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Achieving Energy Self-Sufficiency: An Electricity Supply Analysis of Negros Island Region, Philippines

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Abstract. The urgency to transition to renewable energy sources serves as a motivation to analyze energy systems. This study looks into the electricity supply of the Negros Island Region in the Philippines, focusing on the underutilization of locally available renewable energy sources. It explores scenarios where the island relies solely on its local energy resources, emphasizing the need for increased storage unit capacity and flexibility of power plants. The energy system was modeled using PyPSA with data from 2022. Results show that in one scenario, renewable energy sources could supply most of the region's electricity demand, but around 35% is still sourced from a local diesel power plant. The second scenario which considers 100% renewable energy sources requires the expansion of the BESS in the region to store electricity from geothermal energy. This shows that despite the abundance of solar energy, the model was optimized towards geothermal energy for flexibility and economic considerations.

1 Introduction

In the face of an escalating global climate crisis, the transition from fossil fuels to renewable energy sources has become a topic of importance. A review of literature from 2009 to 2018 reveals that despite efforts to promote renewable energy, fossil fuels remain the dominant source of energy. They contribute 73.5% of worldwide electricity production, while renewables account for only 26.5% [1]. In 2015, the Paris Agreement was adopted by 196 Parties at the UN Climate Change Conference (COP21) as an international treaty on climate change. The primary aim of this agreement was to reduce greenhouse gas emissions, which are a significant contributor to global warming [2].

The Philippines, with its growing economy and increasing energy demands, is facing a significant problem in the energy sector. The majority of the energy mix consists of fossil fuels, coal, natural gas, and oil. However, the Philippines, being an archipelago nation, is endowed with abundant renewable energy sources such as solar, wind, hydropower, and geothermal. The country's dependence on non-renewable resources can

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be significantly reduced if these sources are harnessed. The country is significantly making progress towards energy independence by developing more sustainable sources of energy [3].

The Philippine Energy Plan (PEP) 2023–2050 is the country's latest comprehensive energy blueprint that aims to achieve inclusive and equitable economic growth through secure, sustainable, and resilient energy strategies. Under the current national targets, the plan aims to raise the share of renewable energy in the power generation mix to around 35 percent by 2030 and 50 percent by 2040. [4].

In 2018, the 10th anniversary of the Renewable Energy Law, the launch of the Clean and Affordable Renewable Energy (CARE) Campaign unified various stakeholders such as those from the government offices at both the national and local levels, electric cooperatives, and developers of renewable energy. It also includes electric consumers, financial institutions, academic institutions, non-governmental and people's organizations. Additionally, advocates for renewable energy and communities affected by coal are also part of this collaboration [5].

The Negros Island Region (NIR) was recognized as a key area in achieving 100% of the goals and visions of the CARE Campaign [5]. Known as the renewable energy capital of the Philippines, it boasts a significant potential and installed capacity for renewable energy, backed by the vigorous clean energy campaign of local leaders [6]. Furthermore, the Negros Island Region was chosen as the main site for the implementation of a network powered by renewable energy. This choice was primarily due to the large number of solar energy power plants in the region.

The NIR is home to several renewable and non-renewable plants that derive their energy from sources such as solar, micro hydroelectric, diesel, geothermal, and biomass [7]. Despite the fact that a majority of the power generated in the Negros Island Region is due to renewables, the data provided by the five major distribution utilities of the region shows that about 70% of the electricity being supplied from Negros is outsourced from the neighboring regions, Panay and Cebu, which are sourced from non-renewable energy plants such as coal and diesel [5]. Although both Negros Oriental and Negros Occidental are following the Renewable Energy (RE) initiatives, statistics shown by Oxfam Philippines state that the entire Negros Island Region sources 92% of its power from fossil fuel sources. [8].

There are a total of 24 power plants in NIR. Of these, eleven are biomass power plants, nine are solar power plants, two are geothermal power plants, one is a micro hydroelectric power plant, and the last is a diesel power plant. Table 1 shows the summary of the installed and dependable capacities for each type of energy source in NIR. Data shows the diverse energy mix and the availability of renewable energy sources in the region.

Table 1. Operating Power Plants in Negros Island Region.

Type	Installed Capacity (MW)	Dependable Capacity (MW)	Cost (Php/kWh)
Diesel	31.00	25.90	30.57
Biomass	310.60	200.60	6.63
Geothermal	241.90	220.80	6.15
Solar	347.30	244.30	9.68
Hydro	0.80	0.8	5.90

Besides the power plants, the region also has two energy storage units with a total dependable capacity of 34.7MW that can supply NIR for one hour. Thus, the energy network in the region has a total installed capacity of 966.3 MW, and a dependable capacity of 727.1MW.

Distribution utilities (DUs) are established to be the bridge between the energy production plants and the ordinary consumer. They also provide the infrastructure in cities and municipalities for the electrification of households and commercial facilities. There are five major DUs in the NIR: (1) NORECO I, a distribution utility with a situated coverage of 2,425.20 square kilometers in the eastern portion of Negros Oriental, (2) NORECO II covers the southeastern portion of Negros Oriental including the capital of the province, Dumaguete City, (3) CENECO covers the northwestern portion of Negros Occidental, (4) NOCECO covers the remaining eastern portion of Negros Occidental which faces the neighboring Panay group of islands, and (5) NONECO, which covers the Northernmost portion of the Negros Island Region over its Negros Occidental territory.

Figure 1 shows the aggregate purchase data from the different electricity suppliers in NIR for 2022. The DUs purchase their electricity from one or more of the following types: Geothermal (GCGI), Coal (KSPC, PCPC 1, PCPC 2), Diesel (CENPRI) or the Wholesale Electricity Spot Market (WESM). Solar may be purchased through WESM.

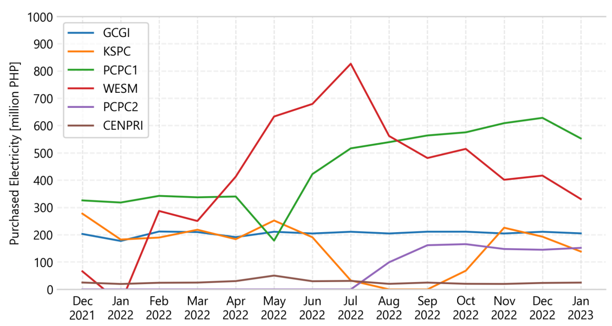

Fig 1. 2022 Electricity supply in the Negros Island Region by source.

KSPC and PCPC are suppliers from nearby islands of Cebu and Iloilo, respectively, while electricity from other suppliers in the country can be purchased through WESM. In Figure 1, electricity from geothermal and diesel provide the baseload. However, some of the DUs prefer to outsource non-renewable energy supply from KSPC and PCPC to meet the electricity demand of the region. Figure 2 shows the DUs that purchase their electricity from renewable energy.

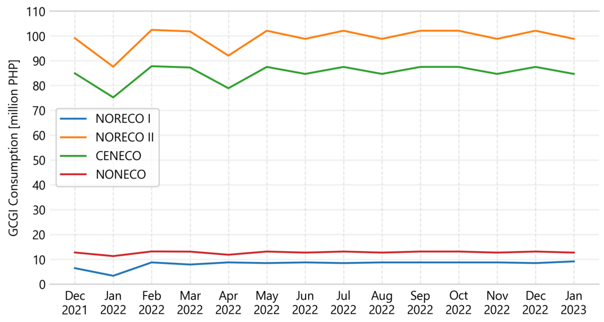

Fig 2. Purchased Renewable Energy by the Distribution Utilities.

NORECO II and CENECO are the top purchasers of renewable energy for their energy mix in 2022, which indicates the efforts done by these distribution utilities to facilitate the use of renewable energy in their electricity mix. The energy demand in NIR is growing as shown in Figure 3. From 2013 to 2022, the trend continued to increase with a monthly peak demand of 418 MW, and a minimum energy demand of 245 MW. This indicates that there is a gradual but continuous increase in the region's energy requirements.

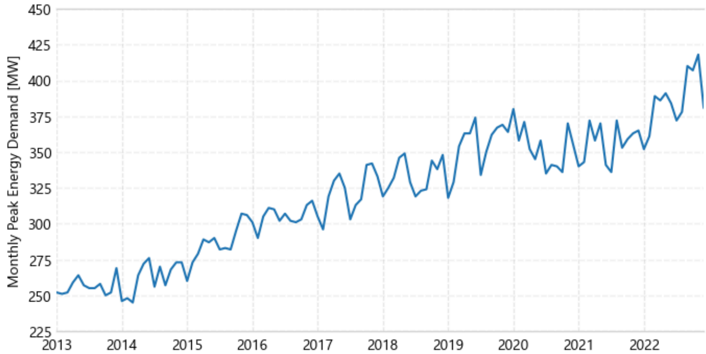

Fig 3. Increasing Trend of Monthly Energy Demand in Negros Island Region Energy from 2013-2022. Data from National Grid Cooperative of the Philippines (NGCP) [9]

In 2022, the power plants in NIR have a total dependable capacity of 727.1 MW. The increasing trend in energy demand peaked at 418 MW in 2022. Clearly, the local power plants can provide the necessary energy for the growing demands of the NIR. Yet, the DUs still contract their electricity supply from outside NIR.

Geothermal and biomass are stable and controllable sources of energy. What about solar? Does the intermittent nature of solar energy lead to instability in the power grid, thus making the power supply unreliable despite the abundance of renewable energy? Which energy source can best secure the supply of the NIR?

Thus, the objective of this study is two-fold. First, to investigate the state of electricity supply in the Negros Island Region, with a particular focus on understanding the reasons behind the underutilization of renewable energy sources. Second, to optimize the use of the existing energy network in the region and simulate the feasibility and potential impacts of a complete transition to renewable energy sources. Ultimately, this study can provide possible scenarios and insights on how to make NIR self-sufficient and energy secured.

2 Methodology

2.1 Energy System Modeling

To investigate the possibility for NIR to rely on its own energy sources to meet the energy demand of its citizens, the energy system was modeled considering two possible cases. Case 1 utilized the dependable capacity of the power plants with diesel as an extendable energy source, and Case 2 removed the diesel power plant from the energy network, and increased the BESS capacity.

For Case 1 consideration looks at the energy demand in 2022 and the energy supply provided by the geothermal power plants acting as the network base load provider at 220.8 MW, as shown in Table 1. However, since the recorded minimum demand is 147 MW, the full capacity of the geothermal power plants cannot be fully utilized. Some capacity must be curtailed (or possibly exported to other regions) in this scenario. The diesel plant was treated as a grid connection from nearby islands, consistent with current practice.

Case 2 considers the potential of solar and the possibility of storing the excess energy to minimize curtailment when solar energy production is at its peak. This will require increasing the capacity of the BESS. However, the current level of excess solar energy is insufficient to supply the power provided by diesel generators in Case 1. In this scenario, geothermal energy is also connected to the BESS. This enables the full utilization of the geothermal plant's capacity; and since this capacity is dispatchable, the region is assured of a sufficient energy supply even on days with minimal or low sunlight.

In both cases, biomass generation was limited to a capacity factor of 26.65%, consistent with the latest recorded performance of the existing biomass power plant. This constraint reflects the current feedstock availability on the island and ensures that simulated biomass utilization remains within its sustainable yield. For the battery storage, the charge and discharge efficiency was set to 90%, with a round trip efficiency of 81%.

2.2 Data and Software

The data are sourced from publicly available tables and transparency documents of the Department of Energy (DOE), the National Grid Corporation of the Philippines (NGCP), and the distribution utilities: Negros Oriental I Electric Cooperative (NORECO I), Negros Oriental II Electric Cooperative (NORECO II), Central Negros Electric Cooperative (CENECO), Negros Oriental Electric Cooperative (NOCECO), and Northern Negros Electric Cooperative (NONECO).

The unavailability of data on the energy produced by the power plants in the region has posed a significant challenge in accurately measuring and assessing the performance of each solar power plant. To bridge this data gap, leveraging weather data from Solcast makes it possible to derive the solar energy production of each solar power plant.

To address the challenges of the energy transition, Python for Power System Analysis (PyPSA) was employed [10]. It is a software tool for simulating and optimizing energy networks. By utilizing the recorded energy demand data in 2022 from the National Grid Cooperative of the Philippines (NGCP) [9] and incorporating available renewable resources in Negros Island Region, the feasibility and potential advantages of transitioning to a fully renewable energy system were evaluated.

The generated energy by the solar power plants was calculated using the pvlib Python library [11]. The solargen module [12], which is a collection of functions used to calculate the solar power based on pvlib, was also utilized. To calculate the maximum output generated by a solar panel, several parameters are required. Initially, the panel data must be specified, which includes the surface tilt, surface azimuth, albedo, and the type of solar panel used. The location must also be specified, which includes the latitude, longitude, timezone, altitude, and the name of the location. Subsequently, weather data such as temperature and Global Horizontal Irradiance (GHI) must be obtained. Using the panel information and weather data, the maximum power output can be calculated.

3 Results

The results of the energy system simulation conducted to assess the potential for NIR to rely on its own renewable energy resources to meet local electricity demand show significant potential for the region to be self-sufficient. The major statistical outcomes under both cases are summarized in Table 2. In Case 1, which includes diesel generation as an extendable energy source, about 35% of the total demand could not be met by the region's renewable energy resources. Biomass provided some flexible generation; however, due to the lower capacity of the geothermal power plant, a significant portion of the demand had to be supplied by diesel generators. In contrast, Case 2 excludes diesel generation and increases BESS capacity to maximize renewable utilization. Connecting the geothermal power plant to the BESS addressed two issues. First, more geothermal capacity could be committed to the system, as the BESS absorbed excess generation on low-demand days. Second, it ensured a sufficient energy supply on days with low solar irradiation.

Table 2. Capacity, Generation, and Capacity Factor by Energy Source

Type	Capacity [MW]		Generation [MWh]		Capacity Factor [%]	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
Diesel	130.8	–	892,525	–	77.59	--
Biomass	200.6	200.6	468,307	468,307	26.65	26.65
Geothermal	100.7	220.8	791,284	1,740,787	90.00	90.00
Solar	244.3	244.0	346,568	304,252	16.23	14.23
Microhydro	0.8	0.8	6,307	6,307	90.00	90.00
BESS	34.7	250	13,670	68,565	4.50	3.13

*The BESS is rated for a 1-hour capacity, capable of full charge or discharge within one hour, and can operate at partial load to discharge at a fraction of its rated power output.

Examining the hourly generation in Case 1 shown in Figure 4, geothermal generation, serving as the baseload supply, is constrained by the region's minimum demand. Nevertheless, it continues to function effectively as a stable baseload provider throughout the year. The biomass power plants, acting as semi-flexible generators, maintain their minimum operating output year-round and adjust generation upward as required by system conditions. For the most part, biomass generation helps mitigate the ramping requirements of diesel units when solar output declines toward the end of the day. Given the limited BESS capacity in this scenario, solar energy storage is minimal. During periods of excess solar production, curtailment becomes necessary, resulting in approximately 4.3% annual solar energy curtailment. Overall, diesel generation remains essential in this configuration, as the current system lacks sufficient flexible generation sources to balance variability in renewable output.

In contrast, the hourly generation in Case 2 in Figure 5 indicates a significantly higher share of power generation from geothermal plants. Although the geothermal units are operated as baseload generators, direct consumption becomes impossible on days with low electricity demand or high solar output. The additional BESS capacity provided the necessary system stability by absorbing excess generation from geothermal plants and releasing it when needed. As illustrated in the October snapshots, the geothermal plant was able to supply the necessary energy even on days with minimal or no solar generation. With this configuration, diesel generation was completely eliminated. Nonetheless, because the geothermal plants produced a larger share of baseload power, the system experienced a higher curtailment rate of 17.5%. Overall, this configuration demonstrates that the island can achieve 100% energy self-sufficiency with adequate storage capacity, primarily enabled by the availability and flexibility of geothermal resources.

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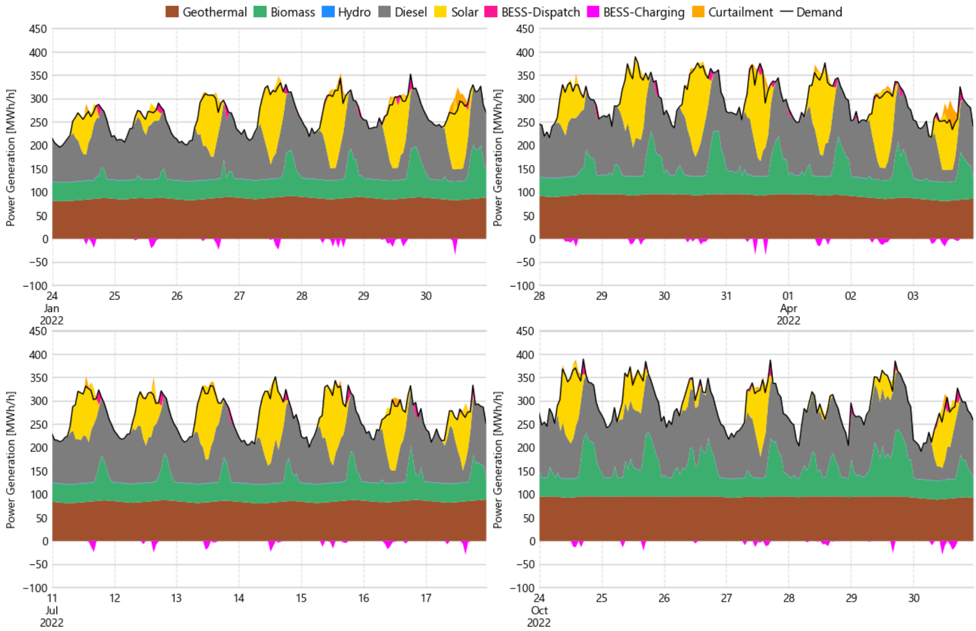

Fig 4. Hourly electricity generation profile for NIR under Case 1, showing the contribution of each energy source to the total supply, as well as the excess solar generation that the system was unable to utilize.

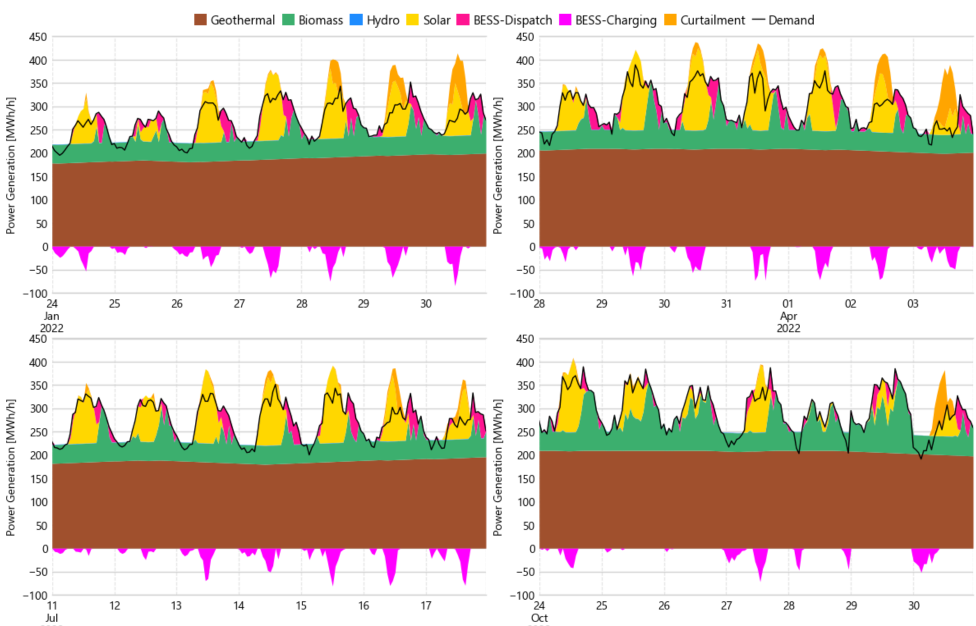

Fig 5. Hourly electricity generation profile for NIR under Case 2, showing the contribution of each energy source to the total supply, as well as the excess solar generation that the system was unable to utilize.

4 Conclusion

The current energy capacity of the power plants in NIR can supply the energy demand of the region based on two scenarios that were investigated by modeling the energy system. The first case utilizes geothermal energy as the baseload and diesel power plants as the extendable source of electricity. The second case considers removing diesel in the mix allowing for 100% renewable energy source for NIR.

Results show that the inclusion of diesel generation in Case 1 enables the region to meet most of its electricity demand, but about 35% of the required energy still depends on non-renewable sources. This reliance highlights the limited flexibility of the current renewable infrastructure, particularly the constrained capacity of geothermal and BESS components. In contrast, Case 2 demonstrates that by expanding BESS capacity and optimizing geothermal generation, NIR can feasibly achieve full energy self-sufficiency without diesel support. Therefore, the simulation results underscore the significant potential for NIR to transition to a fully renewable energy system, provided that future investments focus on enhancing storage systems and maximizing the operational flexibility of geothermal resources. Ultimately, NIR demonstrates that geothermal and BESS can complement VRE sources such as solar and wind to achieve 100% renewable energy.

In the efforts to transition to cleaner energy practices and apply them into the local grid of the region, several considerations must be noted. One consideration is the purchasing power of Negros residents in affording a transition to predominantly renewable energy. Another is to increase the reliability and energy security of the island through better community infrastructure development that would align with already existing renewable energy plants. Through this, it would be possible to integrate sustainable practices without hampering the capability of the residents to pay for their energy needs.

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