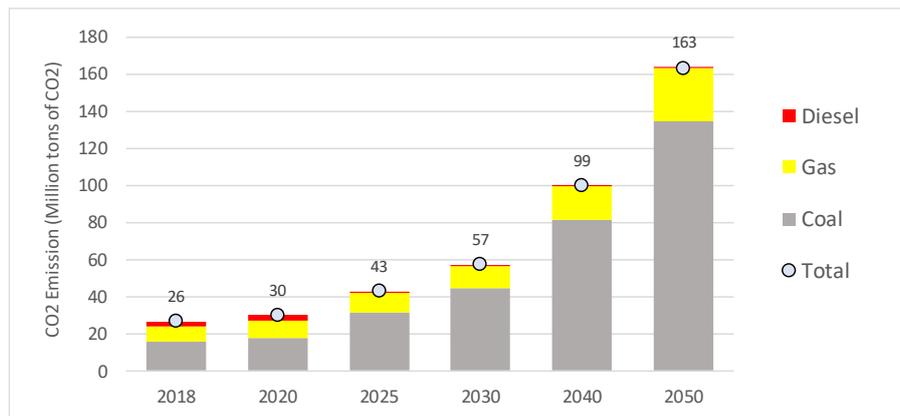


Figure 4 Projection of CO₂ emissions from power plants in Sumatra (BaU scenario)

3.2. Decarbonization pathways

Exploiting all the potential of renewable energy requires new policy breakthroughs in selecting future economic development. The economy is expected to turn towards a green economy slowly. This policy for the electricity sector is in the form of decarbonization, i.e., using power plants with low carbon technology and fuels. Decarbonization options for power plant analyzed for eight renewable and nuclear energy-based technologies, namely: biogas, wind, geothermal, ocean, biomass,

hydropower, solar PV, and nuclear power plant. Each power plant has its strengths and weaknesses in technical and economic terms [1][4][18].

3.2.1. Biogas power plant. The source of fuel from this plant can come from various kinds of waste, such as livestock waste and palm oil mill waste. Biogas power plant from palm oil mill waste is the largest source of fuel with a capacity per unit up to 10 MW. The generation cost is still quite expensive, ranging from 10.08 - 28.03 cents \$/kWh, but it is a business that has prospects in the circular economy era.

3.2.2. Wind power plant. Sidrap and Tolo I wind power plants are the utilization of wind energy, which is already operating commercially in Indonesia. The generation cost is around 10.89 - 11.41 cents \$/kWh with one unit having a capacity of about 2.5 MW. The intermittent wind power plant development must meet the technical, economic, and grid code which applies to the PLN network [19].

3.2.3. Geothermal power plant. The plant is a commercially viable renewable energy-based power plant and currently installed capacity in Indonesia has reached 1,948.3 MW. The generation cost ranges from 11.93 - 12.28 cents \$/kWh depending on the quality of the resource and the condition of the infrastructure. One of the obstacles in developing PLTP is that resources are isolated and far from load centers.

3.2.4. Ocean power plant. This power plant is still in the development stage, and there is no commercial operation yet. The development of ocean energy includes ocean currents and tides. This energy potential needs an inventory with more accurate measurements for a specific area. The generation cost is still prohibitive, above 25 cents \$/kWh.

3.2.5. Biomass power plant. The source of fuel for this power plant mostly comes from agricultural and plantation solid waste. The capacity per unit that is already operating in Indonesia ranges from 2 - 15 MW with a generation cost is around 10.12 - 11.26 cents \$/kWh. The biomass power plant is not intermittent and can be operated as a baseload. The main obstacle in operating this plant is the continuity of fuel supply.

3.2.6. Hydropower plant. This power plant has the cheapest generation cost (around 7.24 cents \$/kWh) with well-established and reliable technology. Currently, the installed capacity of a hydropower plants is more than 4.4 GW, spread across various regions of Indonesia. The capacity per unit that can be generated is equivalent to a fossil fuel power plant in the order of hundreds of MW as long as the potential is available.

3.2.7. Solar PV power plant. The solar PV power plant, which has started to develop with a centralized system and a rooftop. This PV system is equipped with an inverter and allows it to be interconnected with the existing electrical network. This plant is intermittent and requires another power plant as a load follower to compensate for the power fluctuation of the solar PV system. Generation costs range from 5.90 - 18.65 cents \$/kWh, and it is estimated that investment costs will continue to decline over the long term.

3.2.8. Nuclear power plant. The installed capacity of nuclear power plants currently reaches 398.9 GW with 450 units [20]. The planning to develop nuclear power plants in Indonesia has been announced for a long time, although there has been no policy to implement it. The 1,000 MW class pressurized water reactor (PWR) nuclear power plant is a candidate to be considered in the PLN generation planning model. Based on data from the IEA, the generation cost is around 3.44 -13.35 cents \$/kWh [21].

3.3. Potential to reduce CO₂ emission

The calculation results and analysis based on each the power plant options show that the reduction in CO₂ emission in the short term is only relatively small. In 2030, emission could be around 0.1% - 4.8% for renewable energy-based power plant and up to 20.3% for the nuclear power plant from the total CO₂ emission of 57 million tons of CO₂. By 2050 the real potential of renewable energy has been utilized to substitute fossil fuel-based power plants. The nuclear power plants option with a capacity of 29 GW can 100% reduce CO₂ emission, which reaches 163 million tons of CO₂. Nuclear power plants are the best option in the process of decarbonization of power plants in the Sumatra region (See Figure 5). The solar PV option can reduce emissions by up to 86.5% with a capacity of 68.7 GW, but it is technically not possible because solar PV is an intermittent power plant. The intermittent power plant capacity must be smaller than the total capacity of a continuous power plants because it cannot operate continuously for 24 hours. The capacity of the solar PV option has exceeded than continuous power plant that can operate as its load follower.

Meanwhile, a biomass power plants can reduce emission by 53.5% with a capacity of 15.2 GW. This option often experiences operational constraints related to the continuity of fuel supply. The biomass power plant option is less prospective in decarbonizing of power plant because the scale of generating capacity per unit is still relatively small. The hydropower plant can reduce emissions by up to 79.2% with a capacity of 21.3 GW. The next potential option is a geothermal power plant, which can reduce emissions by 27.4% with a capacity of 7.4 GW. Hydropower and geothermal power plant have been proven reliable and can be utilized in a large scale capacity. Other options, such as wind, ocean, and biogas power plant, only reduce CO₂ emissions by less than 20%.

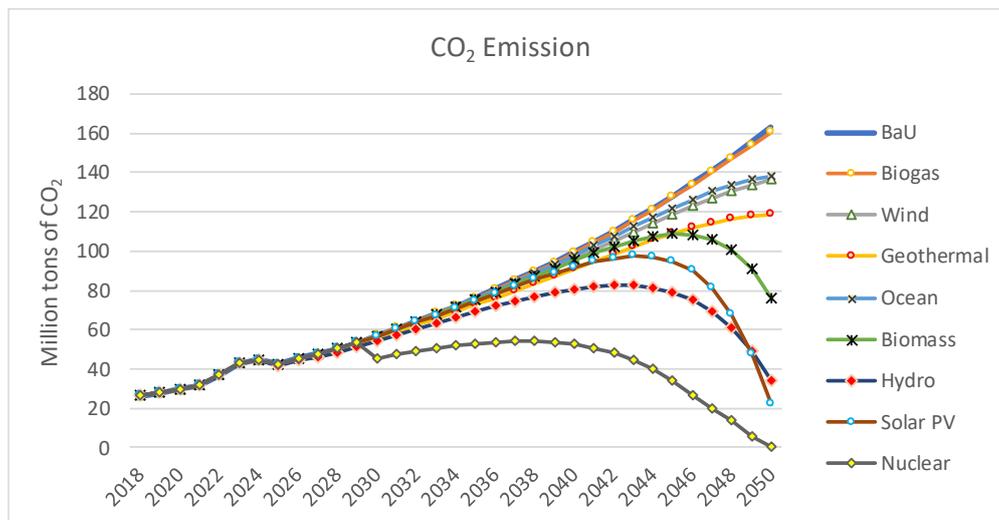


Figure 5 Reducing CO₂ emissions with various decarbonization of power plant options

4. Conclusion and recommendation

The government continues to make efforts to achieve low carbon development or carry out decarbonization. For the electricity sector, the use of renewable energy and nuclear-based power plants is an option to realize these efforts. The Sumatra electricity system is the second-largest interconnection system after Java-Bali electricity system. This region has electricity demand that will grow from 35 TWh in 2018 to 270 TWh in 2050 or an increase by an average of 6.6% per year. In the BaU scenario, electricity demand is met by various power plants, both those based on fossil energy and renewable energy. Coal power plants still dominates the electricity supply with an increasing share from 35% (2018) and to 52% (2050). Under these conditions, CO₂ emissions will increase from 26 million tons of CO₂ in 2018 to 163 million tons of CO₂ in 2050.

In the DeC scenario, it can be seen that the most significant potential for decarbonization of the electricity system in the Sumatra region is the use of the nuclear power plant, which can reach 100% by 2050. The next potential decarbonization option is hydropower plant, which can reach 79.2% with a capacity of 21.3 GW, followed by a geothermal power plant, which can reduce emissions of 27.4% with a capacity of 7.4 GW. Combining of these three power plants with a particular share is a prospective combination for the decarbonization option in the electricity system in the Sumatra region.

Calculations can be developed further to analyze the impact of decarbonization on the generation cost of electricity. Utilizing low carbon technology in the short term will increase generation costs directly. However, in the long run, the overall economy will be better off. The primary key is quantifying the impact of environmental damage economically due to the use of fossil energy. The use of low carbon technology that is environmentally friendly will improve the quality of the community's living environment, therefore the environmental damage in the long term can be minimized.

Author Contributions

All authors contributed equally to this work. All authors discussed the results and implications and commented on the manuscript at all stages.

References

- [1] MEMR, *Handbook of Energy & Economic Statistics of Indonesia*, Ministry of Energy and Mineral Resources, Final Edition, Jakarta, 2018.
- [2] EIA, *Capital Cost Estimates for Utility Scale Electricity Generating Plants*, U.S. Energy Information Administration, 2016.
- [3] DEN, *Ketahan Energi Nasional 2019*, Dewan Energi Nasional, Jakarta, 2019.
- [4] PLN, *Rencana Usaha Penyediaan Tenaga Listrik PT PLN (Persero) 2019-2028*, PT PLN (Persero), Jakarta, 2019.
- [5] Kemenlu, Special Issues: Climate change, Kementerian Luar Negeri, 07/April/2019, *kemlu.go.id*, accessed on March 11, 2020.
- [6] GPI, *Road Map to Decarbonization in the Midcontinent: Electricity Sector*, Great Plains Institute, 2018.
- [7] Bappenas, *Low Carbon Development: A Paradigm Shift Towards a Green Economy in Indonesia*, Ministry of National Development Planning, 2019.
- [8] UWR Siagian, RG Dewi, R Boer, I Hendrawan, BB Yuwono, and GE Ginting, *Pathways to deep decarbonization in Indonesia*, SDSN – IDDRI, 2015.
- [9] IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, Kanagawa, 2006.
- [10] MC Anwar, Tol Listrik Sumatera Bikin PLN Hemat Rp 163 M per Bulan, *CNBC Indonesia*, News, 10 March 2020.
- [11] Ditjen EBTKE, *Statistik EBTKE 2016*, Direktorat Jenderal Energi Baru Terbarukan dan Konservasi Energi, 2016.
- [12] Ditjen Gatrik, *Statistik Ketenagalistrikan 2018*, Direktorat Jenderal Ketenagalistrikan, Kementerian ESDM, 2019.
- [13] PLN, *PLN Statistik 2018*, PT PLN Persero, 2019.
- [14] Bappenas, *Indonesia Population Projection 2010-2035*, Bappenas, BPS and UNPF Publication, Jakarta, 2013.
- [15] DEN, *Outlook Energi Indonesia 2019*, Dewan Energi Nasional, Jakarta, 2019.
- [16] A Sugiyono, Anindhita, I Fitriana, LOMA Wahid, dan Adiarso (Editor), *Outlook Energi Indonesia 2019: Dampak Peningkatan Pemanfaatan Energi Baru Terbarukan Terhadap Perekonomian Nasional*, BPPT, Jakarta, 2019.
- [17] BPS, *Statistik Indonesia 2018*, Badan Pusat Statistik, Jakarta, 2019.
- [18] I Fitriana, Anindhita, A Sugiyono, LOMA Wahid, dan Adiarso (Editor), *Outlook Energi Indonesia 2017: Inisiatif Pengembangan Teknologi Energi Bersih*, BPPT, Jakarta, 2017.

- [19] Ditjen Gatrik, Kebijakan Peningkatan Pemanfaatan EBT untuk Pembangkit Tenaga Listrik, *Seminar Road to Energy Transition*, METI, Jakarta, 12 September 2019.
- [20] S Krikorian, Preliminary Nuclear Power Facts and Figures for 2019, *IAEA*, www.iaea.org, Jan 2020.
- [21] IEA, *Projected Costs of Generating Electricity*, International Energy Agency, Paris, 2015.