A Systems-Based Assessment of Renewable Energy Deployment, Resource Circularity, and Community-Scale Innovation in the Philippines

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Abstract. The Philippine energy sector is increasingly challenged by rising electricity demand, climate vulnerability, and persistent supply instability. Despite its long-standing reliance on geothermal and hydropower, the country remains largely dependent on fossil fuels, and energy access disparities persist, particularly in rural and low-income communities. This study presents a systems-based policy and technical assessment of renewable energy deployment in the Philippines, integrating energy infrastructure analysis, climate risk considerations, and circular resource utilization. A mixed-method approach is employed, combining secondary data analysis from national and international energy databases with comparative benchmarking against ASEAN and global renewable energy trends. The study incorporates conceptual systems and simulation-informed evaluation of decentralized renewable energy solutions, including rooftop solar systems and community-scale innovations supported by recovered materials. The result indicate that while the Philippines has achieved approximately 8.2 GW of installed clean energy capacity, this remains insufficient relative to the national target of 52.8 GW by 2040. At this point in time, the renewable energy mix is heavily concentrated in geothermal and hydropower, contributing around 18.5% of electricity generation, whereas solar and wind technologies remain underdeveloped at around 3.5%. The analysis also demonstrates that rooftop photovoltaic systems provide dual benefits by generating source of electricity and decreasing building heat gain, thereby lowering cooling demand in tropical environments, particularly through junk shop networks. This offers a viable pathway for low-cost renewable energy prototyping and education-driven innovation. This paper concludes that achieving a resilient and sustainable energy transition requires a multi-level strategy that integrates large-scale renewable deployment, decentralized energy systems, and circular economy principles, supported by policy alignment and capacity development.

Keywords. Renewable Energy Policy; Energy Transition; Philippines; Circular Economy; Distributed Energy Systems; Rooftop Solar; Climate

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1 Introduction

The country faces increasing climate risks, rising energy demand, and persistent energy supply constraints, including scheduled power interruptions during peak demand and generation shortfalls. Despite regional leadership in geothermal and hydropower, the electricity sector remains largely fossil-fuel dependent, while traditional fuels such as charcoal continue to be widely used in low-income and rural communities as coping mechanisms during outages. This paper presents a systems-based, policy-oriented assessment of renewable energy development in the Philippines, integrating geographic suitability, disaster risk reduction, circular resource utilization via junk shops, and education-driven innovation. Comparative analysis highlights gaps between current renewable energy deployment, regional benchmarks, and national targets. The study further examines rooftop solar systems in tropical climates, specializing their role in reducing cooling loads and improving household energy resilience during supply interruptions. Simulation-based testing and low-cost prototyping using recovered materials to reduce reliance on charcoal and mitigate the impacts of power shortages, aiming the SDGs 7, 11, 12, and 13.

2 Systems View of the Philippine Energy Landscape

The interaction between climate risk, energy demand, and material use in the Philippines, a systems-level conceptual framework is presented in Figure 1. The framework illustrates how structural pressures collectively influence the country's energy transition from 2023 to 2040.

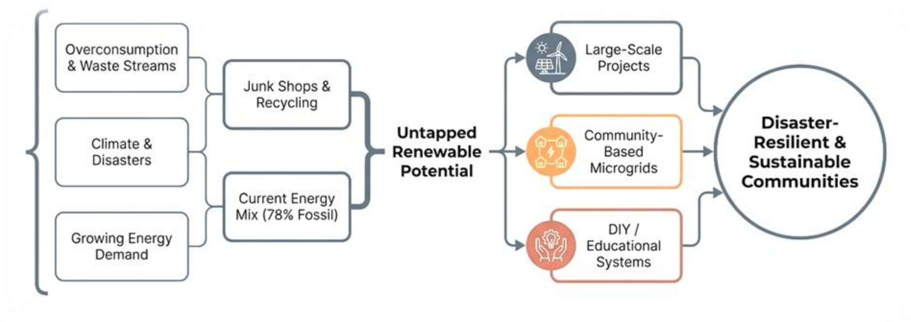

Fig.1. Conceptual framework of geographic sustainability, renewable energy deployment, disaster risk reduction, and circular resource utilization in the Philippines (2023–2040).

To learn more about the interaction between climate risk, energy demand, and material use in the Philippines, a systems-level conceptual framework is presented in Figure 1. Rather than viewing energy challenges as isolated technical issues, the framework illustrates how multiple structural pressures collectively influence the country's energy transition from 2023 to 2040 [1], [2]. The Philippines consumption is increasing due to population growth, urbanization, and rising economic activity, placing additional strain on current generation and transmission facilities and causing scheduled power outages during peak periods [3]. These system stresses are exacerbated by the country's high exposure to climate-related hazards, such as typhoons, flooding, and extreme weather events, which frequently disrupt power infrastructure and late service restoration, underscoring the importance of geographically adapting the disaster-resilient energy systems [4], [5].

At the same time, too much consumption provides a significant waste stream in urban and rural areas, as seen by the prevalence of junk stores and improper recycling facilities. On the other hand, these recovery networks demonstrate material inefficiencies, they also provide a potential for cyclical resource usage, notably in a potential economical renewable energy prototypes, learning environments, and non-grid experiments [6], [7]. Given the country's substantial renewable energy heritage, the electricity mix remains largely fossil-fuel dependent, with conventional fuels accounting for around 78% of generation and only about 20% from low-carbon sources, primarily hydropower and geothermal energy. Limited diversification in solar and wind technologies slows implementation and limits system flexibility during supply outages [8], [9]. Highlighting the intricate limitations requires a multi-pronged renewable energy strategy that includes large-scale capacity growth, community-based microgrids to enhance local resilience, and education and simulation-based systems that build technical capacity from recovered materials. The joint adoption of these paths contributes to a more robust, adaptable, and environmentally friendly energy transition in the Philippines [10, 11].

3 Installed Clean Energy Capacity and Targets

It was mentioned in Energy Tracker Asia Philippines as shown in Fig.2, that the country's clean energy target goal is to have 8.2 GW of installed clean energy capacity, with 4.0 GW of additional projects expected to come online. National targets aim for 15.3 GW by 2030 and 52.8 GW by 2040 under the Clean Energy Scenario [6].

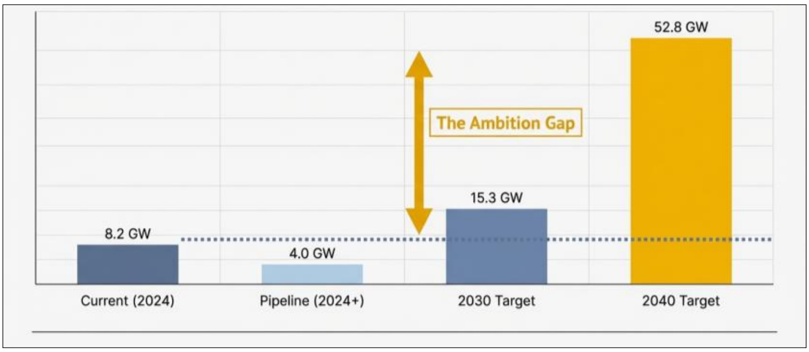

Fig. 2 highlights the gap between the Philippines' current clean energy capacity and its long-term renewable targets.

Reaching the goal for 2040, we need to speed up renewable energy deployment, including faster project development and grid integration, diversification of renewable technologies beyond utility-scale solar and wind, increased investment in energy storage and flexible grid infrastructure. Complementary community-scale initiatives, such as rooftop solar, distributed generation, and energy-efficient building designs, can help bridge deployment gaps while reducing local electricity demand. At the same time, educational and capacity-building programs are essential to strengthen public awareness, workforce readiness, and stakeholder participation in the energy transition. Overall, aligning installed capacity growth with national targets will require a multi-level approach, integrating large-scale renewable investments with community-driven and educational strategies to ensure a sustainable, inclusive, and resilient clean energy transition. The slow pace of expansion suggests the need for complementary community-scale and educational approaches alongside utility-scale projects [8].

3.1 Comparative Renewable Energy Status

Although the Philippines' renewable share in electricity generation remains below the global average, this gap highlights the need for accelerated renewable deployment (IEA, 2023) [7]. The ASEAN and global mean are shown in the figure, along with a breakdown of renewable energy composition of the country. The progress bars shown in Fig.3 describe how much of each category's total electricity generation comes from renewable sources. Approximately 32% of global electricity comes from renewable energy, the largest share among the regions under comparison. Although it is still below global levels, the ASEAN average of 18% indicates moderate penetration of renewable energy. At roughly 22%, the Philippines' renewable energy share is marginally higher than the ASEAN average, though it remains below the global standard. A closer examination of the Philippine renewable energy mix declared a strong reliance on hydropower and geothermal energy, which together contribute approximately 18.5% of total electricity generation.

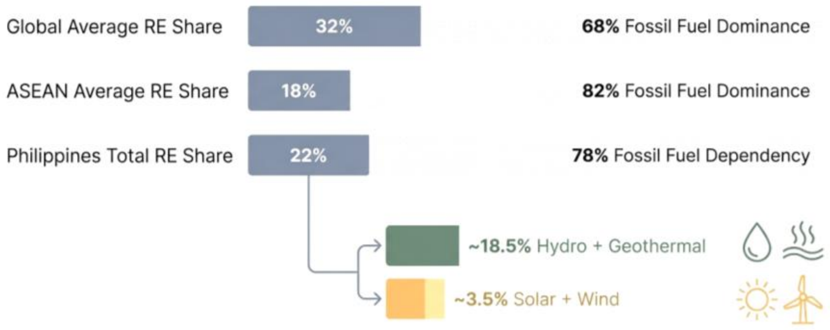

Fig.3. A comparison of the shares of renewable energy (RE) in the Philippines.

These tributes renewables provide stable baseload power but majority of the current renewable portfolio. In contrast, solar and wind energy account for only about 3.5%, highlighting limited diversification and slower deployment of variable renewable technologies. Overall, the chart indicates that while the Philippines performs comparatively well within the ASEAN region, its renewable energy growth remains concentrated in traditional sources, with significant potential to expand solar and wind systems to better align with global renewable energy trends and sustainable decarbonization targets.

4 Policy Implications for Integrated Housing and Resource Systems

Adding renewable energy to homes should be seen as both a technological change and a practical way to deal with rising electricity costs, uncomfortable temperatures, and unstable supply. Rooftop solar photovoltaic systems are especially important because they let homes act as separate energy nodes..

Fig.4. Integrated rooftop solar photovoltaic systems in Philippine residential housing.

In Figure 4. This Demonstrating dual functionality as (Node 1) decentralized electricity generation and (Node 2) passive cooling through reduced solar heat transfer. Also to produce electricity, these systems also contribute to passive thermal regulation by reducing solar heat gain through the roof. This is especially significant in the Philippines, where lightweight roofing materials such as galvanized iron sheets are widely used and where indoor heat accumulation directly increases dependence on electric fans and air-conditioning systems. The air gap between the solar panel and the roof surface further limits conductive heat transfer, thereby improving thermal comfort while lowering household energy demand [1], [2]. In this sense, rooftop solar systems should not be viewed solely as add-on technologies, but as integrated design features that enhance both energy efficiency and residential resilience.

4.1 Circular Material Utilization and Community-Scale Innovation

The viability of housing-integrated renewable energy systems is closely linked to questions of affordability, accessibility, and local material availability. In this regard, junk shops and informal recycling networks in the Philippines represent an important yet often overlooked component of the renewable energy transition. These material recovery systems provide access to reusable metals, plastics, glass, wiring, and electrical parts that may retain functional value for controlled, non-grid applications. When properly screened, classified, and applied within safe limits, such materials can support the fabrication of prototype mounts, training models, demonstration units, and other experimental renewable energy components. Their value lies not in replacing certified materials for operational systems, but in supporting early-stage innovation, technical learning, and low-cost experimentation. By linking renewable energy initiatives with circular material practices already present in local communities, the transition becomes more grounded in the actual socio-economic conditions of the Philippines. This perspective strengthens the argument that sustainable housing innovation can emerge not only from formal infrastructure investment, but also from community-based resource recovery and adaptive engineering practices.

4.2 Policy Implications for Integrated Housing and Resource Systems

Taken together, renewable energy integration in housing and circular material utilization suggest a broader policy direction for the Philippines. Rather than addressing energy, housing, and waste as separate sectors, there is value in framing them as interconnected components of a localized sustainability strategy. Embedding rooftop solar systems into housing programs, while simultaneously supporting technical education and safe community-based prototyping through reclaimed materials, can improve energy resilience and widen participation in renewable innovation. Such an approach is particularly relevant for low-income and disaster-prone communities, where the cost of conventional technologies often limits adoption. From a systems perspective, the alignment of built infrastructure, decentralized energy technologies, and circular resource practices offers a more inclusive and context-responsive pathway toward sustainable development. This reinforces the need for policies that support not only renewable deployment itself, but also the material and institutional ecosystems that allows households and communities to participate meaningfully in the energy transition.

5 Junk Shops, Circular Resource Utilization

The country has numerous of junk shops and recycling facilities nationwide, forming an extensive informal–formal material recovery network that plays a critical role in managing post-consumer waste and industrial scrap [12]. These facilities are most densely concentrated in highly urbanized and industrial regions such as the National Capital Region (NCR) and CALABARZON, where population density, construction activity, and manufacturing output generate large volumes of turn to be waste materials.

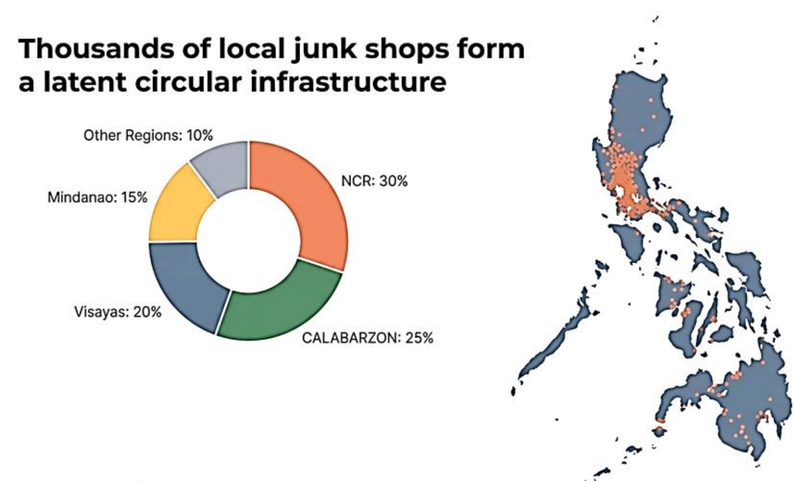

Fig.5. The approximate regional distribution of junk shops and recycling facilities in the Philippines as of 2023, based on aggregated national inventory data.

Substantial shares are also observed in the Visayas and Mindanao, indicating that material recovery systems extend beyond metropolitan centers and remain active across the archipelago as expressed in Fig.5. The geographic spread of junk shops shows a significant opportunity to integrate circular resource utilization into localized innovation and renewable energy development initiatives. Instead of treated solely as waste endpoints, junk shops can be reform as material access hubs that supply affordable components for educational and experimental renewable energy prototypes. Recovered materials commonly available in junk shops such as scrap metals, plastic containers, discarded electrical components, and structural frames, retain sufficient mechanical and functional integrity for non-grid, low-risk applications.

Recovered materials are usually available in junk shops, such as scrap metals, plastic containers, discarded electrical components, and structural frames, retain sufficient mechanical and functional integrity for non-grid, low risk applications. When used within controlled testing environments, these materials can support hands-on learning, prototype validation, and simulation-based experimentation without compromising safety.
Table 1 summarizes typical junk-shop materials, their corresponding renewable energy prototype applications, and the appropriate testing scope.

Table 1. Mapping of commonly recovered materials in junk-shop to renewable energy prototype applications and non-grid testing scopes.

Junk Shop Material	Renewable Prototype Application	Testing Scope (Non-Grid)
Scrap aluminum / steel frames	Solar panel mounts, wind turbine frames	Structural testing, load simulation
Copper wires and tubes	Electrical wiring, micro-hydro coils, heat exchangers	Low-voltage electrical testing
Plastic containers (HDPE)	Floating solar platforms, insulation casing	Buoyancy and flood simulation
Old electric motors	Small wind turbine generators, lab-scale turbines	Mechanical rotation & efficiency testing
Discarded glass ss	Solar concentrator mirrors, glazing	Optical and thermal testing
Electronic components (PCBs)	Sensors and controllers for simulation rigs	Monitoring & data acquisition

The reuse of junk-shop-sourced materials offers multiple benefits. Economically, it decreases material acquisition price, helping renewable energy experimentation accessible to educational intitutions, community groups, and early-stage innovators. Environmentally, it diverts waste from landfills, reduces demand for new materials, and lowers the embodied energy associated with their production of new materials. Integrating junk shop owners into education- and research-oriented initiatives opens pathways for collaborative optimization, including improved material sorting, classification, and safe reuse practices. While the present study focuses on the conceptual and policy relevance of such integration, further investigation is required to quantify economic impacts, safety performance, and scalability, representing an important direction for future research. The widespread presence of junk shops across the Philippines represents a latent circular infrastructure that, when aligned with renewable energy education and prototyping.

6 Quality Assurance and Safety Framework for Renewable Energy Prototyping

The use of recovered materials in renewable energy prototyping introduces both opportunities and risks, particularly in educational and community-based settings. While circular resource utilization enables low-cost innovation, it also requires careful control to ensure that safety and technical reliability are not compromised. In this context, a structured framework is necessary to guide the responsible development, evaluation, and validation of experimental systems. See Fig.6 for reference.

Fig.6. Safety and quality assurance framework for simulation-based renewable energy prototyping.

6.1 Material Screening

The first stage of the framework focuses on evaluating recovered materials before their use in experimental systems. Components sourced from junk shops or recycling networks are subjected to functional classification to determine their structural condition and operational suitability. Materials that exhibit signs of corrosion, degradation, or compromised performance are excluded to prevent system failure and ensure safe handling. This process establishes a baseline level of reliability while maintaining the benefits of circular material utilization.

6.2 Controlled Environments

After validating the material, experimentation is confined to controlled settings with explicitly delineated application boundaries. We only use recovered materials in educational prototypes and low-voltage, non-grid systems, which lowers the risk of electrical and mechanical problems. These controlled conditions make it easier to keep track of testing variables like load, temperature, and system behavior, which keeps experiments safe and manageable.

6.3 Simulation-First Approach

Simulation-based methods will be implemented before any physical assembly, system performance is evaluated through computational tools, and measured laboratory models are used to study relevant procedures, this includes the fluid flow dynamics and heat transfer mechanisms. This approach enables researchers and learners to understand system behavior without direct exposure to environmental hazards, including extreme weather or unstable operating conditions. Prioritizing simulation, the framework reduces uncertainty, minimizes material waste, and enhances the accuracy of experimental design.

6.4 Physical Experimentation

The last step in the framework is actual experimentation through a physical demo. This only happens if the simulation-based validation works. At this point, prototypes are clearly marked as experimental systems and are put through tests in controlled, supervised environments. The goal is to check the results of theories and simulations by observing them in person while following safety rules. This step makes sure that students can learn in a safe way while still being able to experiment with renewable energy in a structured and responsible way.

7 Education-Driven Integration and Community Learnings

An early exposure to renewable energy concepts through elective programs provides an strong foundation for climate literacy and systems analization skills. In the Fig.7, shown when students are introduced to basic principles of physics, chemistry, and material science, learning can naturally progress toward identifying and classifying reclaimed materials from material recovery centers, such as all forms of materials and metals, plastics, and electronic components, based on their properties and potential applications.

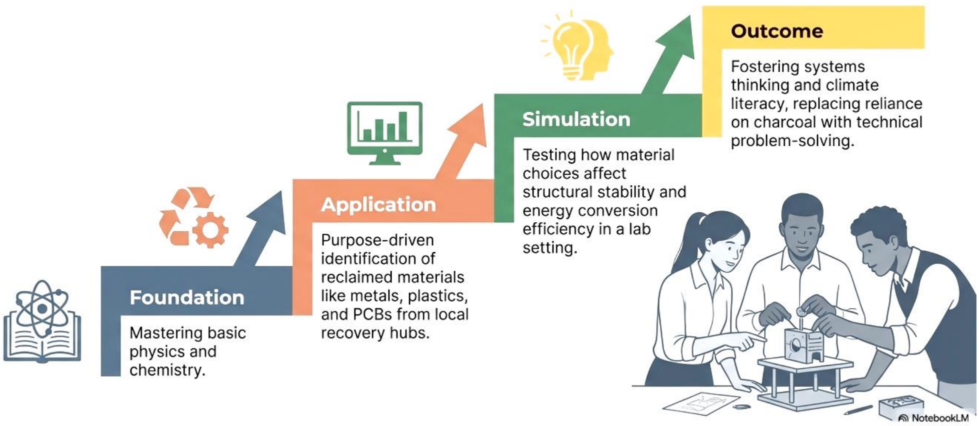

Fig.7. Conceptual illustration of students testing economical renewable energy prototypes using recycle materials in a school laboratory.

Rather than focusing on complex fabrication, instruction emphasizes purpose-driven material identification, basic energy concepts, and simple simulations that demonstrate how renewable energy systems work. Through guided activities, the students will be knowledgeable on how material choice affects structural stability, heat transfer, or energy conversion efficiency, while also understanding the environmental importance of reuse and resource optimization.

This step-by-step learning pathway fosters appreciation of renewable energy not only as a technology, but as part of a broader sustainable environmental system[1].

8 Results and Discussion

The findings indicate a substantial gap between the Philippines' current clean energy capacity and its long-term renewable energy targets. Although installed clean energy capacity has reached 8.2 GW, the projected requirement of 52.8 GW by 2040 suggests that present deployment remains insufficient and that stronger policy execution is necessary. At the same time, the renewable energy mix remains concentrated in geothermal and hydropower, while solar and wind still occupy only a limited share. This pattern identifies as the challenge is not only expansion, but also diversification toward a more flexible and resilient energy system. Beyond utility-scale development, decentralized renewable energy systems offer an important complementary pathway. Rooftop solar, in particular, is highly relevant in the Philippine setting because it can serve as both a source of household electricity and a passive cooling element that reduces indoor heat gain. This dual function strengthens energy resilience at the residential level, especially during supply interruptions. In parallel, junk shop networks and recovered materials provide opportunities for low-cost prototyping and community-based innovation, particularly in educational and experimental settings. When combined with simulation-based testing, these localized approaches support safer, more accessible, and context-responsive renewable energy development.

9 Conclusion

This study demonstrates that the Philippine energy transition requires a comprehensive and integrated approach that extends beyond conventional infrastructure development. While significant progress has been made in renewable energy deployment, current capacity levels remain insufficient to meet long-term targets, and the energy mix lacks adequate diversification. The findings highlights how significant is the decentralized energy systems, particularly rooftop solar technologies, in enhancing household-level energy resilience and efficiency. Furthermore, integrating circular resource systems offers a novel pathway to support innovation, reduce costs, and promote sustainable material use.

Achieving national energy goals will require coordinated efforts across multiple levels, including accelerated investment in renewable technologies, policy alignment, community engagement, and capacity-building initiatives. By incorporating systems thinking and circular economy principles, the Philippines can transition toward a more resilient, inclusive, and sustainable energy future.

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