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Maximizing Solar Energy Opportunities in Mati City with GIS-Based Site Suitability Assessment

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ABSTRACT

Mati City, a coastal city in southern Mindanao, is experiencing rising energy demands. However, the city's dependence on the National Grid Corporation of the Philippines (NGCP) leaves it vulnerable to frequent power interruptions. This growing energy demand underscores the need to explore sustainable alternatives. Given Mati City's geographic location and high solar irradiance, solar energy presents itself as a viable solution. In line with this, the study aims to develop a Solar Energy System Site Suitability Map in Mati City, Davao Oriental, through the integration of Geographic Information Systems (GIS) and multi-criteria decision-making (MCDM) techniques, specifically, the analytical hierarchy process (AHP) and Fuzzy Overlay analysis. Three criteria were considered, particularly the technical dimension (solar irradiation), environmental dimension (land use-land cover), and economic dimension (road proximity, slope, and elevation). The study revealed that Mati City exhibits favorable solar energy system development conditions, boasting a maximum annual solar irradiation of 5.242 kWh/m^2/day. Considering the three criteria, 66.64% (60,859.76 ha) of the land surface area proved suitable for solar energy system development in the city, while 33.36% (30,459.81 ha.) was deemed unsuitable. Within the appropriate regions, there was further classification into moderately suitable (7.59% or 4,619.49 ha) and highly suitable (92.41% or 56,240.27 ha). The findings of this study provide a basis for future research in these disciplines to advance the renewable energy power sector. These efforts are pivotal to the country's pursuit of a low-carbon development strategy, addressing concerns related to climate change, energy security, and accessible energy resources.

Keywords: Analytical Hierarchy Process, Process, Geographic Information System, Multi-Criteria Decision-Making, Site Suitability, Solar energy system

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INTRODUCTION

A coastal city in southern Mindanao, Mati City, continues to experience modest growth in its population size. Despite the meager 0.94% annual population growth rate of the city compared to other component cities of the region, it still boasts a considerable number of residents, amounting to a population of 147,547, according to the Philippine Statistics Authority (2020). Similar to any developing city, Mati City now faces increasing pressure to meet the energy demands of its residents. Furthermore, due to the rising population size, the need for energy security intensified, a concern that remains unaddressed since the city's energy supplier, Davao Oriental Cooperative (DORECO), is reliant on the reserves of the National Grid Corporation of the Philippines (NGCP), leaving the city prone to power interruptions and outages stemming from the susceptibility of the national grid's energy supply to disasters and the absence of viable alternative energy sources. This issue of energy shortages due to the instability of the national grid is well-documented in news outlets, such as in Legaspi (2023), where it was reported that tropical storm Kabayan caused power interruptions in certain parts of Davao Oriental as it hit one of the transmission lines of NGCP, and also in Fernandez and Manlupig (2015), where a massive power outage was reported affecting most of Mindanao, including Mati city, in which the cause was still under investigation but likely because of the Agus-Pulangi hydroelectric power complex. The consequence of having an unreliable energy supply is not only limited to causing the irate of the residents but also extends to impeding economic activities and development, as supported by Francisco and Abrigo (2023), which underscores that frequent power interruptions pose detrimental effects to local economies across the Philippines. With this in mind, the rising population and energy demands necessitate the city to explore and shift to sustainable and reliable energy solutions.

The Philippines, similar to other countries of the world, heavily depends on fossil fuels to meet its energy needs. Moreover, detrimental effects on both the environment and public health are one of the significant effects that a disproportionate dependency on fossil fuels to meet the daily energy requirements of the population causes (Chanchangi et al., 2023). Furthermore, in the study of Denchak (2018), the process of utilizing fossil fuels such as oil, gas, and coal deposits has a detrimental effect on entire ecological communities, damages the beauty of natural landscapes, and causes serious health issues to the public. In light of the various environmental, health, and economic risks associated with dependence on fossil fuels, the goal of meeting the nation's energy demands through unsustainable means exacerbates the effects of climate change and the country's vulnerability to the volatile market of fossil fuels.

Doljak and Stanojevic (2017) state that solar energy is clean, inexhaustible, and free, potentially supplying the increasing energy demands of both developing and developed nations. Finally, according to the data of Global Solar Atlas, Mati City boasts an average solar irradiation of 5.242 kWh/m^2/day, which is considered suitable for solar energy production based on Munkhbat and Choi (2021). Thus, solar energy has the potential to significantly contribute to tropical regions, such as Mati City, in providing sustainable energy production and energy security.

Unquestionably, the Philippines is experiencing a rapid surge in its population demand for electricity; hence, there is a call to action for the nation to transition to sustainable and environmentally friendly practices, specifically the development of solar power plants. Furthermore, to increase the efficiency and effectiveness of such practice, it is crucial to first locate and determine suitable areas for constructing said power plants. In line with this, determining the suitability of solar energy systems throughout the country is critical. The suitability map depicts the optimum areas for solar energy system development in terms of technical, environmental, and economic criteria. In line with this, the study aims to develop a Solar Energy System Site Suitability Map in Mati City, Davao Oriental, and to introduce the fundamental principles, methodologies, and a few practical applications of Geographic Information System (GIS)-based multi-criteria Decision-Making for addressing intricate decision problems related to land suitability allocation and map production. The Analytical Hierarchy Process (AHP) determines criteria weights for assessing current and prospective sites.

MATERIALS AND METHODS

2.1 Identification of the area

Mati, a coastal city in the Second Congressional District of Davao Oriental Province, is an integral part of Davao Oriental. It serves as a hub for numerous corporate and national headquarters educational institutions, including the Provincial Capitol, and encompasses 26 barangays. The central district of Mati is located on Mindanao Island at approximately 6° 58’ N latitude and 126° 13’ E longitude, with an altitude of roughly 77.8 m above sea level. Spanning an expanse of 588.63 km², this area accounts for 10.36% of the overall land area of Davao Oriental. The city has experienced significant population growth due to its favorable location and opportunities, resulting in a surge of people nationwide. Mati City lies along the Mati River, with elevations ranging from 1.5 m to 18 m. The annual summer temperature typically varies between 25.5 °C and 32 °C, while the average daily temperature ranges from 27 °C to 30 °C. With the increasing population, there is a growing requirement for fundamental infrastructure such as water supply, transportation networks, and electricity. Nonetheless, the swift population expansion has generated an escalated demand for electrical power, and Mati City has traditionally depended exclusively on the national power grid to meet its electricity demands.

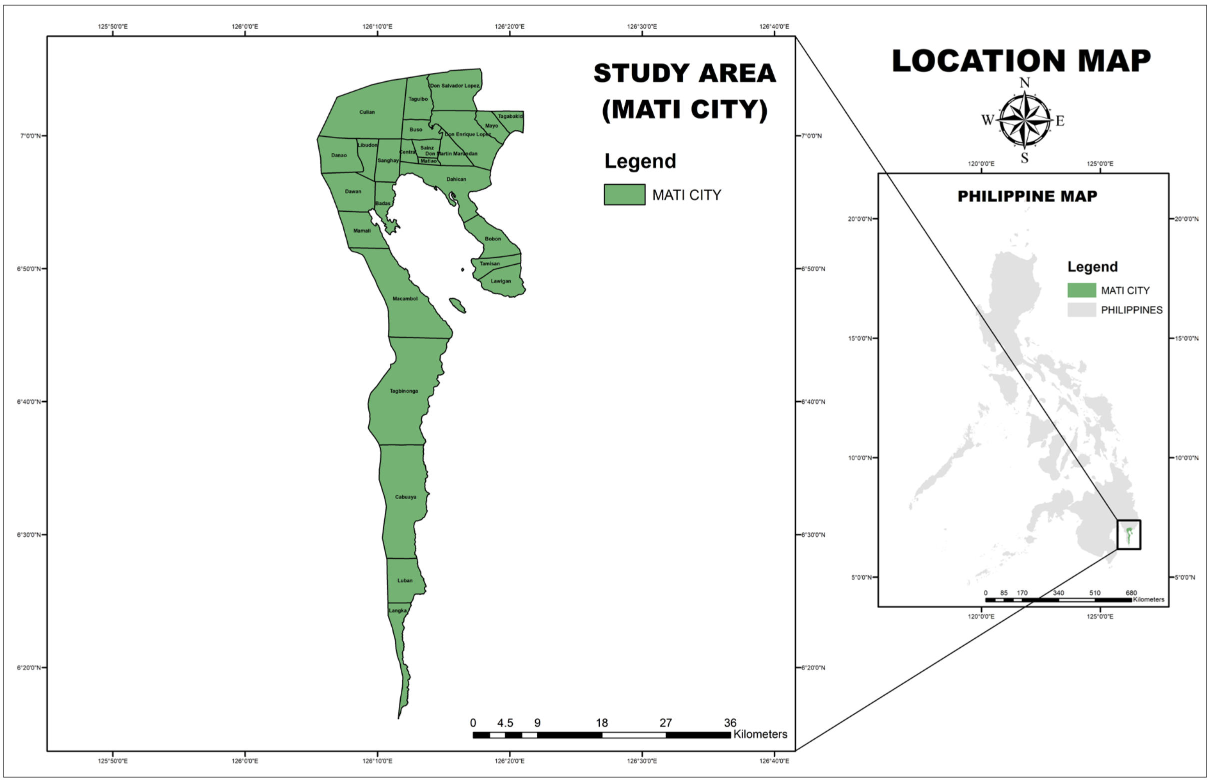

Figure 1. Map of the study area.

2.2 Framework

This study employed a comprehensive strategy to identify appropriate sites for harnessing solar energy in Mati City, utilizing a Geographic Information System (GIS) integrated into a multi-criteria decision-making (MCDM) framework graphically shown in Figure 2. The investigation delved into various factors, including technical considerations like solar irradiance, economic elements such as road distance, slope, elevation, and environmental aspects, including Land Use and Land Cover. These factors collectively influence solar energy extraction in different parts of Mati. The primary objective was to identify areas deemed unsuitable for such purposes. In this context, constraint variables refer to circumstances or regions where the development of PV solar energy is prohibited by domestic protective statutes and conservation regulations, taking into account environmental, ecological, and engineering considerations.

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As PV systems are acknowledged as a sustainable technology capable of reducing local environmental impacts, zones such as those earmarked for environmental protection, ecological conservation, high geotechnical risk, and other areas with restricted development outlined by local laws or regulations have been identified and excluded from the selection process (Suh et al., 2016). Table 1 provides an overview of the criteria, their defined thresholds, and the assigned weights for the weighted overlay. The chosen factor variables should encompass characteristics specific to the location, influencing annual average power production and system costs (Suh et al., 2016). Examples include average solar irradiance potential, environmental conditions and classifications, economic factors, and topography. GIS played a crucial role in generating layers corresponding to the specified criteria, and the application of Weighted Overlay logic facilitated the creation of a map highlighting the unsuitable sections within the city. The process also involved identifying and evaluating criteria influencing solar energy potential, which is integral to the land suitability analysis model. The Analytical Hierarchy Process (AHP) was utilized to assign weights to these evaluation criteria, resulting in the development of layers relevant to these criteria and, ultimately, the formulation of a comprehensive land suitability map for areas conducive to the extraction of solar energy.

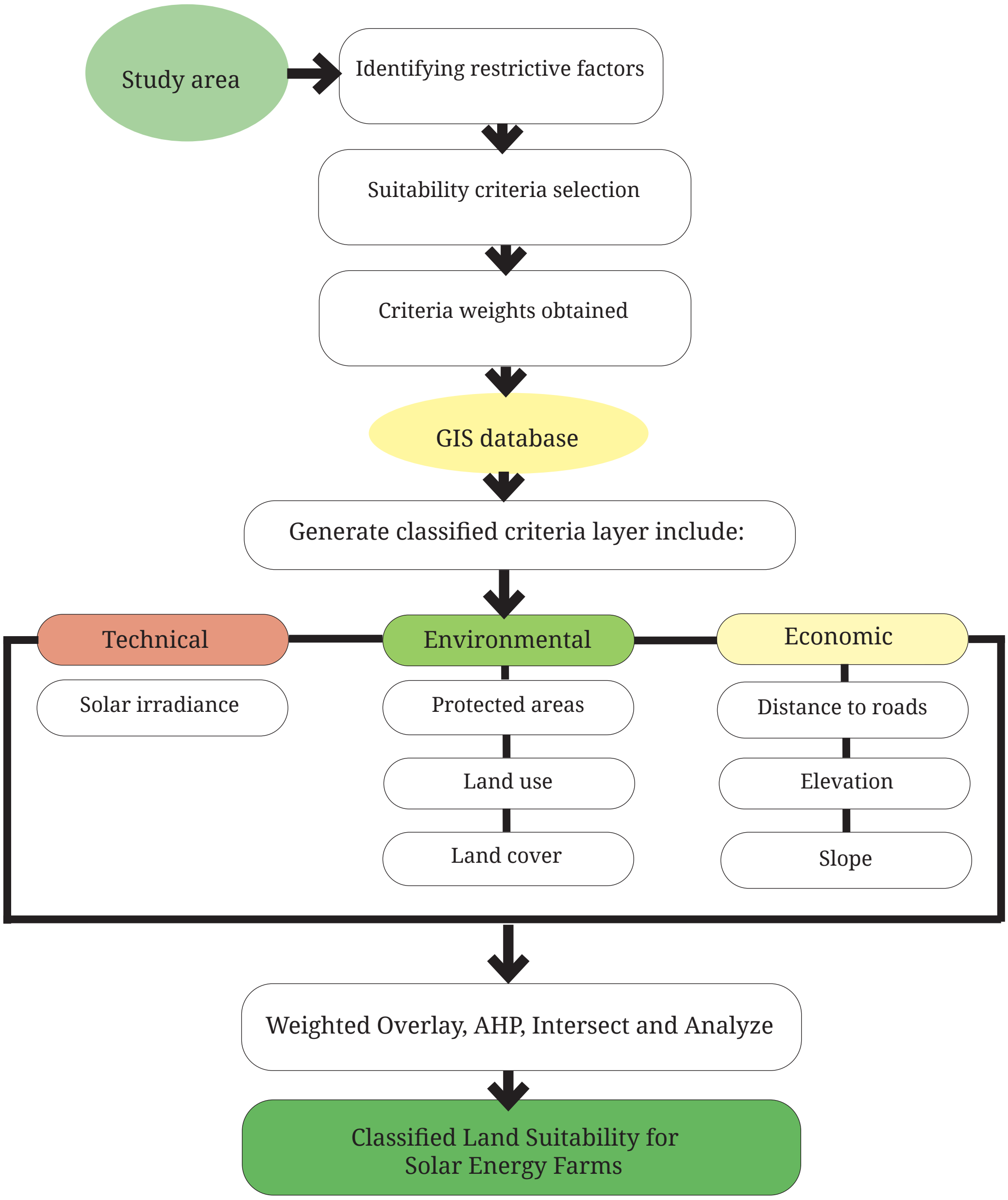

Figure 2. Conceptual framework.

Table 1. Thresholds and calculated weights for defined criteria.

Criteria	Factors	Threshold	Weight
Technical	Solar Irradiance (kWh/m^2/day)	4.31 - 4.62 (Suitable) 4.62 - 4.94 (Unsuitable)	0.76
Environmental	Open/Barren Grassland Brush/Shrubs	Suitable	0.12
	Built-up Inland Water Closed Forest Mangrove Forest Open Forest Fishpond	Restricted	
	Annual Crop	Unsuitable	
Economic	Distance to Roads (km)	< 10 (Suitable)	0.11
		> 10 (Unsuitable)	
	Slope	< 15 (Suitable)	
		> 15 (Unsuitable)	
	Elevation (m)	< 500 (Suitable)	
		> 500 (Unsuitable)	

2.3 Criteria Selection

The criteria for decision-making in this research are sourced from recent literature, the study's objectives, and the availability of remotely sensed geo-referenced data. In this study, technical (solar irradiance), environmental (protected areas, and land use and land cover), and economic (distance to roads, elevation, and slope) factors were taken into account to classify and determine the region's best-suited for solar energy farms in Mati City as shown in Figure 3.

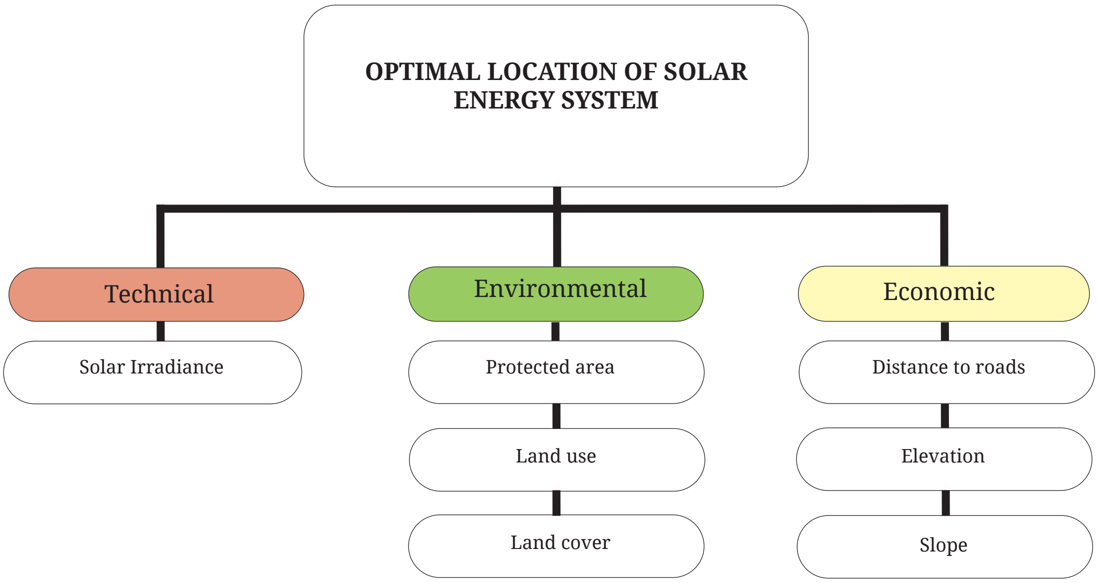

Figure 3. Selection criteria used in solar energy site suitability assessment in Mati City.

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2.4 Technical Criterion

2.4.1 Solar Irradiance

According to Halder et al. (2022), solar radiation is an essential factor and the factor that had the most significant influence on the choice of where to locate the solar power plant. The study area's temperature varies in response to solar radiation, and solar power plants are best suited to regions with high solar radiation (Halder et al., 2022). As a rule of thumb, an area that receives high levels of solar radiation will generate a lot of electricity. According to the study by Islam et al. (2014), the open-circuit voltage and short-circuit current positively correlate with increased solar radiation, hence increasing the maximum power point of solar energy systems. Furthermore, the researchers have used the values in the study of Munkhbat and Choi (2021) to determine the suitability of different locations for developing solar energy systems. In this study, similar to Munkhbat and Choi (2021), the researchers also took the Solar Irradiance data from the Global Solar Atlas website (Figure 4a).

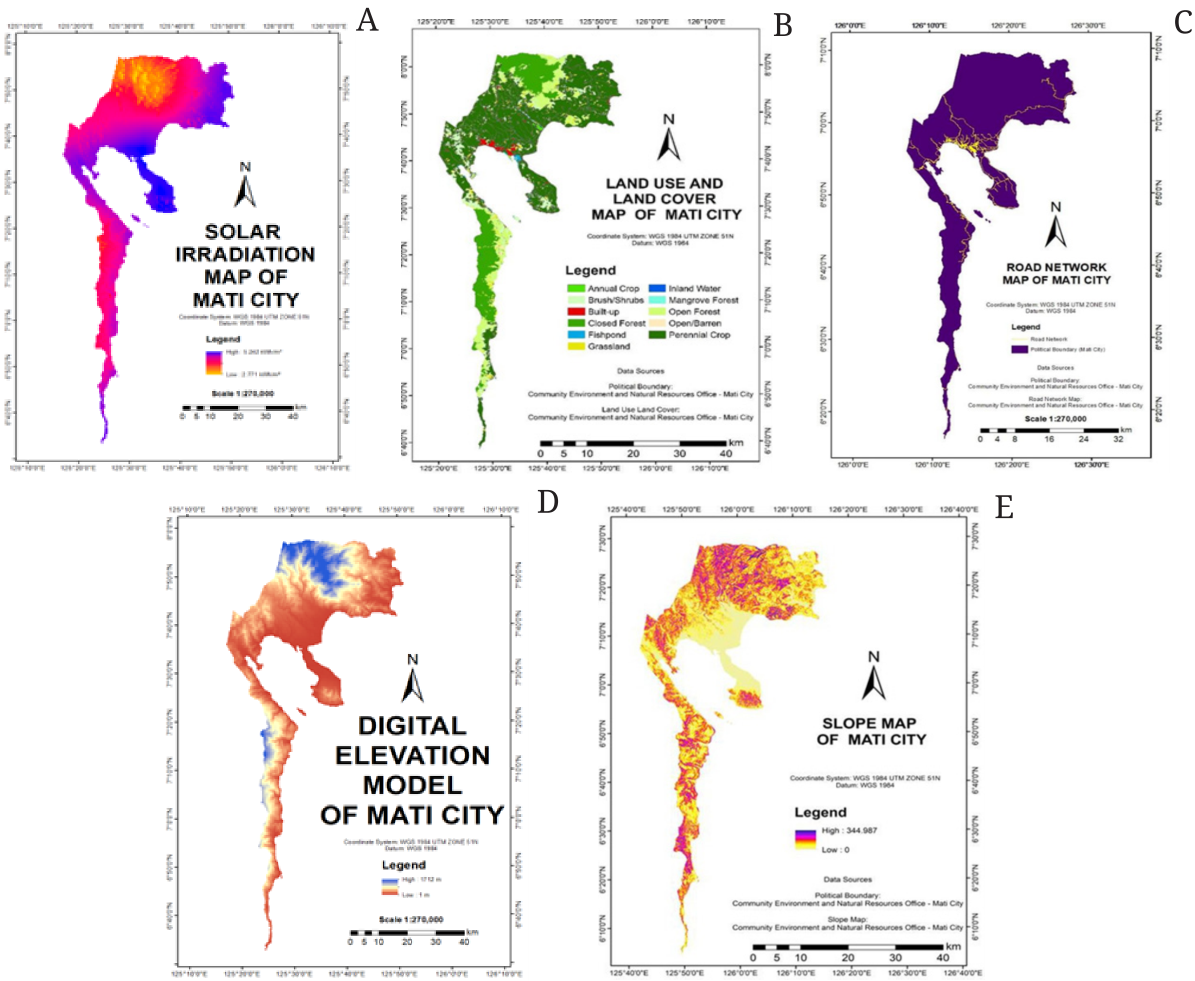

Figure 4. Multiple criteria selection maps of Mati City: Solar irradiation (A), Land use and cover (B), road network (C), digital elevation model (D), and slope map (E).

2.5 Environmental Criterion

2.5.1 Protected Areas

The feasibility of constructing infrastructure on a particular piece of land is closely connected to how the land is presently utilized. In this context, decision-making considers the current use and cover of the land, resulting in the exclusion of areas specifically set aside for natural habitats or designated for commercial or agricultural activities. The utilization of Restriction Parameters aims to eliminate areas with more critical functions, those safeguarded by specific laws, or those structurally unsuitable for establishing a solar power plant. Halder et al. (2022) note that particular locations, such as airports, administrative zones, playgrounds, parks, and gardens, are deemed unsuitable for a solar power plant, from the study of Galvan (2021) that introduces additional exclusions, wildlife-designated zones, marine, and natural reserves, reserved areas for perennial crops, and protected areas, serving diverse purposes from human settlement and food production to raw material extraction and outdoor activities. As underscored by the study conducted by Doljak and Stanojević (2017), such considerations are critical where specific locations present challenges to sunlight penetration and PV system construction. Due to heightened risks associated with biodiversity loss, habitat fragmentation, and visual disturbances affecting human memory, it is advisable toposition solar farms outside protected natural areas. As a result, the assessment procedurerequires excluding protected regions, guided by two pivotal legislations of the Philippines, namely, the R.A No 7586, known as the National Integrated Protected Areas System Act of 1992, and R.A No 11038, recognized as the Expanded National Integrated Protected Areas System Act of 2018.

2.5.2 Land Use and Land Cover

Identifying land areas devoid of alternative productive land uses is imperative. In the study by Noorollahi et al. (2016), land use was assessed across five categories— barren, rangeland, shrub, rainfed, and irrigated areas. The study determined that barren areas were deemed the most suitable, whereas irrigated areas were assigned the lowest priority for establishing solar farms. Evidently, in the survey by Galvan (2021), limitations associated with agricultural and forested regions comprised the most significant factor leading to the decrease in suitable locations. This constraint ensures that the identified suitable areas meet immediate development requirements and align with a dedication to preserving environmental health and biodiversity. Figure 4.b shows the land use and land cover map of Mati City.

2.6 Economic Criterion

2.6.1 Distance to Roads

Considering the distance of a solar energy power plant from an existing road is regarded as an economic factor, as it reduces the need for additional road construction costs and related environmental effects. Ensuring vehicular access to the solar facility site is crucial for construction and maintenance, as emphasized by Munkhbat and Choi (2021). As studied by Opeyemi et al. (2022), distances ranging from 0 km to 10 km are suitable. In contrast, Asakereh et al. (2017) employed a 500 m buffer zone, and for safety considerations, a distance of 150m was utilized, as seen in the study by Al-Yahyai et al. (2012). The study establishes a threshold for site suitability at a distance of 10 km from major roads, deeming locations beyond this distance unsuitable. Figure 4.c shows the road network map of Mati City.

2.6.2 Elevation

Elevation, in the context of this study, is the height of an object above sea level. Galvan (2021) emphasizes that choosing a location with low elevation helps decrease the construction cost for solar projects. Several studies have different threshold values for elevation, as seen in Munkhbat and Choi (2021), where elevations of 2,023 m and higher are preferable. In contrast, Elboshy et al. (2022) have used a value of 450 m and higher as suitable. In the end, the researchers have employed the threshold value of 500 m and greater as unsuitable, similar to the study of Galvan (2021). Figure 4.d shows the Digital Elevation Model of Mati City.

2.6.3 Slope

The optimal management of slopes is a critical factor in site selection. Slope denotes the land surface's degree of incline or flatness (Opeyemi et al., 2022). An increase in slope percentage heightens the risk of shading in solar energy system arrays, where direct sunlight is obstructed, resulting in decreased power output from the solar energy system array (Clifton and Boruff, 2010). Another study by Munkhbat and Choi (2021) has considered slopes greater than 3% suitable, while those less than 3% are treated as unsuitable. On the other hand, Elboshy et al. (2022), along with various other studies, have identified locations with a slope value of 1% as preferable choices. The researchers have decided to use the threshold values found in the study of Galvan (2021) and defined that anything above the slope of 15% is considered unsuitable, while areas with fewer slopes will be deemed suitable. Figure 4.e shows the slope map of Mati City.

2.7 Excluding Unsuitable Areas

The first step of the GIS analysis is to eliminate any areas restricted from developing large-scale solar-generating installations. The accessibility of spatial data and the study's geographic scope (district, nation, region, or continent) are essential considerations when selecting an exclusion criterion. The following exclusion criteria are employed: Built-up Areas, Inland Water, Closed Forest, Mangrove Forest, Open Forest, and lastly, Fishpond.

2.8 Fuzzy Overlay

The fuzzy overlay analysis tool is one of the most commonly used tools in multi-criteria suitability analysis. Unlike traditional or alternative overlay analysis methods, the fuzzy overlay is used for cases with a lack of predetermined or known values for the thresholds or limits. As such, utilizing the fuzzy overlay tool is preferred because relying solely on the researchers to decide the threshold values is complex and challenging. In addition, the approach of Fuzzy overlay is much more flexible in the multi-criteria analysis as it does not only classify factors into binary states, e.g., 1 or 0, but it also considers the possibility that a factor may have a potential relationship among several factors that belong to a different category. Therefore, using the fuzzy overlay tool creates a comprehensive suitability map in cases where clear guidelines are not given.

2.9 Weighted Overlay Analysis

The Weighted Overlay Tool is an analytical tool used in Geographic Information Systems (GIS) that is utilized mainly on suitability mapmaking. The weighted overlay tool is used for overlay analysis to understand problems belonging to multiple criteria, such as suitability and site selection models. Several raster layers of varying weights according to their importance are overlaid to generate a map (Basharat et al., 2016). Furthermore, the tool works by overlaying several raster models, e.g., Land Cover and Land Use, Slope, Elevation, Distance to road networks, and Protected Areas, assigns different weights to each raster according to their importance or influence, and combining them into a single comprehensive map which gives an overall view of the suitability for various locations of the study area with the varying factors taken into account. Employing the Weighted overlay tool allows the researchers to create maps that offer an overall visual representation of the suitability while considering numerous factors indicated in the study.

2.10 Ranking Criteria Based on Related Studies

The ranking criteria and their tier scores were thoroughly defined based on insights from relevant research. Each tier received a numerical score indicating how favorable it is to have a large-scale solar power installation—the least suitable tier will receive a score of 0. In contrast, the highly suitable tier will receive a score of 1. The scale was subjected to the application of the MCDM approach; the scale of 0 to 1 is merely a representative relative scale (i.e., it might be substituted with a scale of 0 to 10).

2.11 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP), formulated by Saaty in the 1970s (Saaty, 2006), is a prominently utilized approach within the realm of Multi-Criteria Decision Making (MCDM) for resolving unstructured problems. Its proficiency lies in managing decision-making situations requiring considerable flexibility, reliability, and acceptance (Asakereh et al., 2017). Utilizing the AHP spatial analyst tool, a pairwise comparison was facilitated, adhering to Saaty's guideline (2006) that the consistency ratio (CR) should ideally be below 0.10. Implemented within the framework of a Geographic Information System (GIS), the AHP produces a suitability map that depicts the distribution of both viable and nonviable locations, each associated with their respective value scores throughout the study area. A location is classified as unsuitable if its value score is 0, while it is regarded as suitable if its value score falls within the range of 1 to 9.

Table 2. Suitability Index.

Suitability	Value Score
Highly Suitable (HS)	6-9
Moderately Suitable (MS)	1-5
Not Suitable (NS)	0

RESULTS

This study illustrates how the integration of Geographic Information System tools with the Multi-Criteria Decision Making (MCDM) approach aids decision-makers in assessing and executing spatial decision-making processes. Taking into account factors and the designated thresholds for technical aspects (solar irradiance), environmental considerations (protected areas, land use, and land cover), and economic factors (distance to roads, elevation, and slope), maps were generated for each specific factor to visualize the impact of the constraints imposed by these factors.

3.1 Technical criterion

3.1.1 Solar irradiance

The determination of suitable areas based on solar irradiance is shown in Figure 9. According to the Global Solar Atlas, the city of Mati has an average of 5.105 kWh/m^2 per day. As stated in Munkhbat and Choi (2021), an average daily solar irradiance between 4.31 kWh/m^2 to 4.62 kWh/m^2 and 4.62 kWh/m^2 to 4.94 kWh/m^2 falls in the Fair and Good suitability class, respectively, for the development of solar power systems. The results of this study indicated that around

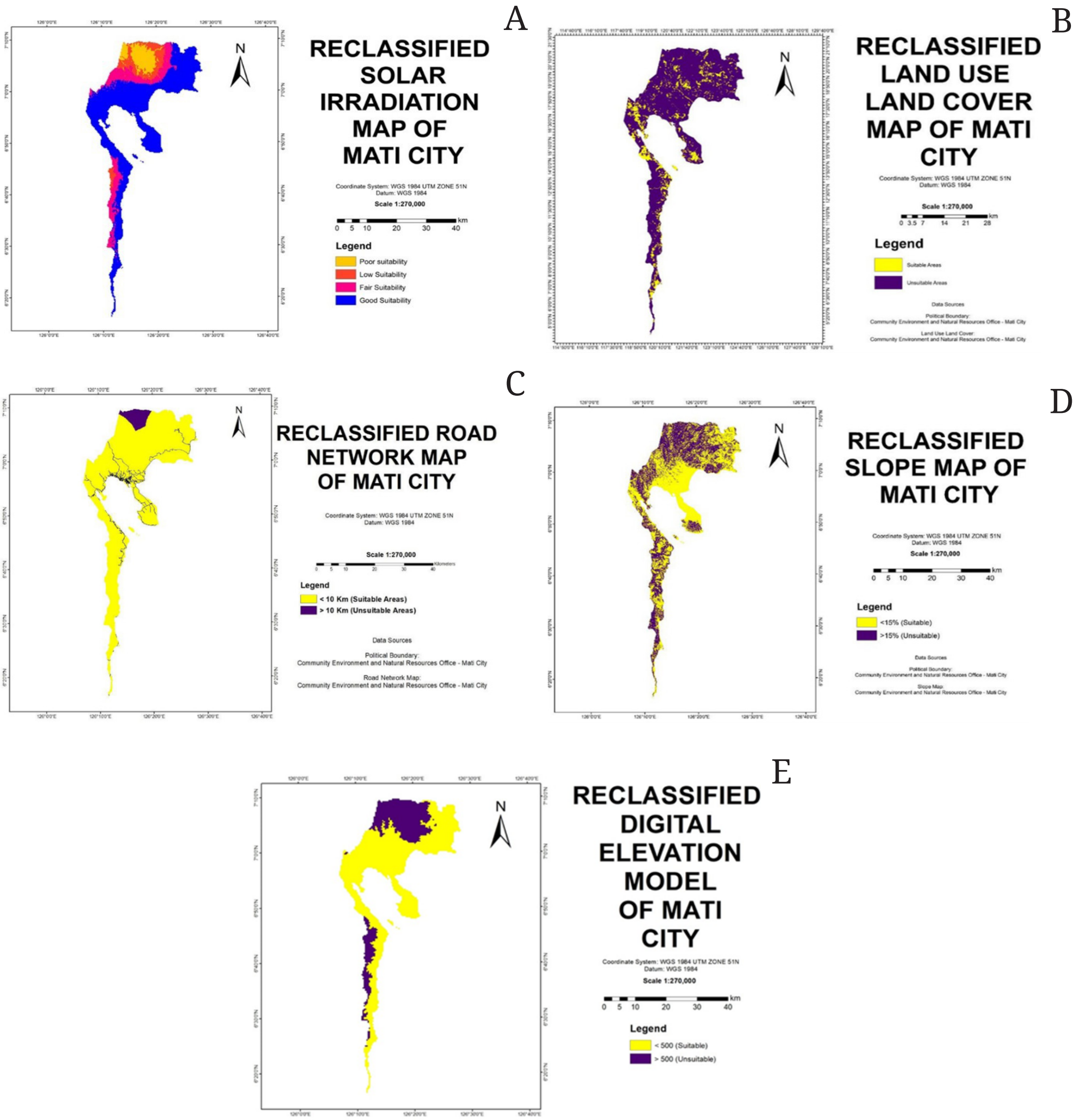

Figure 5. Multiple criteria selection maps of Mati City: Reclassified solar irradiation (A), reclassified land use and cover (B), reclassified road network (C), reclassified slope map (D), and reclassified digital elevation model (E),

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8.89% (8,303.48 ha) of land in Mati City has poor suitability, 9.81% (9,163.88 ha) has low suitability, 16.75% (15,648.33 ha) has fair suitability, and lastly, 64.55% (60,302.04 ha) have good suitability. Based on the results, it can be suggested that most of the areas in the city of Mati are fairly suitable for the development of solar energy systems. Although solar irradiance has a huge influence on the determination of site suitability, the overall potential suitability of the city is considered by numerous factors, such as environmental and economic factors. Figure 5.a shows the reclassified solar irradiation map of Mati City.

3.2 Environmental criterion

3.2.1 Land use and land cover

The imposed restrictions noticeably diminished the potential area for the development of solar energy systems development, as observed in Figure 10. These restrictions encompassed various categories, such as Built-up Areas, Inland Waters, Closed Forests, Mangrove Forests, Open Forests, and Fishponds. Following the guidelines presented by Galvan et al. (2021), areas preserved as natural habitats or designated for industrial, commercial, or agricultural purposes were deemed restricted. Given that Mati primarily functions as an agricultural and forested city, environmental constraints played a substantial role in reducing suitable areas. These restricted zones accounted for 33.5% of the total land area, equivalent to 31,224.7 ha. Among the unsuitable areas, 52%, equivalent to (48,639.6 ha), consisted of Annual Crops. Consequently, a total of 14.3% (13,378.5 ha) of the province's land area remains exploitable for the development of solar energy systems, considering the categories of Barren Land, Grassland, and Shrubs. Considering both areas deemed unsuitable and other limiting factors, only limited portions of Mati are deemed suitable for solar energy development. Figure 5.b shows the reclassified land use and land cover map of Mati City.

3.3 Economic criterion

3.3.1 Distance to road

In this research, a 10 km distance criterion was applied, designating areas situated beyond 10 km from the road as unsuitable, as outlined in Galvan's study (2021). The purpose of this broad range is intended to minimize the risk of neglecting potentially suitable areas in the course of the investigation.

As depicted in Figure 5C, most of the areas in the province are suitable considering the threshold to distance of roads. The areas deemed unsuitable constituted 5%, amounting to 4,598.1 ha. Considering the distance to road constraints, the overall areas identified as economically viable for solar energy system development in the city of Mati accounted for 95%, encompassing approximately 89,045.6 ha. This could indicate that the vast expanse of the city is suitable when taking into account the specified threshold for road distance in the establishment of solar energy systems.

3.3.2 Slope

In this study, the researchers' assessment of the city of Mati's slope utilizes the threshold value of 15% grade slope, which is adopted from Galvan (2021), to determine the suitability of the area for solar energy system development. Furthermore, Figure 5D reveals that a considerable portion of Mati City's expansive land is characterized by slopes of less than 15%, which represents suitable areas.

The findings of the study reveal that the suitable areas having a slope of less than cover about 57.11% (53,448.52 ha) of the city's total area, while the remaining 42.89% (40,139.14 ha) are deemed to be unsuitable. Although the difference is not that significant, it can be implied that Mati City's landscape has more than enough areas for the development of solar energy plants.

3.3.3 Elevation

The study of Galvan (2021) has established that areas with elevations with values of less than 500 m are suitable, while those with values greater than 500 m are deemed unsuitable for the development of solar energy plants. The resulting elevation map, as seen in Figure 5E, reveals that the landscape of the city of Mati, for the most part, is composed of tracts of land with elevations below the 500 m threshold value. This accounts for about 71.96% (67,363.39 ha) of Mati City's area, while the remaining 28.04% (26,245.28 ha) accounts for unsuitable areas that are characterized by having elevations higher than 500 m. This could imply that the extensive land of the city falls within the preferable elevation for the development of solar energy systems, with areas with massive potential for solar energy production. Even with the abundance of suitable areas, it is also important to note that although elevation is a critical factor in the site suitability assessment, the size of the suitable areas can still be reduced if other factors are also taken into consideration.

Table 3. Weights of each criterion.

Objective	Weight
Technical aspect	0.76
Environmental aspect	0.12
Economic aspect	0.11

3.4 Suitability map for solar energy

System development

The evaluation of solar energy system site suitability involved the consolidation, integration, and comparison of three essential criteria: technical (solar irradiation), economic (slope, elevation, and road distance), and environmental (land use-land cover). The weights utilized in Galvan's (2021) study were applied by the researchers, and Table 3 illustrates these weights. Each sub-criterion under the three categories was first standardized and classified into suitability classes based on parameters and threshold values found in Table 1. The resulting raster layer of technical, economic, and environmental aspects was then integrated using the weighted overlay tool, assigning weights outlined in Table 3.

The technical aspect (solar irradiation) was assigned the highest weight, followed by the environmental aspect (12.10%, land use-land cover) and the economic aspect (11.49%, slope, elevation, and road distance). For the economic aspect, the three sub-criteria under it were merged using the fuzzy overlay tool to produce a single economic aspect layer. The solar energy development suitability map (Figure 6) indicates that a substantial portion of the city's overall land area holds significant potential for solar energy system development. Approximately 66.64% (60,859.76 ha) of the land was deemed suitable, while 33.36% (30,459.81 ha) was not. Within the suitable regions, further subdivisions were made, classifying 7.59% (4,619.49 ha) as moderately suitable and 92.41% (56,240.27 ha) as highly suitable. With all things considered, although solar irradiance bears the most significant impact on the final suitability map, covering roughly 70% of the city's landscape, exclusions from the land cover and land use and different terrain constraints limited the final extent of suitable areas.

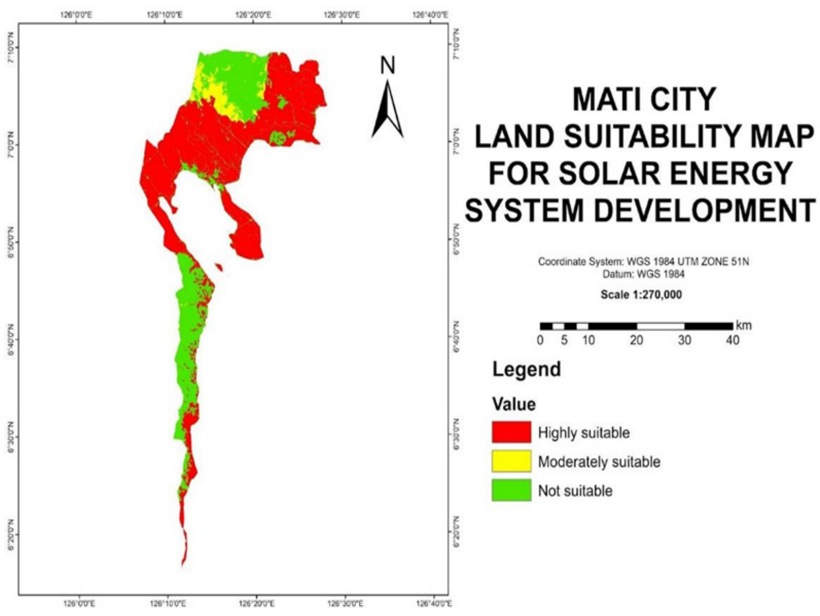

Figure 6. Solar energy development suitability map of Mati City.

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DISCUSSION

4.1 GIS in solar energy optimization

GIS is a tool used by researchers across various disciplines. Masancay et al. (2024c) utilize GIS in mapping urban search and rescue along barangay Poblacion, Davao City. GIS is also used in predicting shoreline shift analysis and prediction along Mayo Bay, Davao Oriental (Masancay et al., 2024a), rainwater harvesting systems in Davao City (Masancay et al., 2024b), and urban sprawl mapping of Land Use and Land Cover in district II of Davao City (Masancay et al., 2025). GIS plays a big role in optimizing solar energy. Massimo et al. (2014) use GIS to estimate energy balance by evaluating the potential for the integration of new solar energy production plants along extra-urban and overly populated areas of Central Italy. GIS is integrated into a multi-criteria decision-making method to determine the suitable location for the exploitation and construction of renewable energy sources and is used in analyzing the optimal solar power plant locations along a 56,594 km^2 land boundary in the Republic of Croatia by Gašparović, I. and Gašparović, M. (2019). A study by Colak et al. (2020) highlights GIS as a method of identifying solar photovoltaic power plant establishment in the Malatya Province of Turkey.

4.2 Significance of solar irradiance in site suitability assessment for solar energy

The findings of the study revealed that the majority of Mati City's landscape, roughly 66.64%, is suitable for the development of solar energy plants. This is likely due to the favorable levels of solar irradiance in Mati City, particularly for the reason that the country is geographically located near the equator and has higher and longer concentrations of sunlight. In addition, solar irradiance, under the technical criterion, was established to have the highest bearing of weight (0.76) in the weighted overlay analysis, resulting in having the most significant influence on the final site suitability map. Moreover, this conclusion is consistent with multiple studies, such as the studies of Munkhbat and Choi (2021) and Halder et al. (2022), wherein both have regarded solar irradiance to have the most significant influence in assessing site suitability for solar energy plants.

With an average solar irradiance of 5.105 kWh/m^2 per day, Mati City falls into the excellent class under the classification provided by the National Renewable Energy Laboratory (NREL) per Asakereh et al. (2017). This is further supported by the study of Nebey et al. (2020), establishing a value of 5 kWh/m^2 per day and above as a suitable area, while anything lower than this value is an unsuitable location for solar power plants.

4.3 Implications for solar energy development in the Philippines

The energy sector of the Philippines has a long history of being completely dominated by fossil fuels, accounting for approximately 75% of the country's total energy mix (Villanueva, 2021). Considering this, Mati City has the potential to contribute significantly to the nation's objective of decreasing its reliance on fossil fuels. Furthermore, the current energy crisis due to the declining reserves of the Malampaya natural gas fields, as highlighted by the International Trade Administration (2022), emphasizes the urgency for the transition to sustainable energy practices, such as the development of solar energy plants, as a viable substitute to curb the ever-increasing energy demand.

CONCLUSION

With the Philippines' growing population and rising energy demands, it is crucial that the country use solar energy system farm installations as a sustainable and ecologically acceptable alternative to meet its electricity needs. To maximize power output while reducing potential damage, suitable places must be prioritized and chosen to optimize the efficiency of installing solar plants. The study revealed that Mati City exhibits overall favorable conditions for solar energy system development, boasting a maximum annual solar irradiation of 5.242 $kWh/m^2/day$. Considering the three criteria, 66.64% (60,859.76 ha) of the land surface area proved suitable for solar energy system development in the city, while 33.36% (30,459.81 ha) was deemed unsuitable. Within the suitable regions, there was further classification into moderately suitable (7.59% or 4,619.49 ha) and highly suitable (92.41% or 56,240.27 ha). The outcomes of this study offer a foundational platform for future research in these domains, aiming to advance the renewable energy sector. The significance of this study lies in its demonstration to investors of the financial and economic viability of establishing a solar energy system in Mati City. These endeavors are crucial in aligning with the country's pursuit of a low-carbon development strategy, addressing concerns related to climate change, energy security, and the availability of energy resources.

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