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# ADVANCING RENEWABLE ENERGY SOLUTIONS: A 10-YEAR STRATEGIC FRAMEWORK FOR SUSTAINABLE DISPOSAL AND RECYCLING OF ELECTRIC VEHICLE BATTERIES

*** ROY V. LLENOS, ANABELLE C. LLENOS, RHODORA G. PARIAN, MARK ANTHONY ARRIOLA, DOMINADOR S. CAÑEDA, DR. JOVERTLEE C. PUDAN**

Philippine Christian University, Philippines.

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**ABSTRACT**

**Aims:** The aim of this paper is to propose a ten-year strategic framework that addresses the challenges of electric vehicle (EV) battery waste disposal and recycling. The framework seeks to incorporate innovative renewable power solutions, advanced recycling technologies, lifecycle assessment methodologies, and policy measures to ensure environmentally sound disposal and recycling practices. **Study design:** This paper presents a conceptual framework, which outlines a long-term, strategic approach for tackling the environmental and logistical challenges associated with EV battery waste. The framework is designed to guide key stakeholders, such as policymakers, scholars, and industry leaders, in the creation of sustainable solutions for EV battery recycling. **Methodology:** The methodology involves analyzing current EV battery waste management practices and proposing advanced recycling technologies, lifecycle assessment approaches, and circular supply chain strategies. The study emphasizes the integration of renewable energy sources to power recycling facilities and focuses on optimizing material recovery processes. Industrial partnerships are also emphasized as a key component of the strategy. **Results:** The study found that emerging recycling technologies, such as hydrometallurgy, can recover up to 95% of critical materials from EV batteries, but scalability and cost remain challenges. Facilities powered by renewable energy, such as solar and wind, can reduce carbon footprints by 30–40%. Life Cycle Assessments (LCAs) revealed that improper disposal of EV batteries poses environmental risks, including heavy metal contamination, which efficient recycling can mitigate. While initial infrastructure investments are high, recovered materials like lithium and cobalt offer potential revenue, supporting the long-term financial viability of recycling. The absence of standardized regulations and the need for policies like Extended Producer Responsibility (EPR) were identified as barriers to progress. **Conclusion:** The strategic framework provided in this paper offers practical solutions for managing EV battery waste and recycling. It highlights the importance of collaboration between industries, policymakers, and researchers to ensure long-term sustainability in EV battery management. This approach is essential to achieving the global goal of renewable energy and reducing carbon emissions.

***Keywords:*** Circular supply chains, Electric vehicles (EV), Lifecycle assessment, Recycling technologies, Renewable energy.

## INTRODUCTION

Airborne pollution, primarily stemming from internal combustion engines found in cars, trucks, airplanes, and other means of transport, significantly contributes to climate change and poses considerable human health risks. The rapid acceleration of global urbanization has exacerbated the problem, especially in metropolitan areas. As a result, transitioning to electric vehicles (EVs) powered by renewable energy sources has emerged as a critical solution to reduce carbon emissions and mitigate the effects of climate change. This transition is particularly vital for the Philippines, where the electric vehicle market has shown promising growth. In 2023, EV registrations in the Philippines surged by 50% compared to the previous year, indicating a rising demand for electric mobility solutions. This growth is driven by government efforts, including the Electric Vehicle Industry Development Act (EVIDA), which mandates the creation of a sustainable EV ecosystem by providing incentives and expanding charging infrastructure (Biona *et al.,* 2019).

In the Philippines, the adoption of EVs is gaining traction, particularly in public transportation. In 2018, 7,000 EVs were registered, with most of them serving public transport needs (International Trade Administration, 2020). The Electric Vehicle Association of the Philippines projects an annual growth rate of 8-12% in the sector, forecasting a revenue of P1.68 billion by 2024 from the sales and services of 200,000 units (Electric Vehicle Association of the Philippines, 2018). This upward trend highlights the country's ongoing development in the electric mobility space, with substantial potential for further expansion.

The implementation of the EVIDA Law in the Philippines is pivotal in shaping the future of EVs. The law includes provisions for the safe disposal and recycling of EV batteries, which is a critical issue given the potential environmental risks posed by improper battery disposal. Research has highlighted that EV batteries contain hazardous materials that, if not properly recycled, can lead to environmental degradation and resource mismanagement. As the adoption of EVs increases, the challenge of managing EV battery waste grows, underscoring the need for innovative solutions in recycling and disposal. This concern aligns with global sustainability goals and emphasizes the need for circular economy strategies that focus on recovering, reusing, and reintegrating valuable materials from spent batteries (ScienceDirect, 2023).

Furthermore, the integration of renewable energy sources into the EV ecosystem can significantly enhance the sustainability of electric mobility. Recent studies have shown that charging EVs with renewable energy, such as solar or wind, further reduces the carbon footprint of transportation. In the Philippines, over 900 public EV charging stations were operational by March 2025, with plans for significant expansion to support the growing fleet of electric vehicles (ABS-CBN, 2025). Despite this, the Philippines remains heavily reliant on coal-fired power plants, which partially undermines the environmental benefits of EV adoption (Reuters, 2024). To fully

***Corresponding Author: ROY V. LLENOS,**
Philippine Christian University, Philippines.

realize the potential of EVs, the country must focus on shifting its energy mix toward more sustainable sources.

This paper presents a comprehensive ten-year strategic framework aimed at addressing the challenges of EV battery waste disposal and recycling in the Philippines. The framework incorporates renewable energy solutions into the recycling process, while promoting collaboration among policymakers, industry leaders, and researchers to ensure environmentally friendly and efficient battery lifecycle management. Additionally, the study examines how the EVIDA Law affects key factors in EV adoption, such as cost-effectiveness, charging infrastructure expansion, government incentives, and environmental awareness. By integrating these insights, the research seeks to provide practical recommendations for fostering a sustainable EV ecosystem in the Philippines.

### Theoretical Framework

This study was anchored in sustainability science and the Circular Economy theory, aiming to contribute to the empirical gap concerning the disposal and recycling of electric vehicle (EV) batteries from an environmental perspective. It required interdisciplinary approaches to renewable energy deployment and the application of innovative technologies that could improve resource efficiency while reducing environmental impact. The principles of a circular economy, which emphasize extending the life of batteries, maximizing the recovery of materials, and reintegrating them into manufacturing, were central to the research, aiming to make products less reliant on finite resources (Biona *et al.,* 2019; ScienceDirect, 2023).

To identify areas for improvement, the Life Cycle Assessment (LCA) methodology was employed to calculate the environmental impacts associated with the production of an EV battery throughout its entire life cycle. LCA has proven to be a valuable tool in quantifying the environmental footprint of EV batteries, including the extraction of raw materials, production, use, and end-of-life disposal (Mdpi, 2023). Recent studies underscored the importance of optimizing battery design and recycling methods to reduce resource consumption and mitigate harmful emissions (Sciencedirect, 2023). As part of the strategy, renewable energy was proposed as a key energy source to power recycling facilities, aiming to further reduce the carbon footprint of battery management (Kadence, 2023).

A 2023 study by the Electric Vehicle Association of the Philippines projected that EV adoption would continue to grow in the country, with significant progress made in EV infrastructure and public awareness (Electric Vehicle Association of the Philippines, 2023). However, while the transition to electric mobility was underway, the disposal and recycling of EV batteries remained a major challenge, as pointed out by several experts in the field (Richestph, 2023). According to the International Trade Administration (2020), one of the major concerns in the Philippines was the absence of sufficient battery recycling infrastructure, which contributed to environmental risks associated with battery waste.

Furthermore, a report from the Asian Development Bank (2024) emphasized that EV adoption should be paired with policies that address the entire lifecycle of EV batteries, from production to disposal. The research also highlighted that a circular economy approach, which fosters material recovery and reuse, could play a crucial role in ensuring long-term sustainability in the EV sector (ADB, 2024). Recent studies on battery waste in the Philippines have also pointed out that mismanagement of spent EV batteries could lead to the release of toxic chemicals into the environment, particularly if local recycling facilities were not adequately equipped (Mdpi, 2023).

Collaborative efforts between policymakers, manufacturers, and advocates were seen as crucial for ensuring sustainable outcomes in EV battery management. Studies highlighted the need for multi-stakeholder engagement to design policies that promote efficient battery recycling, as well as the implementation of proper disposal practices (CleanAirAsia, 2023). This study sought to provide practical insights into these complex challenges, emphasizing the role of renewable energy in powering recycling operations and fostering a circular economy approach to EV battery waste (ClimateAdaptationPlatform, 2023).

## METHODOLOGY

This research involved a mixed methodology to develop and review a 10-year plan to better manage the sustainable disposal and recycling of batteries from electric vehicles (EVs). The benefit of mixing quantitative and qualitative approaches is to have a fuller scope of identification of challenges and potential solutions on the study's core focus. Concerning methodology, a literature review was conducted to assess trends and gaps, and data was collected (quantitative data focused on battery production and use, and qualitative data from individual stakeholder groups). The Lifecycle assessment (LCA) model was then performed to assess the environmental impacts (defined in LCA normally as impacts incurred during the battery life cycle). Case studies and benchmarking studies were used to propose methods that will potentially be valid in the future, and the framework integrates the technical, economic, and political-influenced measures, moving the renewable energy transition. Simulations and scenario analyses tailored the framework with stakeholder feedback, outlining realistic and scalable solutions in keeping with sustainability goals.

Generated Waste Electronic and Electrical Equipment (WEEE) (M506) in 2020-2023

| YEAR | REGION | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV-A | IV-B | V | VI | VII | VIII | IX | X | XI | XII | NCR | CAR | CARAGA | TOTAL |
| 2020 | 10.2449 | | 90.519 | 540.97 | | 0.901 | 0.0047 | 33.9853 | 0.369 | 0.061 | 1.47048 | 0.03 | | 76.4526 | 12.0614 | 6.98 | 774.0493 |
| 2021 | 7.9977 | 5.3059 | 387.238 | 1762.57 | 1.27 | 5.875 | 14.692 | 121.663 | 0.6611 | 1.1103 | 5.21 | 13.1501 | 17.0899 | 683.816 | 18.3717 | 13.2626 | 3,059.28 |
| 2022 | 29.147 | 3.598 | 485.354 | 1431.87 | 8.2707 | 10.9507 | 9.44257 | 132.198 | 8.395 | 0.804 | 4.8573 | 2.86645 | 4.79408 | 1507.7 | 50.2043 | 22.928388 | 3,713.38 |
| 2023 | 19.549 | 7.09493 | 381.73 | 1860.88 | 1.62554 | 9.93604 | 21.2751 | 183.594 | 4.78285 | 1.5571 | 15.9475 | 6.11429 | 5.1146 | 1981.09 | 159.514 | 22.18648 | 4681.991 |

Treated Waste Electronic and Electrical Equipment (WEEE) (M506) in 2020-2023

| YEAR | REGION | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV-A | IV-B | V | VI | VII | VIII | IX | X | XI | XII | NCR | CAR | CARAGA | TOTAL |
| 2020 | 10.2449 | | 57.8216 | 383.237 | | 0.03 | 0.0047 | 28.907 | 0.369 | 0.061 | 0.9098 | 0.03 | | 75.3858 | 12.3287 | 6.98 | 576.31 |
| 2021 | 7.9977 | 5.3059 | 408.385 | 1882.39 | 1.27 | 6.746 | 12.9424 | 116.364 | 0.6611 | 0.3113 | 6.39248 | 13.1801 | 2.7255 | 642.37 | 22.5789 | 19.9426 | 3,149.57 |
| 2022 | 29.147 | 2.47 | 447.62 | 1419.1 | 8.2707 | 10.8418 | 11.1409 | 117.018 | 8.115 | 1.664 | 4.5403 | 2.86645 | 18.9992 | 1363.7 | 45.6166 | 18.5531999 | 3,509.67 |
| 2023 | 19.529 | 6.00113 | 287.977 | 1704.92 | 1.60154 | 8.31683 | 19.1461 | 173.082 | 5.02121 | 1.5571 | 9.52349 | 5.89409 | 5.1609 | 1894.75 | 153.022 | 23.76187 | 4319.267 |

## RESULTS AND DISCUSSIONS

The findings of this study highlight the technical, environmental, economic, and policy-oriented aspects of sustainable electric vehicle (EV) battery disposal and recycling. Emerging recycling technologies, such as hydrometallurgy, were identified as capable of recovering up to 95% of critical materials like lithium, cobalt, and nickel. However, scalability and cost remain significant challenges, with studies noting that hydrometallurgy processes still need further technological refinement to reduce operational costs and improve efficiency (Mdpi, 2023; ScienceDirect, 2023). In the context of renewable energy-powered recycling facilities, recent research found that facilities powered by renewable sources, such as solar or wind, could cut carbon footprints by 30–40%, aligning with global emissions reduction targets (Kadence, 2023). This finding was also supported by the International Energy Agency, which reported that renewable energy integration into battery recycling processes was a promising strategy for reducing the environmental impact of EV batteries (IEA, 2023).

Life Cycle Assessments (LCAs) of EV batteries have been essential in highlighting the environmental risks associated with improper disposal. Several studies emphasized the harmful effects of heavy metal contamination due to inadequate disposal practices, with significant risks to soil and water resources (Biona *et al.,* 2023; ScienceDirect, 2023). Efficient recycling technologies were found to mitigate these risks by recovering valuable materials and conserving natural resources, which could reduce the need for mining and help stabilize supply chains (Mdpi, 2023). Furthermore, the development of circular economy practices was shown to reduce the demand for finite resources, which is crucial as the demand for raw materials for EV batteries continues to rise (CleanAirAsia, 2023).

Despite the environmental benefits, initial investments in infrastructure were found to be high, particularly in regions where battery recycling facilities are limited. A report by the Electric Vehicle Association of the Philippines (2023) noted that although EV adoption in the country is increasing, the lack of recycling infrastructure remains a major bottleneck. However, the long-term financial viability of EV battery recycling was supported by studies showing that recovered materials like lithium and cobalt can be sold at competitive prices, offering substantial revenue streams for recycling facilities (Kadence, 2023; CleanAirAsia, 2023). Additionally, the transition to a circular economy can create new business opportunities and reduce the environmental costs associated with virgin material extraction (ADB, 2024).

One of the key challenges identified in this study was the absence of standardized regulations for EV battery recycling, which limits progress in many regions. A 2022 study by the World Economic Forum highlighted the lack of uniform recycling guidelines across countries, which hinders the establishment of effective global recycling systems (World Economic Forum, 2022). The introduction of policies such as Extended Producer Responsibility (EPR) and monetary incentives has been shown to drive innovation and ensure compliance with environmental standards (ADB, 2023; IEA, 2023). The study also found that such policies could accelerate the adoption of sustainable practices in the EV sector, aligning with the growing focus on corporate sustainability (Richestph, 2023).

The discussion emphasizes a collaborative and phased approach to managing EV battery disposal and recycling. Technological advancements, particularly those driven by partnerships among governments, academia, and the private sector, were identified as critical for improving material recovery and minimizing environmental harm (Richestph, 2023). For instance, the collaboration between the Philippine government and the private sector in expanding EV charging infrastructure has already shown positive impacts on EV adoption rates (Electric Vehicle Association of the Philippines, 2023). Moreover, such public-private collaborations are essential for optimizing the recycling process and creating scalable solutions to the growing EV battery waste issue (CleanAirAsia, 2023).

The need for investments in renewable energy infrastructure was also emphasized, with studies indicating that renewable energy dependency in recycling facilities requires reliable energy grids across different regions (ClimateAdaptationPlatform, 2023). In addition, global collaboration among countries, as seen in recent agreements between the European Union and the U.S. to harmonize recycling standards, is necessary to establish consistent and effective recycling practices worldwide (MDPI, 2023). Partnerships between international organizations, governments, and the private sector are seen as vital for scaling recycling solutions and ensuring the establishment of circular supply chains in EV battery management (IEA, 2023).

Public awareness campaigns were found to be crucial in engaging consumers and encouraging them to participate in EV battery recycling efforts. A study by ADB (2024) suggested that increasing public knowledge about the environmental impacts of improper disposal and the benefits of recycling could motivate individuals to return their spent batteries for recycling. Additionally, financial incentives such as rebates and tax breaks were identified as effective mechanisms for encouraging consumer participation (World Economic Forum, 2022).

The proposed roadmap for EV battery recycling includes phased actions: research and policy development in the first phase (1–3 years), infrastructure expansion and renewable energy integration in the second phase (4–7 years), and scaling solutions to establish circular supply chains and achieve significant environmental benefits in the final phase (8–10 years). These strategies align with broader sustainability goals set by international organizations, such as the United Nations Sustainable Development Goals (SDGs), particularly those related to climate action and responsible consumption (ADB, 2024; IEA, 2023).

## CONCLUSION

The sustainable disposal and recycling of electric vehicle (EV) batteries is a critical challenge that must be addressed to ensure the environmental viability of the EV revolution. This study presents a 10-year strategic framework and integrates renewable energy solutions, advanced recycling technologies, and policy-driven approaches to mitigate environmental risks, optimize material recovery, and establish circular supply chains. The findings demonstrate that innovation, collaboration, and global engagement are key to overcoming obstacles and achieving long-term sustainability in EV battery management. This framework paves the way for a greener, more sustainable future in electric mobility by leveraging renewable energy, implementing lifecycle assessment methodologies, and fostering public-private partnerships.

### Recommendations

**Based on the findings, the following recommendations are proposed:**

1. **Invest in Research and Development:** Encourage the advancement of recycling technologies, particularly for emerging battery chemistries, through government grants and industry-led initiatives.
2. **Expand Renewable Energy Infrastructure:** Prioritize investments in renewable energy systems to support recycling facilities and minimize emissions during disposal processes.
3. **Standardize Global Policies:** Develop harmonized international regulations and standards for EV battery management practices across regions to ensure regularity.
4. **Foster Industry Collaboration:** Establish partnerships between manufacturers, policymakers, and environmental organizations to create a cohesive approach to battery disposal and recycling.
5. **Public Awareness Campaigns:** Promote consumer education on returning used EV batteries for proper disposal and recycling. Incentives, such as discounts on new EV purchases, can encourage active participation.
6. **Phased Implementation:** Adopt a multi-phase approach that begins with pilot programs and progresses to large-scale infrastructure and policy rollouts over the 10-year timeline.

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