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Sustainable Renewable Energy Development in The Philippines: A Technology Management Perspective on Trends and Future Trajectories

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Abstract

Introduction: The Philippines possesses significant renewable energy potential, particularly in solar, wind, geothermal, and hydropower. Analyzing trends in renewable energy capacity is essential for understanding recent progress and guiding future developments in this sector.

Objectives: This study addresses a gap in the literature by providing a comprehensive analysis of renewable energy trends in the Philippines and offering projections that can inform policymakers and stakeholders in shaping energy strategies.

Methods: Using a quantitative research design, the study utilizes secondary data from the Department of Energy (DOE) to examine solar, wind, hydro, geothermal, and biomass installed capacities, alongside annual capacity additions and relevant government policies.

Results: The analysis reveals that solar and wind energy have experienced the most rapid growth, driven primarily by favorable policies and declining costs. At the same time, challenges remain in fully maximizing other resources like biomass and geothermal. Hydropower continues to play a dominant role in the energy mix.

Conclusion: The country reflects a broader global trend toward renewable energy diversification, but realizing its full potential requires more than mere capacity expansion. Strategic policy interventions, robust infrastructure investments, and technological advancements are essential to overcoming existing barriers. The country can enhance its renewable energy capacity by addressing these challenges, ensuring it meets rising energy demands while advancing sustainability goals. Building a resilient and diverse energy future will be key to securing long-term environmental and economic benefits for the Philippines and positioning the nation as a proactive player in global climate change mitigation efforts.

Keywords: Renewable Energy, Installed Generating Capacity, Trend Analysis, Forecasting, Energy Security

. Introduction

The Philippines is highly dependent on fossil fuels, yet it possesses significant renewable energy potential, especially in the solar, wind, geothermal, and hydropower sectors. Analyzing the trends in renewable energy capacity is crucial for understanding the progress made in recent years and projecting future developments.

As the global push toward cleaner energy sources intensifies, the Philippines has set ambitious goals to increase its renewable energy capacity. According to the Department of Energy (DOE), the country aims to have renewable energy contributes 50% of its total energy mix by 2040 (DOE, 2022). While significant progress has been made, especially in installing solar and wind farms, barriers such as regulatory challenges, financing issues, and technological capacity persist (Payel, et al, 2023).

By examining installed generation capacity and projecting future growth trajectories, this study provides valuable insights into how the country can

meet its energy goals while aligning with international sustainability commitments, such as those outlined in the Paris Agreement. Researchers have pointed out that developing countries like the Philippines must adopt aggressive measures in scaling up renewable energy infrastructure to mitigate the effects of climate change (Smith & Rahman, 2020). Furthermore, the increasing frequency of natural disasters in the region underscores the importance of transitioning to more resilient energy systems that can withstand extreme weather events (Cruz & De Castro, 2019).

2. Objectives

The study aims to fill the gap in the literature by providing an in-depth trend analysis of the current renewable energy landscape in the Philippines and offering future trajectories of renewable energy generation capacity as a basis for policymakers and stakeholders in shaping future energy strategies.

3. Methods

This study employs a quantitative research design utilizing secondary data to analyze the trends in Renewable Energy (RE) capacity in the Philippines. The primary data source is the Department of Energy (DOE), which provides detailed statistics on the installed generation capacities of various renewable energy sources such as solar, wind, hydro, geothermal, and biomass. Data collected includes the historical installed capacities of these sources, annual capacity additions, and relevant government policy documents. The trend analysis will examine changes in renewable energy capacity over time, identifying key patterns and growth rates.

In order to assess the installed generating capacity of the identified renewable energy until 2028, the data were treated as time series observations. For each renewable energy, forecast functions were determined through curve fitting. The forecast functions were then utilized to determine the trend until 2028. Year to year forecast values were generated beginning with 2003 and ending with 2028. Analysis of these forecast values was made on a year-to-year basis.

As used by existing software, each observation Yt is assumed to be a function of time t plus random error:

$Yt = f(t) + e(t)$, $t = 1,2,3,4\ldots$

The least-squares criterion was then used to estimate the function f(t). The following criteria were used as the basis for judging the goodness of fit:

MAPE= mean absolute prediction error

MAD = mean absolute deviation

MSD = mean standard deviation

4. Results

The graph below highlights the trends in energy generation from five renewable sources—hydropower, geothermal, biomass, solar, and wind—between 2003 and 2023. Hydropower consistently leads, with capacity rising steadily until around 2012 before stabilizing near 3,200 MW. Geothermal energy shows a stable production level, hovering around 1,900 MW throughout the period. Solar and wind energy, though negligible before 2014, exhibit sharp increases starting from 2015, with solar energy surpassing wind by 2018, reaching approximately 1,500 MW by 2023. Biomass remains the least utilized renewable energy source, maintaining minimal growth and peaking at around 300 MW.

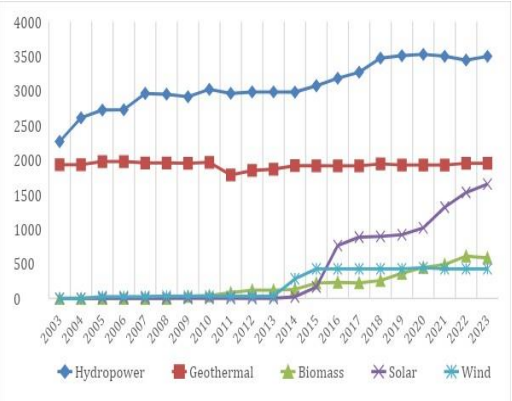

Figure 1. Installed Generation Capacity

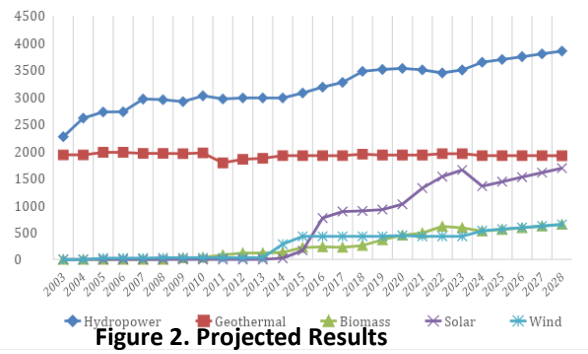

Figure 2. Projected Results

Projections

Table 1. shows the trend results of the five renewable energies available in the country.

Table 1. Trend Analysis of Renewable Energy Installed Generation Capacity

	Hydropower	Geothermal	Biomass	Solar	Wind
2003	2267	132	0	0	0
2004	2610	1932	0	0	0
2005	2723	1978	0	1	25
2006	2726	1978	0	1	25
2007	2962	1958	0	1	25
2008	2950	1958	0	1	33
2009	2914	1953	30	1	33
2010	3021	1966	38	1	33
2011	2963	1783	83	1	33
2012	2983	1848	119	1	33
2013	2983	1868	119	1	33
2014	2982	1918	131	23	283
2015	3073	1917	221	165	427
2016	3181	1916	233	765	427
2017	3269	1916	224	885	427
2018	3473	1944	258	896	427
2019	3508	1928	363	921	427
2020	3527	1928	447	1019	443
2021	3500	1928	489	1317	427
2022	3444	1952	611	1530	427
2023	3499	1952	585	1653	427
2024	3641	1918	524	1353	531
2025	3692	1917	554	1437	560
2026	3744	1917	585	1520	589
2027	3795	1916	616	1603	618
2028	3847	1915	646	1687	647

4. Discussion

In figure 1, in the Philippine context, the abundance of renewable energy varies across the three main regions—Luzon, Visayas, and Mindanao. Luzon, with its large land area and mountain ranges, is rich in hydropower, particularly in areas like Benguet, which hosts the largest hydropower plants. Wind energy is also gaining momentum, especially in Ilocos Norte, home to the iconic Bangui Wind Farm. Visayas is known for its geothermal resources, particularly in Leyte and Negros Island, which contribute significantly to the country's geothermal capacity. The region is also experiencing growth in solar energy installations due to favorable sunlight conditions. Mindanao, while historically dependent on hydropower from its river systems, is also starting to explore more solar and biomass energy, particularly in its agricultural areas. The rise of these renewables is supported by the Renewable Energy Act of 2008, which promotes investment in solar, wind, and other alternatives. This regional diversity in renewable energy sources allows the country to develop a more balanced and sustainable energy portfolio.

The most striking trends in the Figure 2 are the rapid increases in solar and wind capacity, particularly after 2015. This shift aligns with global energy trends, where these two technologies have become more cost-competitive due to innovations, economies of scale, and falling prices for solar panels and wind turbines. For the Philippines, the significant growth in solar energy is especially promising, considering its tropical climate and high solar irradiance. As the country shifts away from fossil fuels, solar has become an attractive option for both grid-connected and off-grid applications. Davidson (2020) highlights the rapid growth of wind and solar energy across Southeast Asia, driven by significant reductions in technology costs and advancements in efficiency. This is clearly reflected in the post-2015 surge in solar and wind capacity shown in the graph. In the Philippines, this growth was further catalyzed by policy measures like the feed-in tariff (FIT) system, which incentivized investment in these technologies. However, Davidson (2020) cautions that solar and wind energy, while promising, face

challenges in terms of intermittency, which requires the development of energy storage and a more resilient grid infrastructure to maintain stability. The increase of wind energy is relevant for the Philippines, which has vast wind energy potential, especially in regions like Ilocos Norte. The rapid development of wind farms such as those in Burgos, Ilocos Norte, and Guimaras Island suggests that wind energy is becoming a crucial component of the country's renewable energy mix. The surge in capacity post-2015 could be attributed to policy shifts like the Renewable Energy Act of 2008 and the implementation of feed-in tariffs (FIT) that incentivize solar and wind investments. However, despite this rapid growth, the intermittent nature of solar energy presents challenges in terms of grid stability, which necessitates investments in energy storage solutions and smart grid technologies to optimize solar energy's potential.

The steady upward trend in hydropower's installed capacity suggests ongoing investment and development, particularly in areas rich in river systems, such as Mindanao and Northern Luzon. Hydropower, which remains the dominant source of renewable energy in the graph, is consistent with Gera and Mercado (2021)'s analysis of the Philippine energy sector. Hydropower has long been a reliable baseload power source for the country, particularly in Mindanao, which is rich in river systems. However, as ecosystem disruption and the displacement of communities. These limitations explain the steady but relatively flat growth trend observed in hydropower over the years, reflecting the challenges of scaling this resource. However, Gera and Mercado (2021) point out that further expansion of hydropower is constrained by environmental concerns, such as ecosystem disruption and the displacement of communities. These limitations explain the steady but relatively flat growth trend observed in hydropower over the years, reflecting the challenges of scaling this resource.

Geothermal energy's stagnation as shown in Figure 3. reflects the insights of Bertani (2021), who notes that while the Philippines is one of the global leaders in geothermal energy production, the sector has struggled to expand. High upfront investment costs, risks associated with drilling, and the limited number of untapped geothermal fields have contributed to this stagnation. Bertani (2021) also highlights regulatory and permitting challenges as factors that further hinder growth in this sector, which is clearly mirrored by the static trend in the graph.

The minimal growth in biomass energy, as shown in the graph, aligns with Sari et al. (2020)'s assessment of the barriers facing the sector in the Philippines. Although the country has abundant biomass resources, particularly from agricultural waste, logistical challenges such as the collection, transport, and processing of biomass have limited its scalability. Sari et al. (2020) also highlight the need for better infrastructure and government support to overcome these issues, which are necessary for biomass to contribute more significantly to the country's renewable energy mix.

Government Policy and Regulatory Framework

The Philippines is acknowledged as a leader in Southeast Asia in terms of policies and public financing. The Philippine Congress passed Republic Act 9367 and Republic Act 9513, which are the Biofuels Act of 2006 and Renewable Energy Act of 2008, which led to the improvement and progress of renewable energy. The Republic Act 9367, which is the Biofuel Act, stated that all liquid fuels for motors and engines contain locally sourced biofuels, specifically a 2% biodiesel blend starting 2009 and a 10% bio-ethanol blend in 2011. This act has been completely observed by the government. The transition period for the final implementation was extended from February 2011 to February 2012, thus allowing greater expansion of local bioethanol production to meet the rapidly increasing local demand. The Republic Act 9513, which is the Renewable Energy Act, establishes the institutional framework and mechanism to apply the development ordinance of the law and for the development, exploration, commercialization, and utilization of renewable energies. The growth of the renewable energy division is essential for national energy security in the Philippine government, while the Philippines fossil fuel division is unrenewable and dependent on the import of non-renewable fuel. However, it gives significant potential in the renewable energy

division. The Philippines has the highest electricity ratio in Asia followed by Japan based on a report of the International Energy Consultants, an Australian consulting firm. Fuel and power transport all over the Philippine archipelago is troublesome due to expensive cost. The Philippines could be known as a model in renewable energy as 30 percent of its power generation is driven by the renewable energy division. The Philippines is known as the world's second-largest fabricator of geothermal energy and was the first Southeast Asian nation to finance large-scale solar and wind technologies. Through the Renewable Energy Act of 2008, promotion and support of renewable energy in the Philippines was focused and intensified. The Philippines aims to triple its renewable energy supply by the year 2030.

The National Renewable Energy Program (NREP) plans the policy framework protected in Republic Act 9513. Through the NREP, the strategic building blocks will support the country to reach the goals intended for the Renewable Energy Act of 2008. The NREP indicates the country's big improvement from disjointed and uncertain RE initiatives into a focused and constant drive towards energy security and improved access to clean energy. The NREP sets out indicative temporary targets for the delivery of renewable energy within the timeframe of 2011 to 2030. Reaching the immense objectives up to 2020 will be challenging as detailed planning, financing, and construction of renewable energy structures will have to be carried out at a scale never done before. The NREP sets down the establishment for developing the Philippines' renewable energy resources, stimulating investments in the RE sector, and providing the motivation for national and local renewable energy planning that will support in identifying the most possible and inexpensive renewable energy development selections.

The NREP continues from the statement that certain activities can be taken immediately, while others will take time to implement. It will need a periodic review to guarantee that it obeys to the policy objectives set out in RA 9513 as a national program.

Energy Security

The word energy security has a different meaning for some countries. For Europe and North America, it still means the necessity for diversification and access to different energy suppliers and sources. This is how the 2006 Energy Green Paper of the European Commission defines the term. China and India fear that their rapidly growing economies will run out of energy and that they will therefore be unable to reach their full development potential. Government movements like increasing taxes, transforming energy companies into public assets and changing supply and demand of energy away from its economic equilibrium. A crisis can progress because of industrial movements such as union- planned attacks and government bans. The cause may be over-consumption, infrastructure aging, and choke point interruption at oil refineries that limit fuel supply. A backup may develop during very cold seasons due to enlarged energy consumption. Pipeline disasters and any other accidents can lead to slight disruptions to energy deliveries. A crisis could arise right after infrastructure damage from a severe climate. Political trials, for example, when government revolution due to regime alteration, monarchy collapse, and coup may disturb oil and gas making and create deficiencies. Fuel shortage can also be due to the excess and useless use of the fuels.

Technological Advancements

Technological advancements in renewable energy have significantly propelled the Philippines' efforts toward sustainability and energy independence. In wind energy, innovations such as larger, more efficient turbines and improved forecasting systems using machine learning algorithms have enhanced energy capture and addressed wind variability, especially in typhoon-prone areas (Ching, 2018). Solar energy has benefited from high-efficiency photovoltaic (PV) cells and advancements in energy storage, particularly with lithium-ion batteries, making solar power more reliable in off-grid locations (Sobamowo et al., 2020). Geothermal energy, where the Philippines is a global leader, has seen progress through enhanced geothermal systems (EGS) and binary cycle power plants, enabling the utilization of previously

inaccessible or low-temperature geothermal resources (Fronda et al., 2021). In hydropower, the development of small- scale, run-of-river systems and innovations in turbine design have made it easier to generate electricity in remote or fluctuating water-level environments (Kabeyi & Olanrewaju, 2022). Bioenergy, derived from biomass and biofuels, has also advanced with improved biomass gasification technologies and anaerobic digestion processes that convert agricultural waste into sustainable energy (Malinauskaite et al, 2022). These technological strides are supported by the Renewable Energy Act of 2008, which provides incentives for renewable energy investments and fosters innovation in the sector. The Department of Energy (DOE) has further encouraged research and development to integrate new technologies, such as offshore wind and energy storage, into the national energy mix. According to Akpan and Olanrewaju (2023), these advancements are crucial to overcoming challenges like energy intermittency and grid integration, positioning the Philippines as a regional leader in renewable energy while advancing its climate action goals.

Impact on the Philippines' Energy Mix

As the country aims to increase the share of renewable energy to 50% of its total energy mix by 2040, the trend analysis conducted reveals key insights into the trajectory of renewable energy development. The notable growth in solar and wind energy generation, spurred by favorable government policies such as the Renewable Energy Act of 2008, reflects a shift towards diversifying the energy mix away from fossil fuels (Briones

& Villanueva, 2020).

This diversification is crucial for enhancing energy security in a nation that remains vulnerable to fuel price volatility and supply disruptions due to its heavy reliance on imported fossil fuels. By emphasizing renewable energy, particularly solar and wind, the Philippines can reduce its dependence on foreign energy sources, stabilize energy prices, and mitigate the risks associated with global fuel market fluctuations.

Moreover, the projected expansion of renewable energy aligns with the country's commitment to international climate agreements, such as the Paris Agreement. Transitioning to cleaner energy sources will not only help reduce greenhouse gas emissions but also position the Philippines as a leader in climate action in Southeast Asia.

The study's forecast of installed renewable capacity through 2028 provides policymakers with valuable data to support decision-making processes that prioritize environmental sustainability while addressing rising energy demands.

The gradual but steady rise in hydropower and geothermal energy highlights their continued importance as baseload power sources, particularly in regions like Mindanao and Northern Luzon. However, the slow uptake of biomass energy indicates the need for more robust investments and infrastructural support to unlock its potential (Sari et al., 2020).

Ultimately, this study serves as a roadmap for enhancing the Philippines' renewable energy capacity, ensuring that future energy strategies are aligned with the country's economic, environmental, and social goals.

5. Conclusion

The study's trend analysis of renewable energy in the Philippines highlights a dynamic shift toward cleaner energy sources, driven by government policies and advancements in technology. Hydropower and geothermal energy continue to serve as reliable baseload sources, while the rapid growth of solar and wind illustrates the country's expanding commitment to renewable energy. However, the limited progress in biomass and the stagnation of geothermal energy signals the need for additional investments and policy reforms to fully utilize the country's diverse renewable resources. The study provides critical insights to guide future energy planning and policy formulation, aligning with the Philippines' goal of achieving 50% renewable energy in its energy mix by 2040. By diversifying the energy portfolio, the country can reduce its reliance on imported fossil fuels, enhancing energy security and mitigating the risks associated with global fuel price volatility. Moreover, expanding renewable energy capacity aligns with the Philippines' international climate commitments under the Paris Agreement,

positioning the country as a regional leader in climate action while meeting rising energy demands. To fully realize the potential of renewable energy, these aspects need to be considered, the strategic policy interventions, technological advancements, and infrastructure investments. Addressing these challenges will secure long-term environmental and economic benefits for the Philippines, ensuring resilience in the face of global energy and climate challenges.

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