Regional Framework Towards Establishing Treatment, Storage, and Disposal (TSD) Facilities for PV Waste Management in the Philippines: A Case Study of Laguna Province

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Keywords: GIS, optimization framework, proximity analysis, PV module waste, TSD facility

Abstract

The accelerated adoption of photovoltaic (PV) systems for renewable power generation in the Philippines will yield a tremendous amount of PV waste. However, the country lacks a comprehensive framework for understanding PV module waste volume growth and optimally siting Treatment, Storage, and Disposal (TSD) facilities for PV waste management based on minimum siting factor. The study aims to develop a regional framework that utilizes a geographic information system (GIS)-based approach to find the potential sites and optimal locations of TSD facilities in Laguna, Philippines, based on the estimated PV module waste growth of solar energy systems with service contracts and minimum siting criteria under Department of Environment and Natural Resources (DENR) Administrative Order 2013-22. By 2060, the projected amount of PV module waste in Laguna province will be around 162,230 metric tons based on the waste projection results. The suitable sites cover around 19,720.5 hectares or 11.21% of the total land area of Laguna, which were determined by various siting factors that encompass social, economic, and environmental factors and obtained using binary suitability analysis and vector overlay analysis. The optimal locations of the two TSD facilities were identified using strategic positioning based on hotspot analysis, clustering algorithm, and proximity analysis. Consequently, the distance and GHG emissions of the two optimal locations were calculated. Indeed, the approach will serve as a guide for policymakers and other stakeholders in understanding PV module waste growth and strategically and optimally position TSD facilities on suitable sites for efficient and effective PV waste management.

1. Introduction

Increasing the share of renewable energy helps mitigate harmful emissions from non-renewable energy (Kramarz et al., 2021; Ndzibah et al., 2022a) and sustain the growing energy demand brought by drastic population growth trend (Rathore & Panwar, 2021). Solar energy has become a popular renewable energy option due to its abundance worldwide. The estimated solar energy capacity of around 4500 gigawatts will generate waste of up to 78 megatons (Contreras-Lisperguer et al., 2017). It is of utmost importance to sustainably manage emerging waste from solar energy systems to prevent environmental pollution and harm to society (Salim et al., 2020)

Photovoltaic (PV) technology is a globally available mature technology (Jain et al., 2022; Ndzibah et al., 2022a), which is cheap, reliable, and environmental-friendly (Chowdhury et al., 2020). PV systems typically include PV modules responsible for converting solar energy to electric currents, cables, mounts, and power electronic devices, such as inverters and batteries. These systems generally operate on-grid, off-grid, or a combination of both. Several studies conducted reviews to understand the state of literature concerning PV waste management (Mahmoudi, Huda, Alavi, et al., 2019; Nain & Kumar, 2022; Oteng et al., 2021; Sica et al., 2018; Xu et al., 2018). This study focuses on PV module waste since it accounts for the majority of PV waste. PV modules have several types depending on the semiconductor materials used and the construction of the modules (Ghosh & Yadav, 2021). Base metals and critical metals can be recovered from PV module waste, such as aluminum, nickel, copper, tin, gallium, tellurium, indium, and manganese. Moreover, toxic substances can also be found in PV modules, like lead, selenium, and cadmium, which can harm the environment and society (Boussaa et al., 2020).

Several studies tried to address the lack of dedicated policies for PV waste management(Jain et al., 2022; Mahmoudi et al., 2021b; Rathore & Panwar, 2021; Sharma et al., 2019; Sheoran et al., 2022; Weiner et al., 2018), and circular economy approach can be incorporated to strengthen policy efficacy (Balaji & Hiremath, 2021; Mahmoudi et al., 2018; Mathur et al., 2020). PV waste assessments have also been conducted worldwide, such as in Spain, Italy, USA, Mexico, and Australia (Domínguez & Geyer, 2017, 2019; Mahmoudi, Huda, & Behnia, 2019; Paiano, 2015; Santos & Alonso-García, 2018). Indeed, the worldwide trend shows growing PV waste due to the rapid adoption of PV technology for commercial and residential applications. PV waste assessment can be a helpful tool for understanding waste generation and management.

PV modules degrade and fail due to internal and external factors (Chowdhury et al., 2020; Mahmoudi et al., 2021a). Improper disposal of decommissioned PV modules may lead to the leaching of toxic and hazardous substances (Nain & Kumar, 2020a, 2020b). Several studies have presented approaches for end-of-life management (EOL) for the sustainability of its operations (Aravelli & Ramavathu, 2021; Ardente et al., 2019; Farrell et al., 2020; Goe & Gaustad, 2014, 2016; Latunussa et al., 2016; MacAlova et al., 2020; Protopapa et al., 2021). Furthermore, efficient and effective EOL of PV waste through strategies and practices is critical to sustainable PV waste management.

The Renewable Energy Act of 2018 supports the adoption and utilization of renewable energy systems, including PV systems. Developers need to secure service contracts to proceed with the development and operation of PV systems. PV waste can be classified as e-waste that contains toxic substances and hazardous waste and is subjected to Republic Act (RA) 6969, also known as the 'Toxic Substances and Hazardous and Nuclear Wastes Control Act of 1990.' Department of Environment and Natural Resources (DENR) Administrative Order 2013-22 (DAO 2013-22 hereafter) streamlines hazardous waste management by prescribing requirements and procedures to waste generators, transporters, and treaters. Under DAO 2013-22, a Treatment, Storage, and Disposal (TSD) facility is a recycling, recovery, storage, and disposal facility for hazardous waste. Establishing TSD facilities for PV module waste management is essential in the country (Bergado, 2022).

One key element of sustainable waste management is transport optimization. The location of collection networks and recycling facilities should be optimized to minimize transport distance. A framework using a mathematical optimization model that uses economic performance in establishing PV recycling facilities (Guo & Kluse, 2020a, 2020b). Another study utilized mixed-input linear programming for PV collection and recycling facilities (Yu & Tong, 2021). Furthermore, a GIS-based approach was utilized through analytic hierarchy process and integer programming to determine the location of collection centers in Turkey (Acar et al., 2015) and PV waste recycling centers in California (Lu, 2019). There is a need for further studies on reverse logistics optimization (Oteng et al., 2021; Seo et al., 2021).

This study aims to develop a geographic information system (GIS)-based regional framework to determine the optimal locations of TSD facilities based on the distribution and location of PV waste generators and siting criteria under DAO 2013-22 in Laguna, Philippines. The proposed comprehensive framework will help policymakers and stakeholders harmoniously establish TSD facilities for effective and efficient PV waste management in the country.

2. Methodology

2.1 Study Design

GIS Spatial Analysis was utilized to identify the potential sites and optimal locations of TSD facilities in the study area guided by the distribution and location of the projected PV module waste of PV systems under various stages of service contracts and siting criteria based on DAO 2013-22. PV module waste projection that follows Weibull distribution was performed in Excel. Raw spatial data that include the location and projected waste volume of PV systems and identified maps of the siting factors under DAO 2013-22 were inputs in Quantum GIS (QGIS hereafter). Hotspot and clustering were applied to the projected PV waste volume, followed by binary suitability analysis and proximity analysis to identify the suitable sites and optimal locations of TSD facilities. The research design is shown in Figure 1.

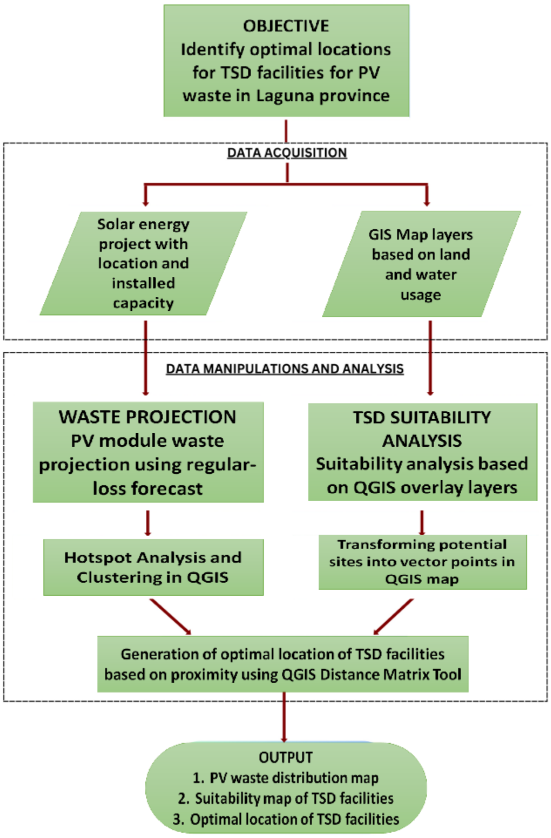
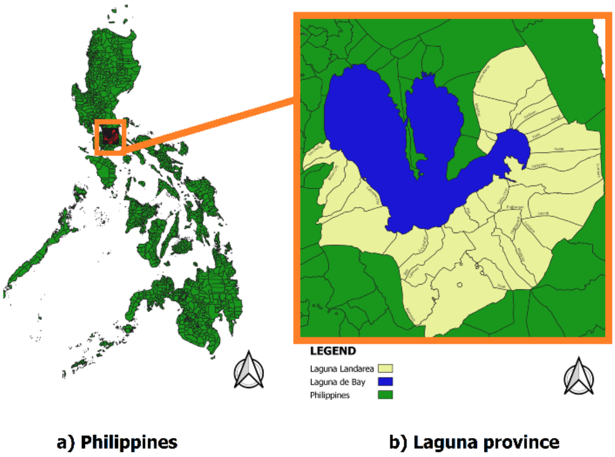


Figure 1. GIS-based Regional Framework for Locating and Siting TSD Facilities

2.2 Study Area

The total land area of Laguna Province is 1,759.73 sq. km. consisting of 24 municipalities and six cities. The province has a projected population of around 4.4 million by 2030. The province ranked 4th in the cities and municipalities competitive index in 2022 (DTI, 2022), and its recorded gross domestic product by 2020 is 2,535,284,422. Around 42% is contributed by the manufacturing industry, and 44% is from various services (PPDCO, 2023). Laguna province was selected as the study area since there are 17 commercial PV systems with service contracts in the area. The map of Laguna province is shown in Figure 2.



a) Philippines **b) Laguna province**

Figure 2. Map of (a) the Philippines, and (b) location of Laguna province

2.3 Data Acquisition

The location, system, potential or installed capacity, and installation year of PV systems were taken from the Department of Energy (DOE) and vector layers from various sources that include road networks, water bodies, critical habitats, active faults, agricultural lands, protected areas, forest areas, and agricultural lands. There are no critical habitats in the province. Table 1 shows the necessary layers for siting the TSD facilities. The buffer layers for the binary suitability analysis were derived from the study of Sadie et al. (2022).

Siting factors	Data Format	Buffer, meters	Sources
Land Use Plan (Physical Framework Development Plan)	Document	-	- Laguna Provincial Planning and Development Office
Agricultural lands Military Forests	Vector	-	- Open Street Map
Road Network	Vector	500	- Open Street Map
Active Faults or Holocene faults	Vector/ Coordinates	700	- Hazard Hunter PH - Philippine Institute of Volcanology and Seismology
Critical habitat	Vector	2000	- Department of Environmental and Natural Resources - Biodiversity Management Bureau
Surface Water	Vector	1000	- Open Street Map

Table 1. Identified siting layers

2.4 Data Manipulations and Analysis

2.4.1 Waste Projection: The study considered the approach of (Mahmoudi, Huda, & Behnia, 2019) and (Lu, 2019) using Weibull distribution for PV module waste projection until 2060 under a regular-loss forecast with the assumed lifespan of 30 years (IRENA & IEA-PVPS, 2016). Equations 1-3 establish the forecasting model.

$$P(t) = 1 - exp[-(t/L)B] \qquad (1)$$

where:
P(t) - Weibull function
t - panel time in years
L – the average life span of PV module waste. Assume 30 years (IRENA & IEA-PVPS, 2016)
B - shape factor (Use B = 5.3759 for regular loss)

The PV module waste at a specific time for each PV system i in the study area can be found using Equation 2.

$$PV\ waste\ (t, j, i) = Installed\ capacity\ (j, i) * ctwr * P(t) \qquad (2)$$

where:
PV waste (t, j, i) - projected PV module waste at year t of installed capacity at year j for each respective PV system i.
Installed capacity (j, i) - the installed capacity at year j of PV system i, in Megawatts
ctwr - capacity-to-weight ratio equal to 70 kg/Megawatts
P(t) = Weibull function

Note: t≤2060

The cumulative PV module waste until 2060 for each PV system can be found using Equation 3.

$$Cumulative\ waste\ (i) = \sum PV\ waste\ (t, j, i) \qquad (3)$$

where:
Cumulative waste (i) - cumulative PV module waste of PV system i
PV waste (t, j, i) - projected PV module waste at year t of installed capacity at year j for each respective PV system i

2.4.2 Hotspot Analysis and Clustering: The hotspot analysis was carried out in QGIS using the Jenks natural breaks approach to find the statistically high-volume waste generators (Oteng et al., 2022) and understand the distribution of the projected PV module waste in 2060. Then, the PV systems were grouped using k-means clustering, a partition-based approach that utilized the location (Eghtesadifard et al., 2020) and waste distribution as a basis of the clusters to account for PV waste flows in the study area. The number of clusters is also the number of TSD facilities. The study simulated two TSD facility scenarios. The TSD facilities will be optimally positioned near the significant PV waste generators to minimize reverse logistic costs. The higher the number of proposed TSD facilities, the lower the travel distance (Lu, 2019), but the higher the installation cost (Yu &Tong, 2021).

2.4.3 Siting the TSD Facilities: To determine the suitable sites for TSD facilities, a binary suitability analysis was conducted in QGIS. Several map vector layers that include the active faults, road networks, and water bodies were added to respective buffers that were then removed from the base map of the land area of Laguna, together with the vector layers of several land use classifications.

2.4.4 Locating the TSD Facilities: Vector proximity analysis (Page-Tan et al., 2021) using the Distance matrix tool in QGIS (Sample et al., 2020) was used to find the optimal locations of TSD facilities in the suitable sites. The significant high-volume waste generators for each cluster were used to strategically position the TSD facilities.

$$GHG = F * M * W_p * T_d \qquad (5)$$

where:
GHG = potential GHG emission, kgCO2eq
F = emission factor of 0.202479 kgCO2eq/mile (Lu et al., 2019)
M = number of PV panels or modules per truck load
W_p = weight per PV panel of 20.5 kg (Bergado 2022)
T_d= total distance between generators and designated TSD facility location, mile

3. Results and discussion

3.1 Waste Projection and Distribution Analysis

The projected PV module waste by 2060 for Laguna province will be 162,230 metric tons, with individual PV waste generation shown in Table 2. PV systems in Laguna and Laguna de Bay were included in the waste projection.

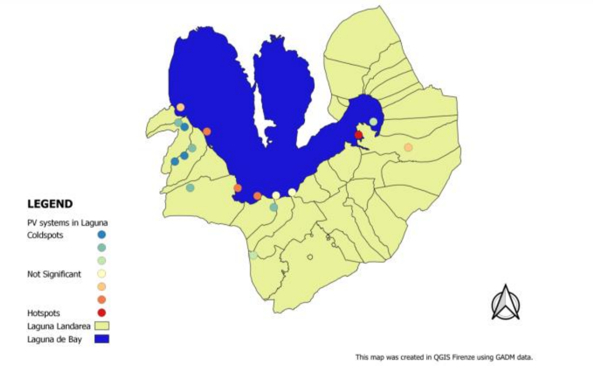
https://doi.org/10.5194/isprs-annals-X-5-2024-49-2024 | © Author(s) 2024. CC BY 4.0 License.

Facility	Waste Projection, metric tons			
	2030	2040	2050	2060
PV1	10.42	1200.46	11277.75	24852.44
PV2	4.20	484.06	4547.48	10021.14
PV3	8.94	1029.42	9670.98	21311.63
PV4	9.66	1113.33	10459.21	23048.63
PV5	1.30	248.54	2751.49	6903.49
PV6	0.02	51.26	984.67	3749.65
PV7	16.81	1936.22	18189.92	40084.58
PV8	5.32	613.14	5760.14	12693.45
PV9	5.13	388.82	3118.17	6078.10
PV10	0.18	5.54	28.23	40.34
PV11	0.00	1.07	20.59	78.40
PV12	0.01	1.90	21.03	52.75
PV13	2.45	468.95	5191.49	13025.45
PV14	0.00	0.09	1.64	6.25
PV15	0.00	2.47	47.44	180.67
PV16	0.25	9.88	58.41	91.56
PV17	0.02	1.21	8.31	14.46
Total	**64.71**	**7556.35**	**72136.94**	**162232.99**

Table 2. Waste Projection of PV module waste in Laguna, Philippines

The identified data based on solar energy distribution (Fig. 3), PV waste generation clusters (Fig. 4), land use plan (Fig. 5), and a minimum space requirement of 10,000 sq. m. (Fig. 6) in Laguna province were overlayed respectively to generate optimum locations of the TSD facilities (Fig. 7). Results and discussion per layer are discussed in the succeeding sections.

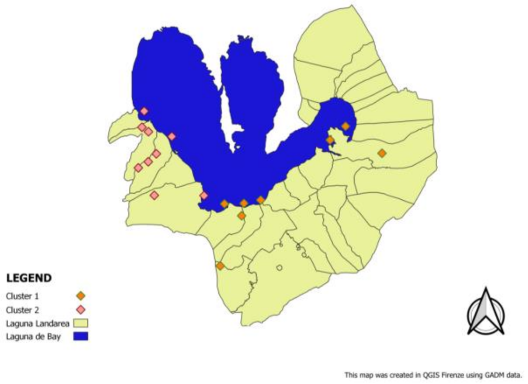
The distribution map shown in Figure 3 shows that many of the hotspots are located on Laguna de Bay. There are higher capacities for floating PV systems than ground-mounted or roof-mounted systems.



This map was created in QGIS Firenze using GADM data.

Figure 3. Distribution of solar energy systems in Laguna

Using GIS tools, the PV waste generators were grouped into two clusters under k-means. The basis for clustering are the proximity and waste volume parameters. Cluster 1 is located in the cities that comprise nine PV systems, while cluster 2 is located in municipalities adjacent to Laguna de Bay, comprised of eight PV systems. The result of the clustering analysis is shown in Figure 4.

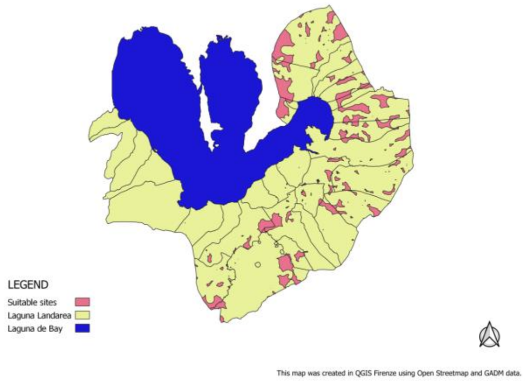


This map was created in QGIS Firenze using GADM data.

Figure 4. PV waste generators clusters using k-means

3.2 Siting the TSD Facilities

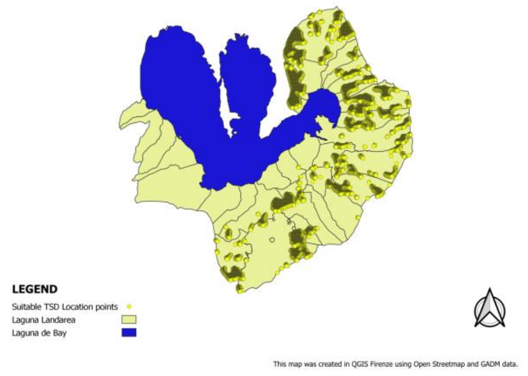
Most suitable areas are in municipalities between the north-eastern and south-eastern parts of the province, shown in Figure 5. The suitable sites readily show the areas where TSD facilities can be installed in conformance with DAO 2013-22. There are a few small patches of suitable sites that cannot accommodate a TSD facility area of 10,000 sq. m. The protected areas, military lands, and forest lands were included so that the land use plan of Laguna province is included in the analysis.



This map was created in QGIS Firenze using Open Streetmap and GADM data.

Figure 5. Suitability Map of TSD Facilities in Laguna, Philippines

Each pixel size is approximately 100 m by 100 m, which is the assumed size of one TSD facility. Around 15,000 location points, which represent the suitable location of a TSD facility having a size of 10,000 sq. m. shown in Figure 6.



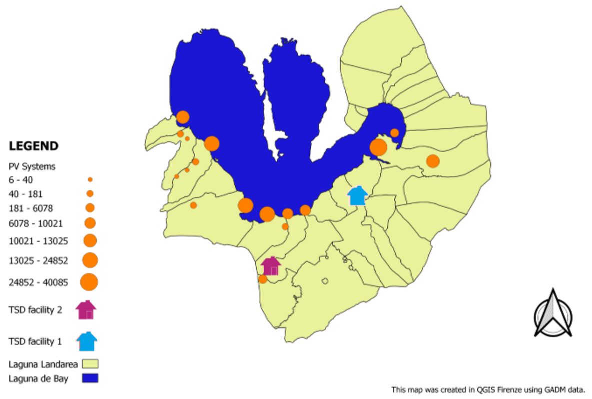
This map was created in QGIS Firenze using Open Streetmap and GADM data.

Figure 6. Suitable location Points of TSD facilities

3.3 Optimal Locations of TSD Facilities and Emissions

Consolidating the data gathered and map generated, the minimal transport distance from the significant waste generators to the TSD facility was determined for each cluster, together with the computation of one-way GHG emissions of the respective TSD facilities. Distance Matrix plugin was utilized to identify the two optimal locations of TSD facilities in the suitable sites that minimize the distance to the significant waste generators. In context, the result from this analysis promotes reduction of proximity or travel time of vehicles, which emits GHG during transport.

The generated locations of the TSD facilities for the two groups of waste generators are presented in Figure 7, as optimized using the previously generated layers in GIS. In relation to minimizing environmental effects, the one-way GHG emissions of the two facilities were calculated using parameters from Lu (2019) and Bergado (2022), summarized in Table 3.



This map was created in QGIS Firenze using GADM data.

Figure 7. Optimally generated locations of the two simulated TSD facilities

Facilities	Location	Distance, km	GHG Emission (kgCO2eq)
TSD Facility 1	Calauan	55.2	94
TSD Facility 2	Pila	74.2	126

Table 3. Transport distance and calculated GHG emissions between TSD facilities and PV systems

3.4 Impact on the Philippine energy share and PV waste management

The adoption of renewable energy is guided by the Renewable Energy Act of 2008, which expedites their development, utilization, and commercialization. The increasing number of service contracts for commercial PV systems in Laguna province strongly indicates the adoption of PV systems, which follows a similar trend worldwide. Several factors could be identified for the growing trends of PV system adoption. For residential PV systems, usefulness, observability, ease of use, and perceived trust, while lower installation cost and government financial incentives for commercial PV systems. The proposed floating PV systems on Laguna de Bay are currently on moratorium as agreed by Laguna Lake Development Authority and DOE. The assessment of the significant impact of floating PV systems is quite a complex task. Based on the investigation of de Lima et al. (2021), floating PV systems do not affect water quality.

The increasing number of applications for commercial PV systems and the possibility of expansion of the developing PV systems are factors that might increase PV system capacity and associated waste. The increasing PV systems in the area can help in reaching the target capacity of 1.35 GWatts in 2040. The unavailability of information about residential PV system capacity and waste flow is the main challenge why residential PV systems were not incorporated into the model. Since there is an observed readily adoption of commercial PV systems in Laguna province and other parts in the country, waste management strategies or best practices should be a priority activity for the implementing agencies like DOE, DENR, and other vital agencies.

PV waste generators with significant waste volumes were found using Jenks natural breaks classification, which can be interpreted as hotspots similar to the study of Lu (2019). Proposed floating PV systems have higher capacity than roof-mounted and ground-mounted PV systems in Laguna province.

The k-means clustering algorithm utilized distance and the waste volume in grouping the data to accommodate PV waste flow that will be carried to the TSD facilities. The groups of waste generators will help to determine the dedicated closest TSD facilities for significant waste generators. The low-volume waste generators should be encouraged to transport their waste to the dedicated TSD facility or the closest facility. PV waste generators may have particular inclinations or preferences due to social factors that should be anticipated. There is a need to enlighten all stakeholders about the impact of transport and the advantages of distance minimization. In addition, the proposed framework was not able to consider finding the optimal number of TSD facilities, which the optimization model of Yu and Tong (2021) can help address based on cost minimization.

The key advantages of Open Streetmap (OSM) layers include ease of acquisition and availability (Vargas-Munoz et al., 2021), which might be attributed to the increasing number of studies in the literature. Available map layers in OSM were utilized due to time constraints. Binary suitability analysis has the capability to discriminate suitable and non-suitable areas that quickly displays the suitable areas much quicker than ranked suitability analysis like analytic hierarchy process or multi-criteria decision analysis that shows the probability of suitability of the entire area of interest that have difficulties in identifying factors (Sadie et al., 2022) and might be prone to biases (Lahtinen et al., 2020). The suitability map will help policymakers and stakeholders quickly determine possible areas and locations to establish TSD facilities. To increase the suitability in the study area, the buffers can be lowered subject to the assessment of LGUs. The physical framework development plan of Laguna province was used to determine necessary land use classifications to incorporate into the framework, such as military lands, agricultural lands, and forest areas. Industrialization is the alternative development strategy next to boosting tourism in the province. However, agricultural lands are restricted from being used in urban expansion and development. In addition, the appropriate locations of ground monitoring wells should be consulted with the National Water Regulatory Board and LGUs concerned. In conducting a suitability analysis, Sadie et al. (2022) acknowledges the challenges of data availability.

After rasterization, a few small patches of suitable areas were not transformed into pixels due to size limitations. The phenomenon warrants that suitable sites with sufficient size will be used in establishing TSD facilities. There is a direct relationship between pixel resolution and the number of suitable location points, while the inverse is for pixel size or the size of the TSD facility area. A high resolution gives a low TSD facility area and a high number of suitable location points. With this abstraction, policymakers can vary the pixel resolution to control the TSD facility size. If there are too many points, sampling the points may be practical to minimize computational resources.

The optimal location of TSD facilities for each cluster to the significant PV waste generators in the suitable areas was found using the distance matrix tool in QGIS. This ensures that the TSD facility is nearer to the significant PV waste generators to minimize reverse logistic costs since the cost is directly proportional to the transported PV waste. In addition, the GHG emissions will be lower if the TSD facilities are at the optimal location. The siting factors under DAO 2013-22 ensure that the TSD facilities greatly consider the sustainability pillars: economic, social, and environmental. By 2030, TSD facility 2 should be established since it is geographically closer to the two clusters of waste generators to be followed by TSD facility 1 in the succeeding years.

3.5 Impact on sustainable development goals

Solar PV modules offer a sustainable source of energy, gaining popularity due to its compact form. This is an appealing option, considering that fossil fuel-based energy sources are depleting. Moreover, fossil fuel utilization generates excessive greenhouse gas emissions, adding burden to climate change. Sustainable development goals (SDG) were created for responsibly conserving resources while aiming for economic development, environmental protection, social relations, and improving the lifestyle of citizens.

SDG 7 pertains to sustainable energy development. Under SDG 7 are the specific targets, aiming to ensure access to affordable, reliable, and sustainable energy for everyone (Obaideen et al. 2021). Considering the case of developing nations such as the Philippines, with the case of Laguna province being set as a benchmark in this study, all of the SDG 7 targets are to be met for proper implementation. With the Philippines having a group of islands, there are areas not provided with electricity at least from the main power grid, thus compromising a considerable amount of the population (SDG 7.1 - access to reliable and clean energy). To solve the problem on the ratio of energy-to-population, solar PV modules are projected to provide the needed power, especially if used in hybrid with other sources (diesel, wind, ocean, etc.) given solar energy is limited during rainy seasons and inaccessible during nighttime (Bertheau and Blechinger 2018). Expansion of solar energy farms could contribute positively to the renewable energy share (SDG 7.2 - share of renewable energy in the global energy mix and SDG 7.3 - improvement in energy efficiency). This will also give proper medium in connecting other nations to provide technical assistance, financial support, and building relationships in the aspect of increasing renewable energy across the globe (SDG 7.4 - enhance international cooperation to facilitate access to clean energy research and technology) (He et al. 2022; Obaideen et al. 2023).

In addition, SDG 12 guides sustainable consumption and responsible production, relating to the proper handling of solar module waste by providing TSD facilities near solar energy facilities. With the some components of solar PV module being hazardous (Boussaa et al., 2020), it is a must that strategic recycling and disposal locations are pointed out even in the early phases of infrastructure development. This could significantly reduce the material carbon footprint from PV module wastes (SDG 12.2 - sustainable management and efficient use of natural resources). Furthermore, recovered secondary materials from broken PV modules could be further processed and reused, contributing to the solar panel life cycle (SDG 12.5 - substantially reduce waste generation through prevention, reduction, recycling and reuse) (Diccion and Duran 2023; Gervais et al. 2021).

4. Conclusion

In this work, a GIS-based framework for finding optimal locations of TSD facilities in suitable areas was developed and successfully applied to the province of Laguna. Two optimal locations in the suitable sites for each cluster were identified based on the location of the significant PV waste generators. Establishing TSD facilities in optimal locations is critical for effective and efficient PV module waste management.

PV module waste growth has been projected from 2030 until 2060 using a probability-based forecasting model. The projected amount of PV module waste will be 162,230 metric tons by 2060. The total area of the suitable sites for establishing TSD facilities is 19, 720.5 has d on the binary suitability analysis of the siting factors identified that are compliant with DAO 2013-22 and the land use plan of the province. The optimal locations in the suitable areas that minimize the distance were found based on the location of the significant PV waste generator for each of the clusters derived by k-means clustering algorithm. Indeed, the lower the distance, the lower the GHG emissions.

Future works should be conducted to find the best model or approach for PV waste assessment and include other parts of PV systems in the analysis, like batteries and inverters. The PV waste flows for commercial and residential should also be a priority to understand PV waste generation. In addition, siting factors of DAO 2013-22 should also be improved to strengthen its adherence to sustainable development principles. Furthermore, studies should investigate incorporating cost in the framework to understand the feasibility of establishing TSD facilities.

TSD facilities for PV waste management gear toward resource sustainability. All stakeholders must understand their respective roles to ensure the sustainability of the operation of the TSD facilities for PV waste. The cooperation and collaboration of policymakers, waste generators, transporters, treaters, and other stakeholders through public-private partnerships are critical to the success of PV waste management (Ndzibah et al., 2022b; Ziaur et al., 2018).

In conclusion, this study presents the first comprehensive framework that can be used as a tool to guide policymakers and other stakeholders in planning efficient and effective PV waste management in the Philippines through PV module waste projection and siting and locating of TSD facilities based on minimum siting criteria under DAO 2013-22.

5. Acknowledgements

The authors would like to express their gratitude to the School of Advanced Studies for guiding the authors during the evaluation of the presented topic for thesis of the 1st author. The authors would also like to thank the University Research and Innovation Committee of Saint Louis University for the support received in the ISPRS TC V Symposium.

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This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
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