Toward Carbon Neutrality in Philippine Higher Education: Scenario Modeling of Energy, Mobility, and Nature-Based Offsets at JRMSU

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Abstract

Higher education institutions (HEIs) play a critical role in climate action, yet resource-constrained universities in the Global South often lack clear frameworks for achieving carbon neutrality. This study builds on the 2025 electronic Greenhouse Gas Inventory (eGHGi) of Jose Rizal Memorial State University (JRMSU), which reported baseline emissions of 640.06 tCO_2e, and applies scenario modeling to evaluate offset strategies aligned with Philippine legal mandates and the Sustainable Development Goals (SDGs). Three categories of interventions were analyzed: energy measures (1 MW rooftop solar photovoltaic [PV], LED retrofits, diesel generator hybridization), mobility programs (electric shuttle service, bike-to-campus incentives, carpooling), and nature-based solutions (50 hectares of mangrove rehabilitation, 1,000 campus trees annually). Emission factors were drawn from the Department of Energy (DOE), International Energy Agency (IEA), Association of Southeast Asian Nations (ASEAN), and Department of Environment and Natural Resources (DENR). Results showed that solar PV could offset ~720 tCO_2e annually, complemented by 35–65 tCO_2e from efficiency and hybridization; mobility strategies contributed 23–33 tCO_2e annually; and nature-based interventions sequestered 170–270 tCO_2e over a 5–7 year horizon. The integrated portfolio achieved a net-negative carbon balance within three to five years. The study concludes that scenario modeling is an effective, policy-aligned tool for HEIs to institutionalize carbon neutrality, supporting national commitments under the Climate Change Act, the NDC, and advancing SDGs 7, 11, 13, 14, and 15.

Keywords and phrases: *Carbon neutrality; Scenario modeling; Higher education institutions; Greenhouse gas inventory; Renewable energy; Nature-based solutions; Sustainable mobility; SDG 7; SDG 11; SDG 13; SDG 14; SDG 15*

Introduction

Higher education institutions (HEIs) are increasingly recognized as critical actors in advancing climate action, both as contributors to emissions and as agents of change through research, innovation, and education. Globally, institutional carbon footprints are largely driven by electricity consumption, commuting, and waste generation (Li et al., 2022; Vásquez & Muñoz, 2020). In the Philippines, systematic greenhouse gas (GHG) inventories are still emerging, yet they are mandated and encouraged by national policies such as the Climate Change Act of 2009 (Republic Act [RA] 9729), the Renewable Energy Act of 2008 (RA 9513), and the Energy Efficiency and Conservation Act of 2019 (RA 11285). These legal frameworks, together with the National Climate Change Action Plan (NCCAP 2011–2028) and the country's Nationally Determined Contribution (NDC 2021), require government institutions, including state universities and colleges (SUCs), to identify and adopt feasible mitigation strategies.

Jose Rizal Memorial State University (JRMSU), a multi-campus SUC in Mindanao, conducted its first electronic Greenhouse Gas Inventory (eGHGi) in 2025, establishing a baseline of 640.06 tCO_2e. Building on this baseline, the present study employs scenario modeling to examine offset strategies that can move the university toward carbon neutrality. Scenario modeling is widely used in climate and energy planning to explore "what-if" conditions under realistic assumptions, especially in contexts where immediate interventions are resource-intensive or long-term (International Energy Agency [IEA], 2023; Association of Southeast Asian Nations [ASEAN], 2021). This approach provides policy-relevant insights that support compliance with national mandates and enable SUCs to serve as exemplars of institutional sustainability.

The study aligns directly with the United Nations Sustainable Development Goals (SDGs), particularly SDG 7 on affordable and clean energy, SDG 11 on sustainable cities and communities, SDG 13 on climate action, SDG 14 on life below water, and SDG 15 on life on land (United Nations, 2023). By embedding offset strategies into its operations, JRMSU contributes to both national climate targets and global sustainability commitments. The specific objectives were to quantify the offset potential of energy interventions such as solar photovoltaic (PV) systems, efficiency measures, and hybridization of diesel generators; to estimate commuting-related emission reductions through electric shuttles, bike-to-campus programs, and carpooling; to assess the sequestration capacity of nature-based solutions including mangrove rehabilitation and tree planting; to develop comparative scenarios integrating these strategies; and to align findings with relevant Philippine laws and SDGs.

The findings revealed that energy interventions, particularly the deployment of a 1 MW rooftop solar PV system complemented by LED retrofits, could offset the entirety of JRMSU's electricity-related emissions, achieving immediate carbon neutrality. Mobility interventions, while modest in terms of carbon reduction, were socially significant for shaping sustainable commuting practices and fostering local partnerships. Nature-based solutions, especially mangrove restoration, offered long-term sequestration benefits with broader ecological and livelihood co-benefits. When modeled as an integrated portfolio, these strategies achieved a net-negative carbon balance within three to five years, underscoring the feasibility of SUCs like JRMSU leading in climate action.

Based on these results, the study concludes that scenario modeling is a practical and ethically sound tool for SUCs to design offset strategies that are both locally feasible and globally relevant. Recommendations include institutionalizing carbon neutrality targets in SUC policies, prioritizing renewable energy and energy efficiency interventions, strengthening green mobility programs through LGU partnerships, expanding mangrove and tree planting initiatives under the Enhanced National Greening Program, and integrating inventory results into teaching, research, and extension. Replicating such offset portfolios across Philippine HEIs would not only accelerate the country's progress toward its NDC commitments but also demonstrate how resource-constrained universities in the Global South can contribute meaningfully to sustainable development, resilience, and climate justice.

Materials and Methods

This study employed a scenario modeling design, a foresight approach that applies "what-if" interventions to a baseline dataset to evaluate potential carbon reductions. Widely used in climate and energy planning (IEA, 2023), this method enables policy-relevant analysis where interventions are costly or long-term. In the Philippines, scenario modeling supports institutional compliance with the National Climate Change Action Plan (NCCAP 2011–2028) and the Nationally Determined Contribution (NDC 2021), both of which call for ex-ante evaluation of mitigation strategies (CCC, 2024; NEDA, 2023).

The setting is a multi-campus state university in Mindanao. The analysis used the 2025 electronic Greenhouse Gas Inventory (eGHGi) (Ongsuco & Rosel, 2025), reporting 640.06 tCO_2e: Scope 1 fuel (9.31), Scope 2 electricity (604.89), and Scope 3 commuting (25.86). Waste activity data were excluded due to the absence of local emission factors, consistent with national practice prioritizing energy and transport (DOE, 2024; Clean Air Asia, 2021).

Intervention choices were anchored on Philippine legal and strategic frameworks:

- RA 9513 (Renewable Energy Act): promotes solar PV adoption.
- RA 11285 (Energy Efficiency and Conservation Act): mandates LED retrofits and efficiency programs.
- RA 9729 (Climate Change Act, as amended): mainstreams climate action across institutions.
- Philippine Development Plan 2023–2028: prioritizes climate-resilient investments.
- DOST HNRDA 2022–2028: includes energy and climate R&D priorities.
  Strategies were also mapped to SDGs 7, 11, 13, 14, and 15 to ensure global alignment.

Three families of interventions were identified:

1. Energy: 1 MW solar PV, LED retrofits, and generator hybridization.
2. Mobility: electric shuttle, bike-to-campus incentives, and carpooling.

3. Nature-Based Solutions (NBS): 50 hectares of mangrove rehabilitation and 1,000 trees/year.

These interventions were chosen for feasibility in provincial HEIs and co-benefits for resilience and community engagement.

Offsets were estimated using published coefficients (Table 1). Energy avoided emissions were based on DOE/IEA grid factors (0.55–0.58 tCO_2e/MWh). Efficiency was modeled as 5–10% of Scope 2. Generator hybridization displaced 50–70% of diesel use. Commuting factors followed the ASEAN ASIF framework (0.103 $kgCO_2/pkm$ for motorcycles). Mangroves were estimated at 3–5 $tCO_2e/ha/year$, while trees sequester ~20–25 $kgCO_2/year$ (DENR ERDB, 2023).

Table 1. Sources of Emission Factors

Category	Parameter	Value/Range	Source
Energy	Grid emission factor (electricity)	0.55–0.58 tCO_2e/MWh	DOE (2024); IEA (2023)
	LED/Efficiency savings	5–10% of Scope 2	DOE IRR of RA 11285 (2019)
	Generator hybridization	50–70% diesel displacement	IPCC (2006); DOE (2023)
Mobility	Motorcycle/tricycle emission factor	0.103 $kgCO_2$/passenger-km	ASEAN ASIF framework (2021); ADB (2023)
	Carpooling consolidation	10% vehicle reduction	ASEAN/ADB assumptions
	Bicycle emission factor	~0.00 $kgCO_2/km$	Clean Air Asia (2021)
Nature-Based Solutions	Mangrove sequestration	3–5 $tCO_2e/ha/year$	UNFCCC REDD+ FRL (2022); Gopez et al. (2024)
	Tree sequestration	20–25 $kgCO_2/tree/year$	DENR ERDB (2023); CCC (2022)

Four scenarios were constructed:

- **A (Energy-Only):** solar + efficiency.
- **B (Nature-Only):** mangroves + trees.
- **C (Mobility-Only):** shuttle + bike + carpooling.
- **D (Integrated):** combination of all strategies.

Annual offset potentials were subtracted from the baseline (640.06 tCO_2e) to calculate **net institutional emissions** and carbon neutrality timelines.

Sensitivity bounds were applied: PV yield (1,200–1,400 MWh/year), efficiency savings (5–10%), commuting participation (±10 pp), mangrove sequestration (3–5 $tCO_2e/ha/yr$), and tree sequestration (20–25 $kgCO_2/tree/yr$). Reporting ranges instead of single values reflects best practice in policy modeling (IEA, 2023; ASEAN, 2021).

Ethical Considerations

This article reuses the JRMSU eGHGi dataset for secondary analysis. To prevent duplication: (i) the research question was reframed toward offset evaluation, (ii) new analyses were produced (scenarios, sensitivity ranges, portfolio modeling), and (iii) the parent study is explicitly cited. These safeguards comply with publication ethics on derivative analyses.

Results and Discussions

The results of the scenario modeling are presented in terms of estimated offset potentials across three primary domains—energy, mobility, and nature-based solutions. These interventions were selected based on their feasibility within the Philippine higher education context, compliance with existing laws such as the Renewable Energy Act of 2008 (RA 9513), the Energy Efficiency and Conservation Act of 2019 (RA 11285), and the Climate Change Act of 2009 (RA 9729), as well as their alignment with the Philippines' Nationally Determined Contribution (Republic of the Philippines, 2021; Climate Change Commission, 2024). The offsets are reported as annual carbon dioxide equivalent (tCO_2e) reductions or sequestration, with time horizons reflecting either immediate operational savings or long-term ecosystem benefits. Table 2 summarizes the offset potentials by intervention category, providing a comparative basis for identifying the most effective portfolio toward achieving institutional carbon neutrality and contributing to the attainment of SDGs 7 (Affordable and Clean Energy), 11 (Sustainable Cities and Communities), 13 (Climate Action), 14 (Life Below Water), and 15 (Life on Land).

Table 2. Estimated Offset Potentials by Intervention Category

Category	Intervention	Annual Offset (tCO_2e)	Time Horizon	Source of Emission Factor
Energy	1 MW rooftop solar PV	~720	Annual	DOE (2024); IEA (2023)
	LED retrofits & efficiency measures	30–60	Annual	DOE (2019, RA 11285 IRR)
	Diesel generator hybridization	5–7	Annual	DOE (2024)
Mobility	Electric shuttle	15–20	Annual	Clean Air Asia (2021)
	Bike-to-campus incentives	5–8	Annual	ASEAN (2021)
	Faculty/staff carpooling	3–5	Annual	ASEAN (2021)
Nature-based	50 ha mangrove rehabilitation	150–250	5–7 years	UNFCCC (2022); DENR-ERDB (2023)
	1,000 trees planted annually	~20	5–7 years	DENR-ERDB (2023)
Scenarios	A: Energy-only	780+	Immediate	Modeled from above data
	B: Nature-only	170–270	5–7 years	Modeled from above data
	C: Mobility-only	23–33	Annual	Modeled from above data

	D: Integrated (energy, mobility, NBS)	970–1,080	3–5 years	Modeled from above data

The findings reveal that energy interventions represent the most effective pathway toward institutional carbon neutrality. A 1 MW rooftop solar photovoltaic (PV) system could displace ~720 tCO_2e annually, more than enough to neutralize JRMSU's Scope 2 baseline of 604.89 tCO_2e. This outcome supports Cortes (2022), who documented that electricity is the dominant source of emissions in the UP Cebu GHG inventory, and aligns with the International Energy Agency (2023) which reports that electricity use drives most institutional carbon footprints. LED retrofits and efficiency measures contribute 30–60 tCO_2e annually, consistent with the Department of Energy's (2019) implementation of RA 11285 on efficiency and conservation. As emphasized in the systematic review of Rebelatto et al. (2020), such retrofits provide high returns with minimal capital requirements, making them suitable for resource-constrained universities.

Mobility interventions, while offsetting only 23–33 tCO_2e annually, are socially and culturally important. An electric shuttle system contributes 15–20 tCO_2e savings, while bike-to-campus programs and carpooling offset 5–8 and 3–5 tCO_2e respectively. These estimates are consistent with Clean Air Asia (2021), which highlights that motorcycles and tricycles dominate urban transport emissions, and ASEAN (2021), which stresses the co-benefits of mode-shift policies for congestion and health. Although modest in carbon terms, mobility initiatives cultivate a culture of sustainability, align with LGU priorities, and advance SDG 11 on sustainable communities.

Nature-based solutions (NBS) provide long-term but substantial sequestration. Restoring 50 hectares of mangroves captures 150–250 tCO_2e annually, while tree planting programs (~1,000 trees per year) contribute ~20 tCO_2e once trees are established. These estimates are aligned with sequestration rates reported in the Philippines' REDD+ forest reference level submission (UNFCCC, 2022) and DENR's ERDB (2023) local data. Beyond carbon, NBS interventions deliver biodiversity, coastal protection, and livelihood benefits. These co-benefits are emphasized in the Philippines' Nationally Determined Contribution (2021), the NDC Implementation Plan (CCC, 2024), and the Biennial Transparency Report (Republic of the Philippines, 2024). The World Bank's (2022) *Country Climate and Development Report* also highlights that scaling NBS is critical given that only 2.71% of the Philippine NDC is unconditional, with the rest requiring external financing.

Across scenarios, Scenario A (energy-only) delivers immediate neutrality, Scenario B (nature-only) achieves 40–60% offsets in 5–7 years, and Scenario C (mobility-only) provides marginal but high-visibility reductions. The integrated portfolio (Scenario D) is the most effective, achieving 970–1,080 tCO_2e in offsets annually and enabling a net-negative carbon balance within 3–5 years. This demonstrates that Philippine SUCs can achieve neutrality by combining renewable energy, sustainable mobility, and NBS—a conclusion reinforced by Rebelatto et al. (2020), who found that integrated approaches across technical and ecological domains are the most sustainable pathways for universities worldwide.

Overall, the results confirm that SUCs can realistically align institutional operations with RA 9513 (Renewable Energy Act), RA 11285 (Energy Efficiency and Conservation Act), and the Climate Change Act (RA 9729) while contributing to the Philippines' NDC and SDGs 7, 11, 13, 14, and 15.

Conclusions

This study applied scenario modeling to evaluate feasible offset strategies for Jose Rizal Memorial State University, using its 2025 GHG baseline as reference. The results show that energy interventions—notably a 1 MW rooftop solar PV system, LED retrofits, and generator hybridization—can immediately offset the university's Scope 2 emissions, providing the most impactful pathway to neutrality. Mobility initiatives, while modest in offset potential, contribute to behavioral change, health co-benefits, and partnerships with local governments. Nature-based solutions, including mangrove rehabilitation and tree planting, offer substantial long-term sequestration with additional ecological and livelihood benefits.

Among the modeled portfolios, the integrated scenario (energy + mobility + nature-based) was the most effective, offsetting 970–1,080 tCO_2e annually and achieving a net-negative balance within three to five years. These results demonstrate that Philippine higher education institutions can realistically pursue carbon neutrality through a combination of technical, behavioral, and ecological strategies. The findings are aligned with national policies (RA 9513, RA 11285, RA 9729), the Philippines' NDC (Republic of the Philippines, 2021), the NDC Implementation Plan (Climate Change Commission, 2024), and the Biennial Transparency Report (Republic of the Philippines, 2024), while also contributing directly to SDGs 7, 11, 13, 14, and 15.

Based on the findings of this study, the following are recommended:

1. **Institutional Policy Integration.** Embed carbon neutrality goals into SUC strategic and operational plans, ensuring alignment with CHED's Institutional Sustainability Assessment and ISO certification frameworks.
2. **Energy Investments.** Prioritize rooftop solar PV deployment and efficiency retrofits, leveraging incentives under RA 9513 and RA 11285. Establish financing partnerships with LGUs, DOE, and private sector actors.
3. **Sustainable Mobility.** Develop campus-level programs such as electric shuttles, bike incentives, and carpool systems in collaboration with LGUs to promote low-carbon commuting.
4. **Nature-Based Solutions.** Scale mangrove and tree-planting initiatives under DENR's Enhanced National Greening Program, ensuring monitoring and community co-ownership to maximize co-benefits.
5. **Integration into Research and Extension.** Use eGHGi data and scenario modeling outputs as teaching and extension tools. Encourage faculty-student projects that translate offsets into local policies and ordinances.
6. **Replication Across SUCs.** Promote adoption of integrated carbon-neutral portfolios across Philippine HEIs to accelerate collective progress toward the NDC

and strengthen the higher education sector's role in climate action.

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Disclosure: Use of AI Tools

In compliance with Threshold's guidelines for the ethical use of artificial intelligence (AI) and automated tools in academic research, the authors disclose the use of OpenAI's ChatGPT for enhancing the quality and clarity of the manuscript. ChatGPT was utilized to assist in refining the language, structure, and formatting of the text, ensuring a high level of academic rigor and coherence. The authors confirm that all data analysis, critical interpretations, and conclusions presented in this manuscript were conducted independently by the research team. The AI tool was employed strictly for editorial assistance and did not influence the scientific content or ethical considerations of the study. All intellectual contributions from the AI tool are in accordance with the authors' original intentions and have been reviewed and approved by all co-authors. The use of ChatGPT complies with Threshold's ethical standards and guidelines for transparent reporting of AI involvement in research. The authors remain fully responsible for the integrity and accuracy of the content presented in this paper.

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