Using Multi-Attribute Decision Making to Compare Ocean, Wind, Solar, Geothermal and Hydro Renewable Energy Business Options in Indonesia[1]

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ABSTRACT

Indonesia has a target using renewable energy in the national energy mix of 23% in 2025 and 31% in 2050. But, by 2018, the installed capacity of renewable energy power plants 2.13% from the total potential renewable energy in Indonesia. Along with that, with the prediction, the earth will face global cooling instead of global warming in 2020 – 2050 because of the grand solar minimum. Therefore, the utilization plan of renewable energy must align with grand solar minimum phenomena.

This paper is developed to find whether the plan to use of renewable energy up to 2050 is appropriate regarding grand solar minimum effect and seek what is renewable energy solution to align with grand solar minimum.

In this paper, the author demonstrates using dominance and non-dimensional scaling multi-attribute decision making to determine the best option for renewable energy business for Indonesia covers the effect of grand solar minimum, total life cycle cost, availability capacity factor, feed-in tariff, energy supply potential, and Government's regulation. The paper concludes that Geothermal and Hydropower covers most conditions and align with the grand solar minimum.

Key words: Grand Solar Minimum, Renewable Energy, National Energy Potential, Geothermal, Solar, Hydro Power, Wind energy, Ocean energy, Dominance, Non-dimensional Scaling Multi-attribute

INTRODUCTION

1. 1. Grand Solar Minimum

From 1645 to 1715 and 1790 to 1820, “Temperatures across the Northern Hemisphere plunged when the Sun entered a quiet phase now called the Grand Solar Minimum (GSM). During this period, very few sunspots appeared on the surface of the Sun, and the overall brightness of the Sun decreased slightly.”[2] “Already in a colder-than-average period called the Little Ice Age,

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[2] Nasa.(2006). Chilly Temperatures During The Maunder Minimum. Retrieved from https://earthobservatory.nasa.gov/images/7122/chilly-temperatures-during-the-maunder-minimum

Europe, and North America went into a deep freeze."[3] This research has been conducted by Valentina Zarkova, which is linked the solar activity to the average sunspot number resemblance report in the past on Maunder Minimum (1645 – 1715) and Dalton Minimum (1790-1820). It predicts the modern grand solar minimum will approaching the sun in 2020 -2055.

This cycle is driven by a magnetic field, which produces sunspots, fire, bright areas, and other disturbances. For this reason, the luminosity of the sun changes from year to year. These changes have subtle but essential influences on the Earth's climate. Solar behavior is consistent with the decrease in solar luminosity and must be accompanied by a colder climate on Earth.

"An uptick in high-level volcanic eruptions is also associated with low solar activity. Increasing Cosmic Rays are believed to heat the muons in subsurface silica-rich magma. And larger eruptions (ones that fire volcanic ash above 32,800 feet (10 km) and into the Stratosphere) have a direct cooling effect on the planet, as these ejected particulates effectively block out the sun."[4]

"Using computer climate models, the researchers of the new study concluded that, if an eruption like Mount Tambora's happens in 2085, the Earth will cool up to 40 percent more than the 1815 eruption, assuming current rates of climate change continue. However, they also predict that the cooling will be spread out over several years."[5]

1. 2. Supply and Demand Energy in Indonesia

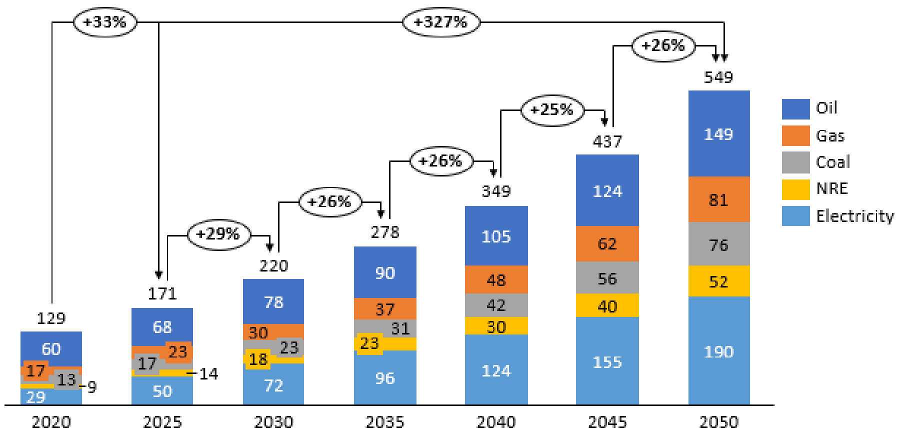

Figure 1. Energy Demand in Indonesia in Mtoe[6]

[3] Morano,Marc. (2018). Solar Minimum May Bring 50 Years of Global Cooling. Retrieved from https://www.climatedepot.com/2018/02/08/solar-minimum-may-bring-50-years-of-global-cooling/
[4] Allon.Cap.(2019). Professor Valentina Zharkova's "Expanded" Analysis Still Confirms Super Grand Solar Minimum (2020-2025). Retrieved from https://electroverse.net/professor-valentina-zharkovas-expanded-analysis-still-confirms-super-grand-solar-minimum-2020-2055/
[5] Hess.Peter.(2017). Future Volcanic Eruptions Will Screw With Climate Change More Than Before. Retrieved from https://www.inverse.com/article/37941-volcano-eruption-climate-change
[6] National Energy Council. (2019). Indonesia Energy Outlook 2019.

Based on data from Outlook Energy in Indonesia 2019, show in 2050, Indonesia's energy demand three times higher compared to 2020, with the most significant portion in the oil and electricity sector.

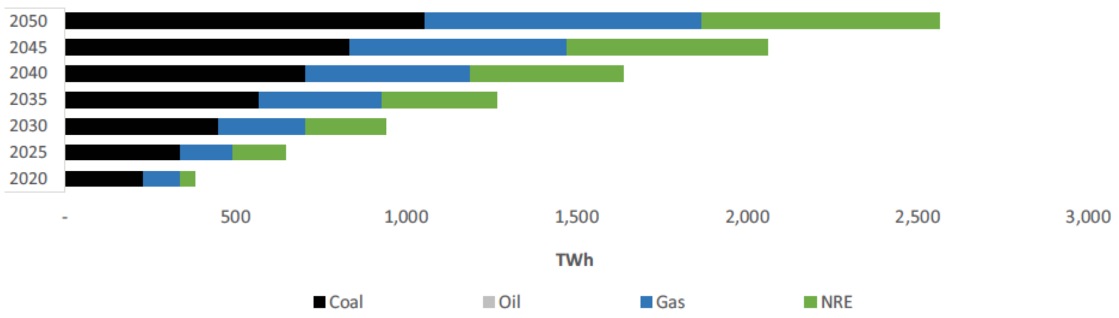

Figure 2. Electricity production by energy type[7]

In 2050 electricity production will reach 2.562 Twh and still will be dominated by the coal-generated power plant. But decrease the portion from 57% in 2018 to 41% in 2050 for coal production. Otherwise, the proportion of Renewable energy generated for electricity will increase from 12.4% in 2018 to 27% in 2050.

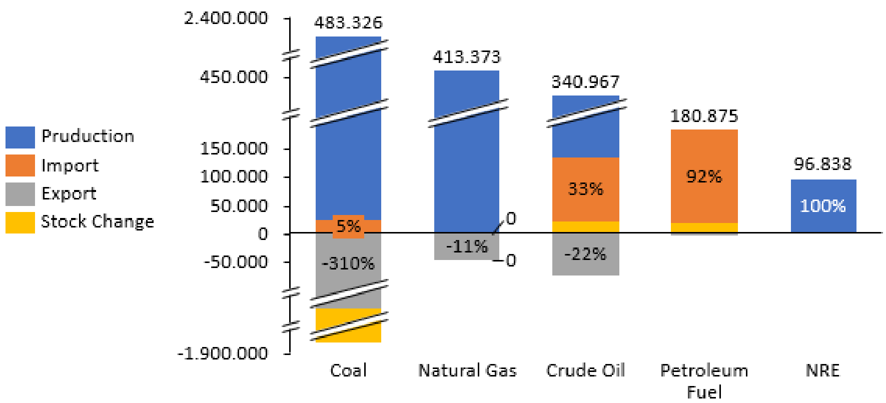

Figure 3. Indonesia Energy Balance 2019 in Thousand BOE[8]

Data from ESDM on figure 3 show supply production from coal mainly is being exported, 89% natural gas production is used for domestic consumption, 33% crude oil and 92% petroleum fuel is imported, and 100% renewable energy is produced and used for local consumption.

From figure one until three, we can conclude from now until 2050 that oil demand in Indonesia is still increasing, but supply oil will be dominated by import. Demand for coal, mostly for electricity, is still growing but can be fulfilled with Indonesia's domestic production. Renewable energy demand will be increasing and need to explore other renewable energy options to fulfill the demand until 2050.

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[7] National Energy Council. (2019). Indonesia Energy Outlook 2019.
[8] Ministry of Energy and Mineral Resources Republic of Indonesia.(2019). Handbook of Energy Economic Statistic of Indonesia.

METHODOLOGY

Step 1 - Problem Statement

With the prediction the earth will face global cooling instead of global warming in 2020 – 2050 and energy demand in Indonesia will reach 327% in 2050, we must find potential solutions regarding the grand solar minimum effect. And also, To become energy independence from dependence from import, we have looking for energy alternative coming possibility Indonesia has much reserve in renewable energy. The objective of this paper is:

- To explore whether the plan to use of renewable energy up to 2050 is appropriate regarding the grand solar minimum effect
- To find potential renewable energy solution to align with grand solar minimum phenomena

Step 2 - Renewable Energy Potential in Indonesia

The declining fossil fuel energy potential, especially oil and gas, has encouraged the government to increase the utilization of renewable energy as a main priority to maintain energy security. With an energy perspective as a development capital, renewable energy plays a vital role in driving a green, sustainable, and low carbon emission. Development with this long term awareness has become a development trend throughout the world, Renewable energy potential in Indonesia is enormous but currently has not been utilized maximally and spread out across the country. Renewable energy potential in Indonesia is not limited to solar PV, hydro, wind, geothermal, biomass, and ocean energy resources. Renewable energy potential in Indonesia reaches 443 GW, but renewable energy utilization until 2015 only reaches 1.9% from total potential. Detail for renewable energy potential distribution per sector shown in figure 4.

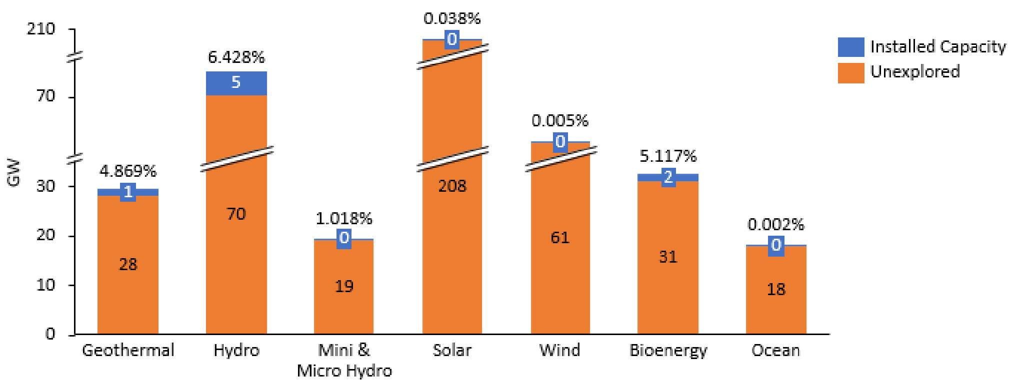

Figure 4. Renewable Energy Potential in Indonesia by 2015[9]

Solar energy resources in Indonesia has the highest number, more than 207MW and followed by hydro and wind energy. Even Indonesia has broad and diverse renewable energy potential, but the utilization of renewable energy remains low.

[9] Perpres RI. (2017). Peraturan Presiden RI No 22 Tahun 2017 :Rencana Umum Energi Nasional.

"Indonesia has a target using renewable energy in the national energy mix of 23% in 2025 and 31% in 2050."[10] This target is equivalent to 45.2 GW of renewable energy power plants by 2025. But, as of 2018, the installed capacity of renewable energy power plants is 9.471GW or only 2.13% of 443 GW from the total potential renewable energy in Indonesia[11]. The target for every energy sector, as shown in figure 5 below:

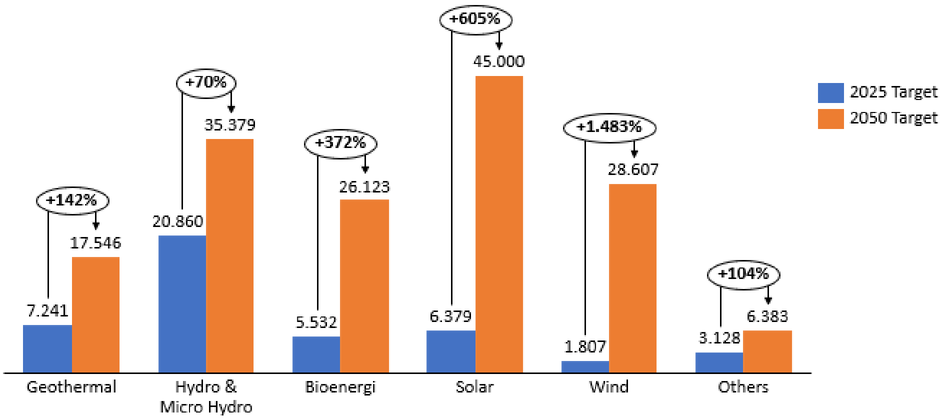

Figure 5. Development Target of Renewable Energy in GW [12]

Renewable Energy development in Indonesia is still left behind when compared to the G20 countries that are making a transition to a low carbon economy to achieve the Paris Agreement target. Indonesia has challenging homework to make use of renewable energy and reduce dependence on fossil energy.

Step 3 - Renewable Energy Resources

3. 1. Ocean

Ocean energy is an emerging technology with 532 MW installed globally by the end of 2018 (IRENA, 2018). While none of this has been installed in Indonesia. This can be considered ambitious, given the immaturity of the technology. There are three types of ocean energy:

- Tidal
  "Tidal power converts the energy from the natural rise and fall of the tides into electricity. Tides are caused by the combined effects of gravitational forces exerted by the moon, the sun, and the rotation of the earth. Tidal energy can only be installed along the coastlines. Coastlines often experience two high tides and two low tides daily. The difference in water levels must be at least 5 meters high to produce electricity. The adoption of tidal technologies has been slow, and the amount of power generated from tidal power plants is very small. This is largely due to the particular site requirements necessary to produce tidal electricity. Additionally, the tide cycle does not always match the daily consumption pattern of electricity and, therefore, does not provide sufficient capacity to satisfy the demand."[13]

[10] Perpres RI. (2017). Peraturan Presiden RI No 22 Tahun 2017: Rencana Umum Energi Nasional.
[11] IRENA.(2019). Renewable Capacity Statistic 2019. International Renewable Energy Agency (IRENA), Abu Dhabi.
[12] Perpres RI. (2017). Peraturan Presiden RI No 22 Tahun 2017: Rencana Umum Energi Nasional.
[13] Kabeya, Annick.(2019.) Tidal Power.Calgary: Canada. Student Energy. Retrieved from https://www.studentenergy.org/topics/tidal-power

- Wave
  "Wave energy is energy harnessed from the ocean or sea waves. The rigorous vertical motion of surface ocean waves contains a lot of kinetic energy that is captured by wave energy technologies." [14]
- Ocean Thermal Energy Conservation (OTEC)
  Use the ocean's natural thermal gradient to drive a power-producing cycle. The fact that the ocean's layers of water have different temperatures.

As per today, only the potential of ocean currents has been measured, and the potential for wave and OCTD has not been assessed in detailed yet. Detail energy potential for tidal in Indonesia shown in table 1 below:

Table 1 Tidal Energy Potential in MW[15]

Region	Potential
West Nusa Tenggara	8,644
Riau Island	6,027
West Java - Lampung	2,273
West Papua	391
East Nusa Tenggara	333
Bali	320
Total	17,988

The biggest potential tidal energy is in Riau island, and Alas Strait in West Nusa Tenggara with the current velocity across location varies from 1.39 to 3 m/s and lasts for only about two hours of the day.

The disadvantages of ocean energy are expensive to build, which is required huge capital outlay, maintenance, and actual cost, also challenging to capture since ocean energy is in an early stage of development. Not only that, but ocean energy also damages the sea life ecosystem and has environmental effects such as fish and plant migration, silt deposits and has the potential to pollute the water from hydraulic fluid from the device resulting in marine life deaths. On the other side, ocean energy face challenge for connection to the grid because located in the ocean, technology is not fully developed and can be produced only 10 hours out of the day even though tidal energy is more predicted that wind and solar energy.

Ocean energy is not covered by specific regulations since there is no commercial plant that has been built in Indonesia.

3. 2. Wind

Wind energy source comes from air movement due to changes in air temperature due to heating from solar radiation. Wind Energy Potential in Indonesia Naturally is relatively small because

[14] Rinkesh.(2019). What is Wave Energy. Retrieved from: https://www.conserve-energy-future.com/waveenergy.php
[15] Perpres RI. (2017). Peraturan Presiden RI No 22 Tahun 2017: Rencana Umum Energi Nasional.

Indonesia located in the equator. However, there are regions which geographically has wind potential because it's a nozzle effect area or narrowing between two islands or mountain slope area between two adjacent mountains. Based on preliminary study, Wind potential in Indonesia spread out in Jawa and Sulawesi with wind speed from 2.2 to 7.5 m/s, with the most significant potential is in East Nusa Tenggara.

Table 2 Wind Energy Potential in MW[16]

Region	Wind Energy Potential
Papua	1,848
Kalimantan	2,586
Sulawesi	8,380
Sumatra	7,397
Jawa	22,992
Bali - Nusa Tenggara	13,812
Maluku	3,692
Total	60,707

In Indonesia, modern wind turbine technology not yet fully mastered, so research is still needed, which is intensive to develop wind turbines that match with potential wind energy in Indonesia. The government needs the effort to do commercialization of Wind energy technology besides encouraging manufacturing local to develop its production capacity. In Indonesia, investment growth private sector in the construction of wind turbines must also be driven by feed policies in tariffs that are attractive to investors. There is no feed-in tariff for wind power, and projects underway have been negotiated directly with PLN.

There are challenges to applying wind technologies in Indonesia, mostly because of the more complex installation process, difficulties in transportation of wind towers and blades. The other key factor, un-favored wind, is because the speeds are lower in Indonesia compared to other countries that have commercialized wind. The slow development of wind power in Indonesia also due to policy and regulatory barriers, as well as the grid capacity and readiness of PLN's system to address intermittency challenges. "Offshore wind energy has not been included in Indonesia's renewable energy ambitions because the application is not viable at present due to the potential is mainly in the Indian ocean, where costs are anticipated to be high due to sea depth."[17]

The difference between onshore and offshore wind turbine as illustrated in the figure below:

[16] Perpres RI. (2017). Peraturan Presiden RI No 22 Tahun 2017: Rencana Umum Energi Nasional.
[17] Victor, Pamela. (2018). Indonesia's Wind Energy Potential. Retrieved from https://theaseanpost.com/article/indonesias-wind-energy-potential

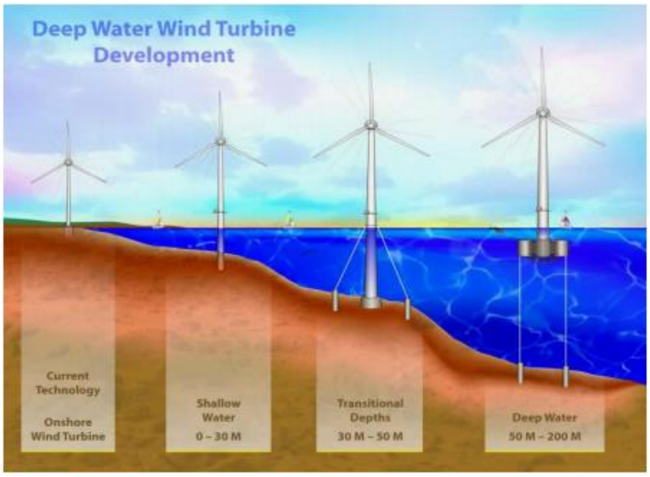

Figure 6 Deepwater Wind Turbine Development [18]

In Indonesia, wind energy is not covered by specific regulation now, although a feed-in tariff is under discussion.

3. 3. Solar

Solar power through solar cell device works by converting sunlight into electricity. Power generation using solar energy has a big potential in Indonesia. This is led by an uneven distribution of electricity across Indonesia, which causes to low electrification rate and frequent blackout in Indonesia. Indonesia, as a tropical country, has enormous solar energy potentials due to being located on the equator, with solar radiation of 4.80 kWh/m2/ day. This challenge could be overcome using solar technologies. Solar energy is an intermittent energy source, producing electricity in a fluctuating amount. In operation, a backup energy system is needed as support to anticipate when the intensity of sunlight has decreased due to the cloud or in the evening. So, for each region with different sun radiation intensity, a different study is also needed to assess the feasibility of the Solar PV project, especially for a large scale.

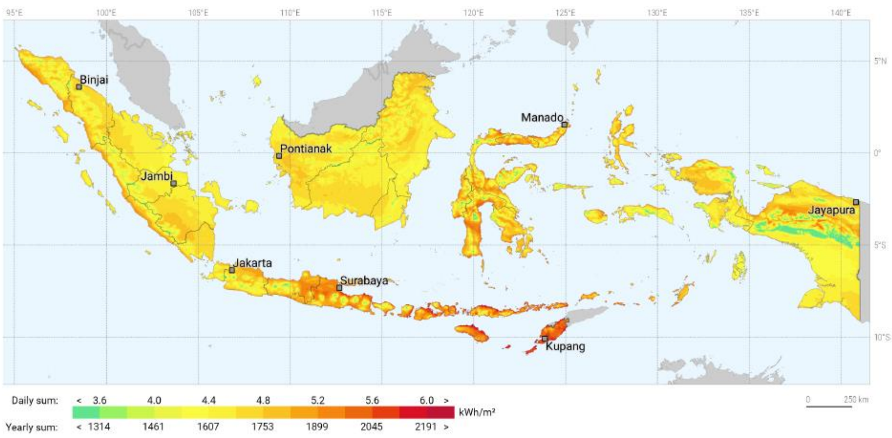

Figure 7 Indonesia Global Horizontal Irradiation[19]

[18] Breithaupt, Nikolaus Benedikt. (2015). "Dynamic Penetration of a Flying Wing Anchor in Sand in Relation to Floating Offshore Wind Turbines" Open Access Master's Theses. Paper 678. http://digitalcommons.uri.edu/theses/678
[19] Solargis.(2019). Global Horizontal Irradiation. Retrieved from https://solargis.com/maps-and-gis-data/download/indonesia

Global Horizontal Irradiation (GHI) is used as a reference value for comparing solar potential related to the PV electricity system, as it eliminates the possible variations, given by choice of technical components and the PV system design.[20]

The Highest GHI is identified in southern Indonesia, with the average daily totals reach 5.6 kWh/m2. Northern Indonesia has an average daily total of GHIS between 3.8 kWh/m2 and 4.8 kWh/m2. Figure 7 shows that the energy potential for solar PV is not spread evenly; only southern Indonesia has significant potential.

The current regulations in Indonesia do not support the demand growth for solar panels**:**

- PermenESDM No.12/2017 sets a very low selling price from IPP to PLN (85% local bare electricity production cost) [21]
- PermenESDM No.50/2017 obligates BOOT scheme for IPP business in selling electricity to PLN[22]
- PermenESDM No.49/2018 regulates a net metering scheme for residential with a low selling price to PLN (65% of electricity price)[23]
- PermenPerin No.05/2017 sets a high minimum local content of PV modules (60% from 2019; 40% from 2018)[24]

And some regulation support market growth in Indonesia:

- PermenKeu No.110/2018 set[25]
  - free import tax for PV modules from overseas, and
  - moderate (5% - 19.5%) import tax for PV modules components

3. 4. Hydro

Hydropower is energy derived from falling or flowing the water to drive a water turbine and generate electricity. Hydropower plants consist of basic configuration with dams and reservoirs or without.[26] Regarding the various scale of hydropower, there is still no internationally agreed definition. In Indonesia, micro-hydropower has potential up to 1 MW, mini-hydro up to 10 MW, and hydro more than 10 MW.

Micro-hydro utilizes heights and the amount of water from river water flow or irrigation to generate electricity. Micro-hydro can produce enough electricity for home, farm, ranch, or village, mostly target rural electrification. Mini hydro is generated with diverting river water by

[20] World Bank Group (2017). Solar Resource and Photovoltaic Power Potential of Indonesia.Washington DC : ESMAP
[21] Permen ESDM. (2017). Peraturan Menteri ESDM No 12 tahun 2017.
[22] Permen ESDM. (2017). Peraturan Menteri ESDM No 50 tahun 2017
[23] Permen ESDM. (2018). Peraturan Menteri ESDM No 49 tahun 2018
[24] Permen Perin. (2017). Peraturan Menteri Perindustrian No 05 tahun 2017
[25] Permen Keu. (2018). Peraturan Menteri Keuangan No 110 tahun 2018
[26] IRENA.(2019). Hydropower. International Renewable Energy Agency (IRENA). Retrieved from: https://www.irena.org/hydropower

making a dam. Water collected, and water rotates through the turbine and is returned to the river. Meanwhile, hydropower with a scale of more than 10 MW is similar to mini-hydro but with a more complex system and bigger capacity. The illustrated between micro and hydro, as described in figure 7 below on the left side, is micro-hydro power, and the right side is hydro.

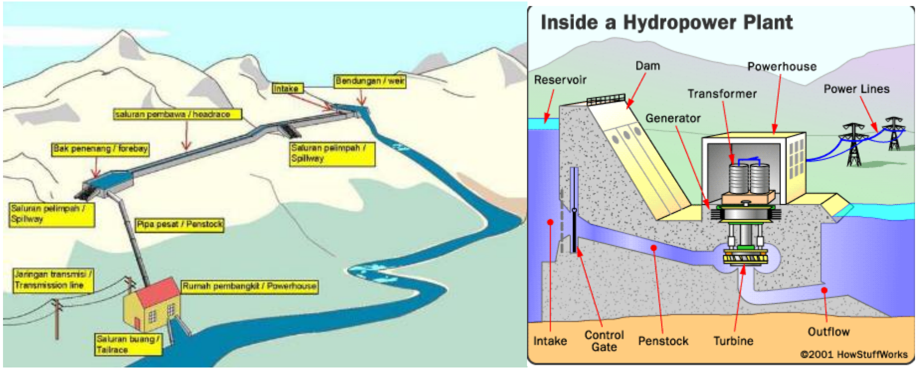

Figure 8 Micro Hydro[27] and Hydro Power[28]

Hydro Power generation and mini/micro hydropower generation are spread across the country with the potential reach of 94.476 GW and utilization only 5.8% from total potential.

Table 3 Hydro Power Potential in MW [29]

Region	Hydro	Mini/Micro Hydro
Papua	22,371	618
Kalimantan	21,581	8,100
Sulawesi	10,307	1,668
Sumatra	15,579	5,734
Jawa	4,199	2,910
Bali - Nusa Tenggara	624	141
Maluku	430	214
Total	75,091	19,385

With the most significant potential in Papua reaches 22 GW and Kalimantan reach 29 GW. Hydropower generation is not only flexible in production, but it can also produce fast as long as there is adequate water in the reservoir.

The development of environmental change and changes in the function of forests affect the potential and sustainability of hydropower utilization. The downside of using hydropower when in the dry season. If a drought occurs, it will immediately raise the threat of an electricity crisis. When the flow of river water decreases, it will cause a hydropower capacity to drop by 60%. The lack of water debit is exacerbated because the government will reduce the use of water for electricity generation in some reservoirs and irrigation in the dry season to be diverted for the

[27] Sukardi.(2019).Pembangkit Listrik Mikrohidro Tingkatkan Perekonomian Indonesia. Retrieved from https://indonesiadevelopmentforum.com/2018/ideas/4452-pembangkit-listrik-mikrohidro-tingkatkan-perekonomian-indonesia
[28] Taufan,Mufid.(2019). Prinsip Kerja PLTA. Retrieved from https://mufidtaufan.wordpress.com/prinsip-kerja-plta/
[29] Perpres RI. (2017). Peraturan Presiden RI No 22 Tahun 2017: Rencana Umum Energi Nasional.

benefit of food production. This is one of the government's efforts to maintain food supplies during the dry season.

Several regulations support market growth for Hydropower in Indonesia:

- Permen ESDM No 19/2015 sets the purchase of electricity from hydropower with a capacity of up to 10 MW by PT PLN.[30]
- Permen PUPR No 09/2016 sets the procedure for implementing the cooperation between the government and business entities in the utilization of water resources infrastructure for the construction of hydroelectric, micro/mini hydroelectric power plants.[31]

3. 5. Geothermal

"Geothermal is a source of heat energy contained in hot water, water vapor, and rocks along with associated minerals and other gases"[32] trapped beneath the earth's surface. Geothermal heat found in the volcanic areas commonly comes from magma. Volcanoes can be attractive for geothermal energy development. Indonesia is a country with enormous geothermal potential spread across the country; most of them have low to medium enthalpy. The country's geothermal reserves amount roughly around 29 GW or equivalent to 40% of the world's total reserves[33]. This potential is because geographical of Indonesia located in the pacific ring of fire. The existence of these sources of geothermal extending the volcanic mountain ranges from Sumatra, Jawa, Bali, Nusa Tenggara, North Sulawesi, and Maluku, with 312 potential points. By 2018 Currently, the existing plants have covered only 1.948,5 MW capacity or only 6.7% from total capacity[34]. This indicates that a lot of geothermal potential in Indonesia has not been fully optimized. Furthermore, with RUEN target to meet national electricity needs with 23% of that amount is expected to come from renewable energy, and by 2025 the target for geothermal is 7.2GW. However, a significant gap between target ramp-up and to date capacity is still huge.

However, since most of those potentials are low to medium enthalpy heat, Indonesia needs to establish mature binary/ flash technology to utilize those potentials. Several other challenges also make geothermal more challenging to achieve the ambitious target. Those challenges include the cost to build geothermal power plants and the remote location of geothermal mines. Economically, the capital cost to build a geothermal power plant is less appealing than the capital cost needed for fossil fuel power plant construction. Then, geothermal locations are located in the mountainous areas, where the topography and soil surface conditions are challenging to reach. Also, some geothermal reserves are located in protected forest areas and national parts, which is prohibit any mining activities. Nevertheless, Perpres No 21/2014 excluded activities

[30] Permen ESDM. (2015). Peraturan Menteri ESDM No 19 tahun 2015
[31] Permen PUPR. (2016). Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat No 09 tahun 2016.
[32] Azzam,I., & Hendrasto,F.(2019). Hydrogeochemical Study Of Ciseeng Thermal Springs, West Java Province, Indonesia. Retrieved from https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/14110.pdf
[33]OJK.(2017). Renewable Energy for Indonesia. Retrieved from https://www.ojk.go.id/sustainable-finance/id/publikasi/riset-dan-statistik/Pages/RENEWABLE-ENERGY-FOR-INDONESIA-2017.aspx
[34] ESDM.(2019). Laporan Kinerja Tahun 2018.

related to geothermal as mining activities. This law has successfully created a breakthrough in geothermal extraction.

Table 4. Geothermal Potential in MW[35]

No	Island	Total Location	Resources		Reserve			Total
			Speculative	Hypotethical	Possible	Probable	Proven	
1	Sumatra	93	3,182	2,519	6,790	15	380	12,979
2	Jawa	73	1,560	1,737	4,023	658	1,815	9,866
3	Bali -Nusa Tenggara	33	412	431	1,049	0	15	1,940
4	Sulawesi	76	1,239	343	1,419	150	78	3,305
5	Maluku	32	532	89	800	0	0	1,453
6	Kalimantan	14	163	0	0	0	0	177
7	Papua	3	75	0	0	0	0	78
Total		324	7,163	5,119	14,081	823	2,288	29,798

3. 6. Cost of Generating Electricity

3.6.1. *Total Life Cycle Cost*

Table 5 Cost & Efficiency Data of Power Generation[36]

Power Plant	Investment Cost (thousand USD/ MW)	Fixed Cost O&M (Thousand USD/ MW)	Variable Cost O& M (USD/ MWh)	Fuel Efficiency	Availability Capacity Factor
Geothermal	2300	40	0.7	25%	80%
Hydro Power	2300	54	3.8	25%	41%
Micro Hydro	3100	61	3.8	25%	46%
Solar	1800	23	0.4	25%	15 - 19%
Onshore Wind	1400	37	0.8	25%	35%
Tidal	NA	NA	NA	NA	NA

3.6.2. *Feed-in Tariff*

Feed-in tariff prices for purchasing energy prices based on the cost of producing new and renewable energy. Renewable Energy Feed-in Tariff by Energy Sector is:

a. Solar Power Plant
   Based on Permen ESDM No 17/2013 electricity purchase price will be 25 cents USD/kWh. If using local content, at least 40% of Feed-in Tariff will be 20 cents USD/kWh.[37]

b. Geothermal Power Plant
   Based on Permen ESDM No 17/2014 for highest benchmark price for commercial of date of a geothermal plant every year the electricity price is:

[35] ESDM. (2017). Kajian Penyediaan dan Pemanfaatan Migas, Batubara, EBT dan Listrik, 1st ed.
[36] National Energy Council.(2016). Indonesia Energy Outlook 2016. Jakarta.
[37] Permen ESDM.(2013). Peraturan Menteri ESDM No 17 tahun 2013

Table 6 Feed-in Tariff for Geothermal Power Plant in cents USD/kWh[38]

Year COD	Region I	Region II	Region III
2015	11.8	18	25.4
2016	12.2	17.6	25.8
2017	12.6	18.2	26.2
2018	13	18.8	26.6
2019	13.4	19.4	27
2020	13.8	20	27.7
2021	14.2	20.6	27.8
2022	14.6	21.3	28.3
2023	15	21.9	28.7
2024	15.5	22.6	29.2
2025	15.9	23.3	29.6

Region I: Sumatra, Jawa & Bali
Region III: Sulawesi, Nusa Tenggara, Maluku, Papua, Kalimantan
Region III: isolated transmission on Region I & II

Using PERT formula with P90 for each region and average the result give Feed-in tariff geothermal power plant is 21 cents USD/kWh.

c. Hydro Power Plant
As per Permen ESDM 19/2015, the electricity purchase cost shall follow:

Table 7 Feed-in Tariff for Hydro Power Plant[39]

Generating Capacity	Region	Feed in Tariff (cent USD/kWh)
Medium Voltage up to 10MW	Jawa, Bali & Madura	9.3
	Sumatera	10.23
	Kalimantan & Sulawesi	11.16
	Nusa Tenggara	11.625
	Maluku	12.09
	Papua	14.88
Low Voltage up to 250 kW	Jawa, Bali & Madura	12.1
	Sumatera	12.1
	Kalimantan & Sulawesi	13.2
	Nusa Tenggara	13.75
	Maluku	14.3
	Papua	17.6

Calculating using PERT formula with P90, the electricity purchase cost for hydropower is 14 cents USD/ kWh.

[38] Permen ESDM. (2014). Peraturan Menteri ESDM No 17 tahun 2014
[39] Permen ESDM. (2015). Peraturan Menteri ESDM No 19 tahun 2015

Step 4 - Multi-attribute Decision Making

Based on information on section 3, renewable energy resources in Indonesia are summarized in table 8 below:

Table 8 Renewable Energy Resource in Indonesia[40]

Attributes	Solar	Geothermal	Hydro	Ocean	Wind
Grand Solar Minimum Effect to each type of energy	Weak Correlation	Strong Correlation	Not Related	Not Related	Not Related
Total Life Cycle Cost (thousand USD/MW)	1823	2340	2757.5	-	1437
Availability Capacity Factor	19%	80%	43.5%	-	35%
Feed in Tariff (cents USD/kWh)	25	21	14	-	-
Energy Supply Potential (GW)	207.8	29.7	94.4	17.9	60.7
Indonesia Regulation	Doesn't Support Utilization of RE	Support Utilization of RE	Support Utilization of RE	-	-

Best Value
Worst Value

4.1. Dominance

"Dominance is a tool for eliminating inferior alternatives from the analysis. When one option is better than another to all attributes, there is no problem deciding between them. In this case, the first alternative dominates the second one." [41]By comparing each possible pair of other options, give the result in table 9 below:

Table 9 Dominance Technique for Renewable Energy Resource[42]

Attributes	Geothermal vs Hydro	Geothermal vs Solar	Geothermal vs Wind	Geothermal vs Ocean	Hydro vs Solar	Hydro vs Wind	Hydro vs Ocean	Solar vs Wind	Solar vs Ocean	Wind vs Ocean
Grand Solar Minimum Effect to each type of energy	Better	Better	Better	Better	Better	Equal	Equal	Worse	Worse	Equal
Total Life Cycle Cost	Better	Worse	Worse	Better	Worse	Worse	Better	Worse	Better	Better
Availability Capacity Factor	Better	Better	Better	Better	Better	Better	Better	Worse	Better	Better
Feed in Tariff	Worse	Better	Better	Better	Better	Better	Better	Better	Better	Equal
Energy Supply Potential	Worse	Worse	Worse	Better	Worse	Better	Better	Better	Better	Better
Indonesia Regulation	Equal	Better	Better	Better	Better	Better	Better	Better	Better	Equal
Dominance	No	No	No	Yes	No	No	Yes	No	Yes	No

As a result, in table 9 above, Geothermal, Hydro, and Solar are dominance renewable energy comparing to the wind and ocean energy.

4.2. The Additive Weighting Technique

"Additive weighting provides for the direct use of nondimensional attributes and the results of the ordinal ranking. The procedure involves developing weights for attributes based on ordinal rankings that can be multiplied by the appropriate nondimensional attribute value to produce a partial contribution to the overall score for a particular alternative. When the partial contribution of all attributes is summed, the resulting set of alternative scores can be used to compare alternatives directly."[43]

[40] By Author
[41] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2014). Engineering Economy 16th Edition. New York, NY: Pearson. Chapter 14, Section 14.6.1 Dominance
[42] By Author
[43] Sullivan, W. G., Wicks, E. M., & Koelling, C. P. (2014). Engineering Economy 16th Edition. New York, NY: Pearson. Chapter 14, Section 14.7 Compensatory Models

For this study, the level of priority for each attribute shall follow:

Table 10 Ordinal Ranking[44]

Grand Solar Minimum Effect to each type of energy	5
Total Life Cycle Cost	4
Availability Capacity Factor	3
Feed-in Tariff	2
Energy Supply Potential	1
Indonesia Regulation	0

Grand solar minimum is the most critical parameter to consider and follow by total life cycle cost, availability capacity factor, feed-in tariff, energy supply potential, and the least is Indonesia regulation.

The option evaluated using multi-attribute decision analysis, which considers some parameters as described in table 11.

Table 11 Nondimensional Scaling [45]

Attribute	Value	Rating Procedure	Dimensionless Value
Grand Solar Minimum Effect to each type of energy	Strong Correlation	$\frac{Relative\ Rank - 1}{3}$	1
	Not Related		0.5
	Weak Correlation		0
Total Life Cycle Cost	1823 thousand USD/MW	$\frac{2757.5 - cost}{934.5}$	1.00
	2340 thousand USD/MW		0.45
	2757.5 thousand USD/MW		0
Availability Capacity Factor	80%	$\frac{Availability - 19}{61}$	1
	43.5%		0.40
	19%		0
Feed in Tariff	14 cents USD/kWh	$\frac{25 - cost}{11}$	1
	21 cents USD/kWh		0.36
	25 cents USD/kWh		0
Energy Supply Potential	207.8 GW	$\frac{Resource - 17.9}{178.1}$	1
	94.4 GW		0.36
	29.7 GW		0
Indonesia Regulation	Support utilization of Renewable Energy	$\frac{Relative\ Rank - 1}{2}$	1
	Doesn't Support utilization of Renewable Energy		0

FINDINGS

Step 5 - Analysis and Comparison Among Potential Renewable in Indonesia

Using the data from table 11 and perform a calculation using the additive weighting technique gives the result for each option as calculated in table 12 below:

[44] By Author
[45] By Author

Table 12 The Additive Weighting Technique[46]

Attributes	Relative Rank	Normalized Weight	Solar		Geothermal		Hydro	
		(A)	(B)	(A)x(B)	(B)	(A)x(B)	(B)	(A)x(B)
Grand Solar Minimum Effect to each type of energy	6	0.29	0	0	1	0.29	0.5	0.14
Total Life Cycle Cost	5	0.24	1	0.24	0.45	0.11	0	0
Availability Capacity Factor	4	0.19	0	0	1	0.19	0.40	0.08
Feed in Tariff	3	0.14	0	0	0.36	0.05	1	0.14
Energy Supply Potential	2	0.095	1	0.095	0	0.00	0.36	0.03
Indonesia Regulation	1	0.05	0	0	1	0.05	1	0.05
Sum	**21**	**1**		**0.33**		**0.68**		**0.44**

As shown in Table 12 above, Geothermal has the highest result with the total number of 0.68 compared to hydro with the number 0.44 and solar with the number 0.33 when running calculation using multi-attribute decision analysis.

Step 6 - Selection for Suitable Energy Business in Indonesia

Geothermal is the best option for renewable energy business for Indonesia up to 2050 and regarding grand solar minimum. The highest consideration because the grand solar minimum is associated with high-level volcanic eruptions. Knowing that Geothermal heat found in the volcanic areas commonly comes from magma and Volcanoes can be the most significant advantage for geothermal energy development. Even geothermal plant has big investment cost average of 2.3 million USD but has the highest availability factor up to 80%. This means that heat taken from the reservoir 80% turns into electricity. Not only that, Indonesia has 40% world geothermal potential or 29 GW, but only 6.7% has been utilized. Most of the potential is low to medium enthalpy heat, Indonesia needs to establish mature binary/ flash technology to utilize those potentials. The government encourages geothermal development through Perpres No 21/2014. Geothermal has been excluded from mining activity.

Hydropower is the second-best option for renewable energy business for Indonesia up to 2050. With energy, potential reach 94 GW but utilization only 5.8%. Hydropower is also easier to implement compared to other alternatives.

Step 7 - Performance Monitoring

From the result, Geothermal and Hydropower need to be considered while selecting a renewable energy business in Indonesia. The next monitoring can be done by re-assessment of existing renewable energy projects, whether it has reached the desired target or not. Moreover, to find out whether the Grand Solar Minimum phenomenon will occur, it can be observed from several natural phenomena that occur starting from 2020.

[46] By Author

CONCLUSION

This paper was undertaken to answer these questions:

- To explore whether the plan to use of renewable energy up to 2050 is appropriate regarding the grand solar minimum effect

This result shows that Geothermal and Hydro are the best options, among other alternatives for renewable energy business for Indonesia. Indonesia has a target using renewable energy in the national energy mix of 23% in 2025 and 31% in 2050. The government set the goal for geothermal in 2025, reaching 7.2 GW, and increase the target in 2050 up to 17.5 GW. The government's target for Hydro in 2025 reach 20 GW and in 2050, reach 35 GW. The government's target for solar power reaches 6.3 GW in 2025 and 45 GW in 2050. Geothermal and Hydropower already in line with the government's plan to increase the utilization of renewable energy and also align with grand solar minimum phenomena. But the government's plan to utilize in solar is inappropriate regarding grand solar minimum. Where the effect of grand solar minimum is the earth will face global cooling instead of global warming due to low solar activity. This means the intensity of solar radiation will decrease and cause absorption of the sunlight using photovoltaic will not last long. Also, photovoltaic efficiency is still low, only reach 19% means that it takes a large area and a lot of photovoltaic to generate electricity.

- To find potential renewable energy solution to align with grand solar minimum phenomena

The best solution for renewable energy businesses in Indonesia regarding the grand solar minimum is geothermal energy. The country's geothermal reserves amount roughly around 29 GW with the existing plants that have covered only 6.7% of total capacity. The second best option is hydropower for renewable energy businesses in Indonesia. Hydro Power generation and mini/micro hydropower generation are spread across the country with the potential reach of 94.476 GW and utilization only 5.8% from total potential. These two options will give Indonesia the most significant advantage regarding grand solar minimum phenomena.

FOLLOW ON RESEARCH

For wind and ocean energy, more research should be done into these options. Especially for ocean energy because of immaturity, the technology for wind energy research is still needed, which is intensive to develop wind turbines that match with potential wind energy in Indonesia. Moreover, the development of wind energy must also be driven by feed policies in tariffs.

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