Geographic Information System (GIS) Based Feasibility Study for Wind and Solar Farms – A Case Study of Songkhla Province, Thailand

Shahid Ali

A Thesis Submitted in Fulfillment of the Requirements for the Degree of Master of Science in Sustainable Energy Management
Prince of Songkla University
2018

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ABSTRACT

The study reported in this study focuses on finding suitable sites for wind and solar farms in Songkhla Province, Thailand. Geographic Information System (GIS) and analytical hierarchy process (AHP) were used combinedly to examine three main siting criteria, i.e. physiographic, environmental and economic criteria. The secondary data were obtained from online portals and government organizations. In addition, the Global Horizontal Irradiance (GHI) solar map for Songkhla province was obtained from Solargis map for Thailand at a resolution of 1km/pixel. Wind resource map for Songkhla province on 100 m above ground level having a resolution of 200 m was previously available in the study area. AHP based weights for this study identifies that climate is the most dominant criterion for wind and solar energy applications. The results of the study indicate that Songkhla has a potential land area of up to 66.11 km^2 and 844.93 km^2 for wind and solar farms respectively, however, only areas of 38.74 km^2 and 69.50 km^2 were judged as being "highly suitable" for wind and solar farms respectively. Ranot district hosts most of those highly suitable areas. The results of this study provide a significant starting point for stakeholders who are interested in investing in renewable energy in Southern Thailand.

Keywords: Geographic Information System (GIS), Multi-criteria Decision Making (MCDM), Analytic Hierarchy Process (AHP), Wind Farms, Solar Farms, Renewable Energy, Thailand.

DEDICATION

This thesis is dedicated to my beloved parents and my sisters.

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Shahid Ali

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LIST OF ABBREVIATIONS

AEDP	Alternative Energy Development Plan
AHP	Analytical Hierarchy Process
CI	Consistency Index
CR	Consistency Ratio
DEDE	Department of Alternative Energy and Development Efficiency
EGAT	Electricity Generating Authority Thailand
EPPO	Energy Policy and Planning Office
GHI	Global Horizontal Irradiance
GIS	Geographic Information System
IEA	International Energy Agency
MADM	Multi-Attribute Decision Making
MCDM	Multi-Criteria Decision Making
MODM	Multi-Objective Decision Making
NCGIA	National Center for Geographic Information and Analysis
PDP	Power Development Plan
RER	Renewable Energy Resources
SWT	Siemens Wind Turbine
TIEB	Thailand Integrated Energy Blueprint
WB	World Bank

LIST OF PUBLICATIONS

1. Shahid Ali, Juntakan Taweekun*, Kuaanan Techato, Jompob Waewsak, and Saroj Gyawali (2019). GIS based site suitability assessment for wind and solar farms in Songkhla, Thailand. Renewable Energy, 132, 1360-1372. https://doi.org/10.1016/j.renene.2018.09.035 (ISI Web of Science; IF 4.98)

2. Shahid Ali, Kuaanan Techato*, Juntakan Taweekun and Saroj Gyawali (2018). Assessment of land use suitability for natural rubber using GIS in the U-tapao River basin, Thailand. Kasetsart Journal of Social Sciences, 1–8. https://doi.org/10.1016/j.kjss.2018.07.002 (SCOPUS)

CHAPTER 1

INTRODUCTION

1.1 Background

In a current global scenario energy is the main drive behind economic and industrial growth (Jangid et al., 2016; Noorollahi, Yousefi, and Mohammadi, 2016). Since there are two broad categories of energy resources, one is conventional resources that comprise of resources that have formed over millions of years of geological processes such as coal, petroleum, and natural gas and the other is non-conventional resources which generate as a result of natural processes that are continuously replenished such as wind, solar, geothermal, hydropower, tidal, and biomass energy (Nayyar, Zaigham, and Qadeer, 2014).

Nevertheless, fossil fuels are the main source of energy worldwide and the International Energy Agency reported in 2010 (IEA, 2010), that 90% emission such as CO2 is due to the usage of fossil fuels that fulfils 82% of the energy needs across the world (Fig. 1.1).

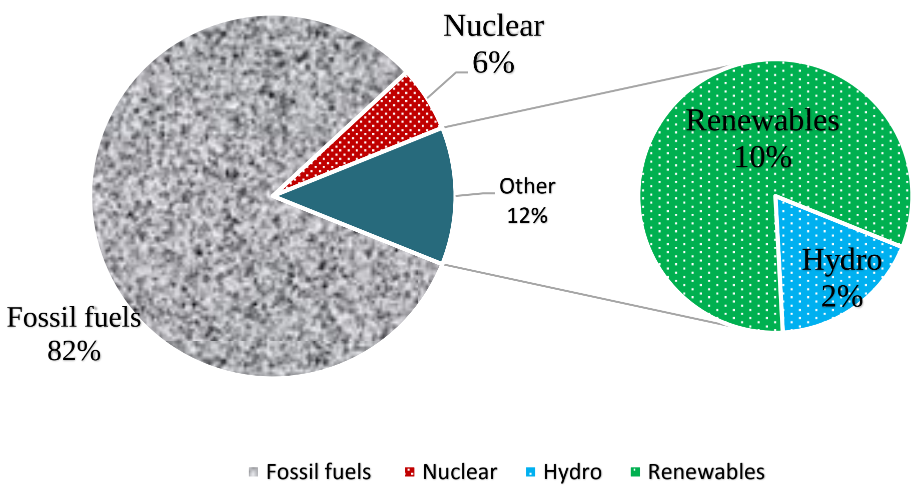

Fig. 1.1 Total world energy consumption, as of 2008 (IEA, 2010)**.**

Where, the consumption of fossil fuels had increased 51% between 1995-2015, and it is anticipated that the consumptions will further expand 18% between 2015–35. In 1995, the entire primary energy consumptions by the mean of oil, natural gas, and coal were 38%, 22%, and 26% (87% in total), respectively; that, in 2015, the total primary energy consumption were 32%, 24%, and 29% (85% in total) for oil, natural gas and coal; and it is anticipated that, by 2035, the shares will be further decreased to 29%, 25%, and 24% (78% in total). Although it's believed that the share of fossil fuels will be decreasing yet, they will continue to be a key player in the primary energy mix in the future as more unconventional sources are explored (Yıldız, 2018).

Climate change, in other words, a global warming which is an average increase in the temperature of the atmosphere near the Earth's surface is one of the causes of the overexploitation of fossil fuels during recent decades and as a result, the carbonic gas release in the atmosphere has massively escalated. This has made the environment more vulnerable to the human than ever before. The consequences may be seen everywhere, in forms of heats waves, quickly melting glaciers, rising sea levels, floods, severe droughts in some parts and strong hurricanes etc. (Change, 2010). According to the World Bank (WB) report, the world is likely to get warmer by 4 degrees Celsius or 7.2 degrees Fahrenheit by 2100. The poor or the developing countries are more likely to be exposed to the global warming menace (The World Bank, 2012). The German watch Climate Risk Index, which grades the countries as per the extreme weather risks, says that all countries in the top ten of these indexes are developing countries, led by Bangladesh, Myanmar and Honduras. Where, Thailand has particularly been vulnerable to droughts and floods in the recent past. As in 2015-16 Thailand has experienced one of the worst droughts in decades, leading to critically low levels of water reservoirs countrywide. Since climate change knows no boundaries and it is likely that Thailand will be disproportionately affected by climate change consequences (Naruchaikusol, 2016). Thus, the exploitation of alternative sources has become indispensable for the long-term survival of human anywhere or everywhere on this planet.

The electricity generation of Thailand, is used to be 32,600 MW in the year 2012 (EGAT, 2018; Janjai et al., 2014) and in 2017 it had increased to 42,163 MW (EPPO, 2017), where the natural gas accounts for the 67% of the total generation (EPPO, 2018). Thailand's Ministry of Energy power development plan 2010 (PDP 2010) has estimated that the generation capacity will reach to 70,868 MW by 2030 (Aroonrat and Wongwises, 2015; Ministry of Energy, 2015). But the Natural Gas resources are said to be run out by 2021, which is alarming, therefore Thailand struggles for alternative sources. In the scenario, Alternative Energy Development Plan (AEDP) for Thailand, looks committed to replacing fossil fuels up to 30% by 2036 under the recently proposed power development plan (PDP) 2015-2036 (DEDE, 2012; Ministry of Energy, 2015) (see Fig. 1.2).

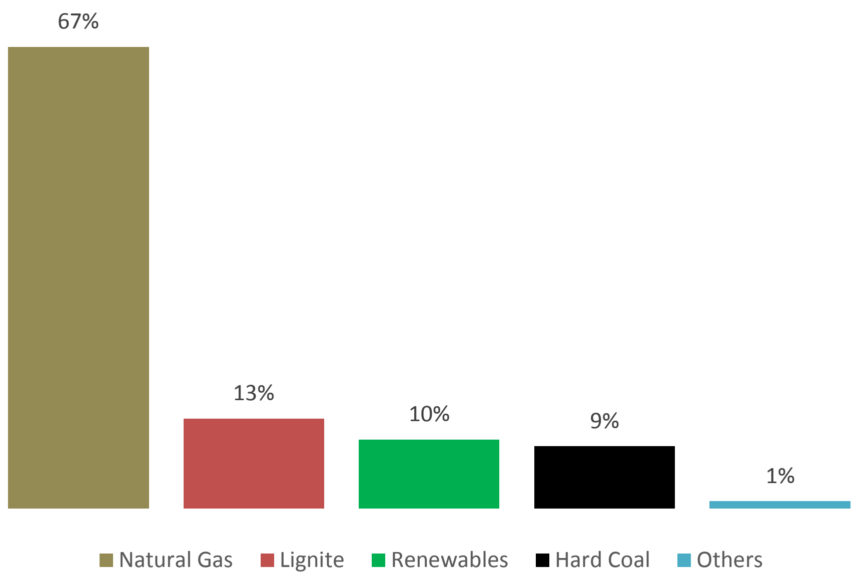

Fig. 1.2 Thailand's electricity generation by fuel, 2016 (EGAT, 2018)

Ministry of Energy had prepared the Thailand Integrated Energy Blueprint (TIEB) in 2015 by considering both consumption and resources management (Ali, Taweekun, Techato, Waewsak, and Gyawali, 2019). Where, the Ministry of Energy has also revised Energy Efficiency Development Plan (EEDP), Alternative Energy Development Plan (AEDP), and Power Development Plan (PDP) (DEDE, 2012; EGCO, 2018; Ministry of Energy, 2015). And the TIEB (Traivivatana, Wangjiraniran, Junlakarn, and Wansophark, 2017) has come up with the following three objectives;

i. Energy Security - Energy supply and allocation incorporate with the economic and population statistics.

ii. Economy Energy – the pricing should be such as that it balances the cost and benefit and wouldn't obstruct the business arenas as well as prevent the ill use of reserves.

iii. Ecology – exploitation of renewable resources for environment-friendly sustainable development and to mitigate future energy challenges.

These objectives define the renewable energy roadmap in Thailand (DEDE, 2018; EPPO, 2018; Ministry of Energy, 2015). Our study aims to contribute to the above commitments.

1.2 Statement of problem

The conventional way of generating electricity has adverse effects on the ecosystems also the resources deplete with time. Thailand hugely relies on Natural Gas for energy needs but a recent report by Department of Alternative Energy Development and Efficiency (DEDE) is alarming which specifies that Thailand will be running out of Natural Gas resources by 2021. This is not easy to digest for developing countries such as Thailand, which is in its initial stage of development and industries are just growing, all these are directly linked to the secure and reliable sources of energy.

Coming to the south, Songkhla province, has recently shown a rising trend to the overall electricity demand of the province. The Songkhla province is the bordering province to Malaysia, therefore host numbers of tourist throughout, which is one of the reasons behind this rising electricity demand. Thai electricity departments look quite concerned about these issues and therefore continuously looking to explore alternative energy options.

Previously some researchers have conducted study on wind energy for some of the provinces of Southern Thailand but they are somewhat out of date because changing demographics and growing industrialization have by now changed the land availability (Bennui, Rattanamanee, Puetpaiboon, Phukpattaranont, and Chetpattananondh, 2007; Meyfroidt, Lambin, Erb, and Hertel, 2013).

1.3 Research objectives

The aim of this study was to explore suitable areas for siting wind and solar farms, using multi-criteria GIS modelling techniques in Songkhla Province, Thailand. They can be further specified as;

1) To find the ideal sites for wind and solar farms in Songkhla Province, Thailand.

2) To evaluate the social acceptance of wind farms and incorporating public opinions in achieving objective 1.

3) To provide guidelines for both autonomous and composite forms of wind and solar energy applications.

1.4 Research questions

This study seeks an answer to the following questions.

1) Which are the most ideal locations in Songkhla Province for wind and solar farms? Is the location physically able to accommodate a utility-scale facility?

2) Are the ideal locations for wind and solar farms close enough, so they could be combined to act as a single entity in order to provide a reliable source of electricity for Songkhla Province in future?

1.5 Research significance

This study aims to find the ideal siting locations for wind and solar farms in Songkhla Province, using GIS and MCDM. To date, this is the first detailed study for the case of Songkhla, that uses GIS and MCDM to simultaneously discover wind and solar farms.

The only previous by Adul Bennui (Bennui et al., 2007) for large wind turbine siting in Songkhla province, fails to provide some sophisticated basis for MCDM applications in GIS environment and had the limitation of using arbitrary scores for their AHP calculations.

Therefore, in this current study, we are overcoming the shortcomings of Adul Bennui’s study (Bennui et al., 2007), using regional experts and public opinions to provide some basis for our AHP calculations, as well as our study, covers both wind and solar energies. Therefore, it will likely provide important insight for both stand-alone and hybrid versions of wind and solar energy applications.

1.6 Research scopes

The present study is focused on its aim of identifying the suitable locations for wind and solar farms in Songkhla Province. The study hugely relied on the reputation of the online portals and government organizations for most of the secondary data such as land use, road and transmission line accessibility, wind speed and solar resource maps and others which have been used in this research.

CHAPTER 2

LITERATURE REVIEWS

2.1 Wind and Solar energy in Thailand

The increasing environmental concerns, diminishing reserves and high energy prices have driven the search for renewable energy opportunities (Janke, 2010; Kannan and Vakeesan, 2016). As, Renewable energy is cheaper, eco-friendly, sustainable and grants energy security to our future generations. The resources are distributed over a large area; that quickly replenish through natural process (Alrikabi, 2014). Wind and solar being one of the cleanest forms of energy has been favourited for its use in Thailand, where DEDE is showing high interest to generate electricity by these means, as well as Thailand is rich in solar potential.

Geographically, Thailand situates near the equator, hence receives maximum sunlight throughout the year (Chimres and Wongwises, 2016). Studies identify that annual average daily solar radiation in Thailand is around 5.0 to 5.3 kWh/m^2/day equivalent to 18-19 MJ/m^2/day. High values of 20-24 MJ/m^2/day have also been recorded previously, in the months of April and May. The northeastern and northern regions receive roughly 2,200 to 2,900 hours of sunshine per year (equivalent to 6-8 sunshine-hours per day). Therefore, the first PV system installation in Thailand was started in 1983. In 2015, Thailand had more solar power capacity than all Southeast Asia combined i.e. about 2,500-2,800 MW.

The wind speed across Thailand is not significant yet can’t be ousted. Studies recognize that most parts of Thailand hold class 1-1.4 (2.8-4 m/s) and some places having class 3 (6.4 m/s and above) wind speeds (Chingulpitak and Wongwises, 2014). It is because of the two of the monsoon seasons; Northeast Monsoon and Southwest Monsoon (Gyawali, Techato, Monprapussorn, and Yuangyai, 2013). The Northeast Monsoon coming from South China Sea during November to March produces strong wind along the coastal areas of Southern Thailand, where Southwest Monsoon coming from Indian Sea during May to October produces strong wind at the mountain peaks in the western part of upper southern and lower northern Thailand (Ali et al., 2019).

2.2 Barriers to the wind and solar technologies

Solar PV and wind facilities are best considered for commercial uses, as both of these resources are environment-friendly and having both in syndicate prove essential to overcome the only drawback of intermittency associated to these resources (Khare, Nema, and Baredar, 2016; Shivarama Krishna and Sathish Kumar, 2015). However, despite the enormous economic and environmental gains, wind and solar technologies have erupted debates in social circles (Devlin, 2009; Heras-Saizarbitoria, Cilleruelo, and Zamanillo, 2011).

The reservations that have frequently reported regarding wind technology in literature are noise nuisance and visual intrusion, while those of utility-scale solar facilities are land degradation and habitat loss (Heras-Saizarbitoria et al., 2011; Tabassum, Premalatha, Abbasi, and Abbasi, 2014). Nevertheless, careful assessment of locations for the construction of wind and solar farms can mitigate these problems (Ali et al., 2019; Kaldellis, Kapsali, Kaldelli, and Katsanou, 2013).

2.3 Role of GIS in renewable energy developments

Geographic Information System (GIS) is a computer-based tool that has become popular due to its ability to combine apparently distinct data to obtain specific objectives of resources assessments, such as wind and solar farms locations (Anwarzai and Nagasaka, 2017; Jahangiri, Ghaderi, Haghani, and Nematollahi, 2016; Janke, 2010; Watson and Hudson, 2015). It capacitates to combine the opinions of a various group of people that can influence the project, as inputs to with multi-criteria decision making (MCDM) models (Baseer, Rehman, Meyer, and Alam, 2017; Martin-Martínez, Sánchez-Miralles, and Rivier, 2016; Watson and Hudson, 2015). This apparently turns down the social and environmental impacts of renewable energy projects, therefore, highlighting the facts that may be mistaken as less important when looking at them in a less organized fashion.

National Center for Geographic Information and Analysis (NCGIA) the USA defines Geographic information systems (GIS) as *"a hardware and software system which has been designed for the capture, storage, analysis, modelling and data* *presentation, spatially referenced for the resolution of complex problems of planning and management."* (Sánchez-Lozano, Teruel-Solano, Soto-Elvira, and Socorro García-Cascales, 2013). Therefore, it is a tool that can be used to integrate geographically referenced data.

Where, MCDM is a sophisticated approach to handle complex decision-making problems, most importantly when a single objective has to be achieved that is linked to multiple factors (Abu-Taha, 2011; Kumar et al., 2017). Previous studies (Al Garni and Awasthi, 2017; Aly, Jensen, and Pedersen, 2017; Baseer et al., 2017; Sánchez-Lozano et al., 2013; Watson and Hudson, 2015) have favored the use of the GIS-MCDM method for assessment studies related to wind and solar energy, for either combined or independent patterns. Moreover, the analytic hierarchy process (AHP) technique in MCDM affords to involve the view of experts and decision-makers in pairwise comparisons of numerous factors, which can be used in a GIS environment to accomplish optimum goals (Höfer, Sunak, Siddique, and Madlener, 2016).

2.4 GIS based studies on wind and solar energy applications

2.4.1 GIS for wind farms

(Miller and Li, 2014) has used geospatial approach to prioritize wind farms in the USA using seven criteria such as wind energy potential, land use, population density, distance from major roads, slope, distance from transmission line and exclusion zones as cities, town, wetlands, airports and roads.

(Noorollahi et al., 2016) has employed multicriteria decision support system for wind farm site selection using GIS in Iran. He maintains that identifying the site for wind farms obtained through surveys and studies is complex and demands sophisticated method of decision which may subject to human errors, therefore GIS is the most suitable tool to rectify the human error hence identifying the potential area via integrating digital maps.

(Janke, 2010) has used GIS modelling for wind and solar in Colorado, considering mountain summits, steep slopes, woodlands (forests) and dense population as an excluded area for wind site selection on basis of surveys and literature studies.

(Janjai et al., 2014) has evaluated wind energy in Thailand using atmospheric mesoscale model and GIS approach. The author said that to evaluate wind potential of any area, it is necessary to know the wind speed data of that area, which can be obtained from wind masts using sonic anemometer (an instrument which measures wind speed above 100 m on masts). The authors obtained 7 maps on basis of various parameters.

(Siyal et al., 2015) has studied wind energy assessment for Sweden considering the geographic and environmental restrictions using GIS based approach. Environmental perspectives such as near of transmission grids, roads and wind availability at the site were considered. Marco (Beccali, Galletto, Noto, and Provenza, 2015) has discussed the assessment of the technical and economic potential of offshore wind using GIS application and various parameters in a conference proceeding in Italy. (Medimorec, Knezevic, Vorkapic, and Skrlec, 2011) has also highlighted the wind energy and environmental protection using GIS techniques considering suitable parameters.

2.4.2 GIS for solar farms

(Sánchez-Lozano et al., 2013) has employed GIS and MCDM approaches to evaluate solar farm locations for southern Spain. Where the researcher accepted that the climate is the most key factor while selecting a site for PV. Effat (Effat, 2016) has mapped solar energy potential in Egypt around a Lake Nasser Region. The author asserted that climate is a highly-preferred criterion for decision rule for PV site selection over location as it is possible to build new urban areas and roads.

(Sun et al., 2013) has adopted a GIS based approach for the potential analysis of Solar PV generation at regional scale taking a case study of Fujian China. The author says GIS is a significant tool which integrates data of various constraints to produce a geospatial map for solar. The author has employed ArcGIS 9.3 to investigate solar radiation map. Brewer (Brewer, Ames, Solan, Lee, and Carlisle, 2015) has used GIS analytics and social preference data to evaluate utility-scale solar power site in the United States.

(Gastli and Charabi, 2010) has discussed the Solar PV siting in Oman using the GIS-based spatial multi-criteria method considering three constraints i.e. technical, economic and environmental constraints to find the land suitability for Solar PV installation.

CHAPTER 3

STUDY AREA

3.1 Study area description

Songkhla is a province in southern Thailand near the Malaysian border, laying at 968 km distance from the Bangkok city towards the south. By the area it is the 26^{th} largest province of Thailand, having an area of 7,393.9 km^2 (1.44% the area of Thailand) and in 2014 had a population of 1.401 million people, making it the 11th most populous province in Thailand (see Fig. 3.1). Geographically, it is situated at 7° 12' 13.20" N latitude and 100° 35' 28.79" E longitude. The lowest elevation is 11 m (36 ft.) and the highest elevation is 295 m (968 ft.) and the difference in elevation is thus 284 m (932 ft.) (Ali et al., 2019; FloodMap.net, 2018). This low elevation difference indicates a mostly smooth surface, which is promising for the development of wind and solar projects, as high elevation may subject to higher construction costs (Ali et al., 2019).

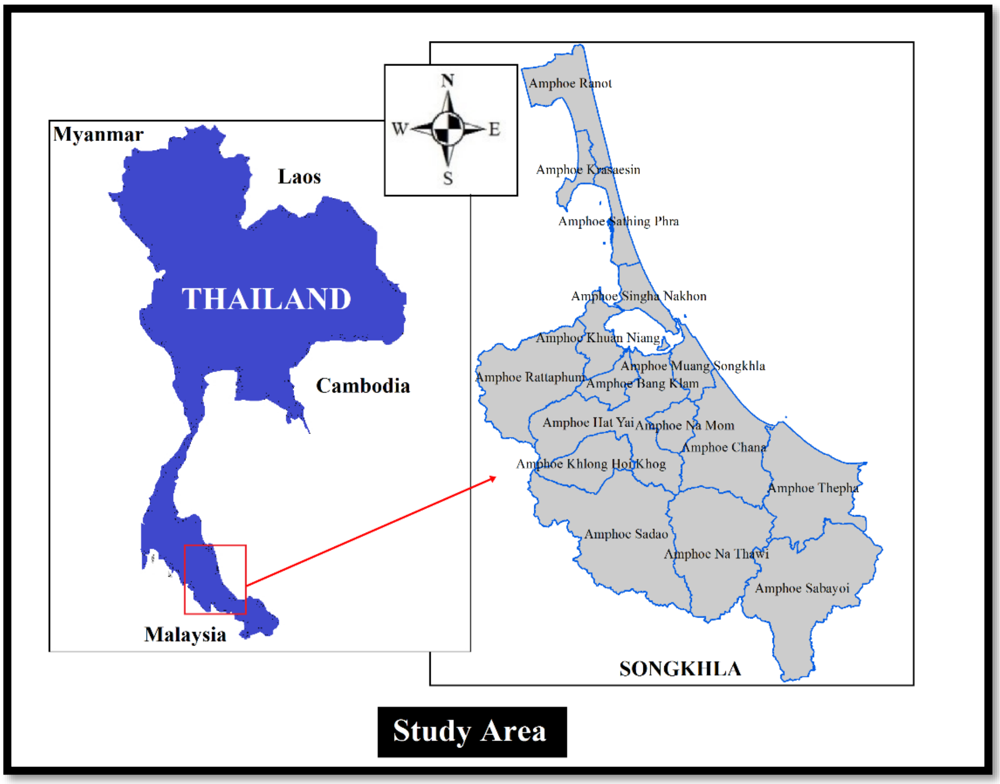

Fig. 3.1 Songkhla Province, Thailand (Ali et al., 2019).

3.2 The climate of the study area

Generally, Thailand has hot and humid weather. Specifically, Songkhla has a tropical monsoon climate where usually the temperatures are high. In 2016, in the South of Thailand the lowest monthly mean temperature recorded in December on the east coast was (26.5 ºC) the highest mean temperature, that was recorded in April was (30.1 ºC), where on west coast, the lowest monthly mean temperature (27.1 ºC) was recorded in December and the highest mean temperature (30.5 ºC) was recorded in April, where they formed an annual mean temperatures of 28.2 ºC on the east coast and 28.3 ºC on the west coast (TMD, 2014). The generally high temperatures are ideal for energy applications, more importantly for solar energy exploitations. Moreover, Songkhla is substantially ideal for wind energy exploitations as reports identify that availability of wind speed of above 6 m/s (Waewsak, Landry, and Gagnon, 2013). This makes it indispensable to utilize the resources timely to benefit the mankind of this region.

3.3 Power shortfalls in southern Thailand

In April 2016, EGAT announced a rapid growth in power demand in the southern provinces of Thailand of 5% against previous years by 125 MW to 2,600 MW mainly due to two reasons that's hot weather and the increased use of air conditioners (EGAT, 2018). Also, the power consumption of Songkhla increases due to accommodating a large number of tourists each year from Malaysia, which is in adjacent. This highlights the necessity to construct new power plants with the less damage to the environmental, most probably by the means of wind and solar whose indications are evident in countries such as Thailand (Ali et al., 2019).

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Methodology overview

Fig. 4.1 presents the workflow of this research. The study area was identified at first after primary consideration of the geographical position, renewable resources viability and signs of the increasing power demands in the region. As a next step, required secondary data have been collected from various governmental organizations and online portals. Worldwide criteria for the site selection of wind and solar farms were deeply studied and the criterions best fit to the study area were sorted out in sharing knowledge with the regional experts and the public (previously exposed to energy projects such as wind or solar) (Ali et al., 2019).

Next, the MCDM technique was used to find the weight of each criterion, which highly relied on the scoring made by the experts chosen for this study. Finally, thematic maps were produced in the GIS environment using the above techniques and information.

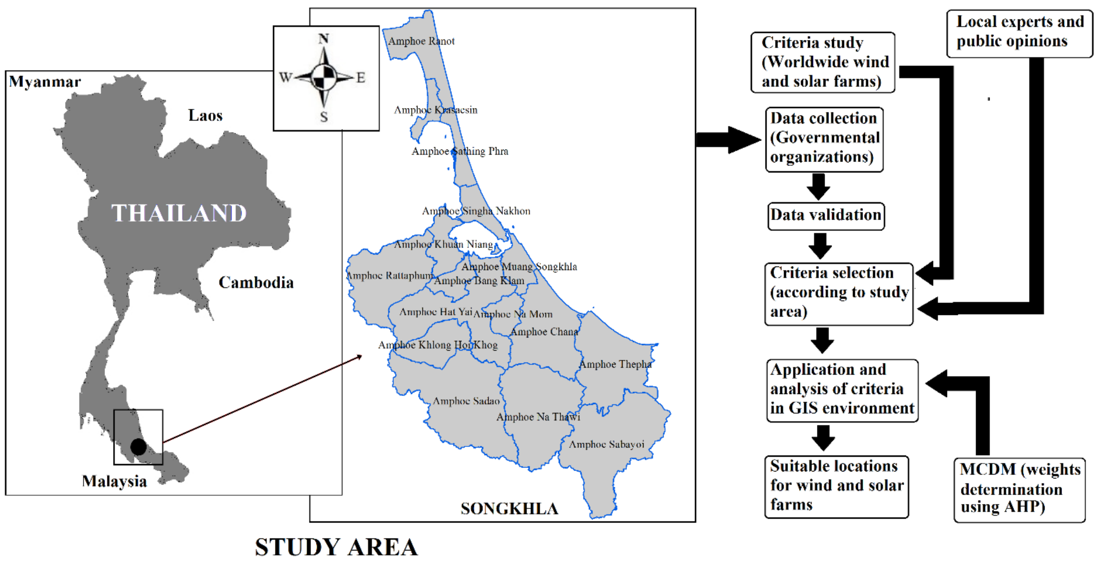

Fig. 4.1 Methodology overview of this study (Ali et al., 2019).

4.2 Data sources

As the aim of this study was to evaluate the ideal sites for wind and solar farms which was hugely reliant on the availability of the necessary data and information. Therefore, all important data were collected before working on it in a GIS environment. The secondary data were mainly collected from the online portals of various organizations working under or for the government. The accessed government organization for data were Thai Survey Department, Southern Regional Center of Geo-Informatics and Space Technology, PSU and others (Ali et al., 2019). However, a wind resource map on 100 m above ground at the spatial resolution of 200 m was collected from a previous study conducted by Jompob Waewsak while constructing a high-resolution wind atlas of Nakhon Si Thammarat and Songkhla provinces at the Solar and Wind Research Unit of Thaksin University (see Fig. 4.2) (Ali et al., 2019; Waewsak et al., 2013).

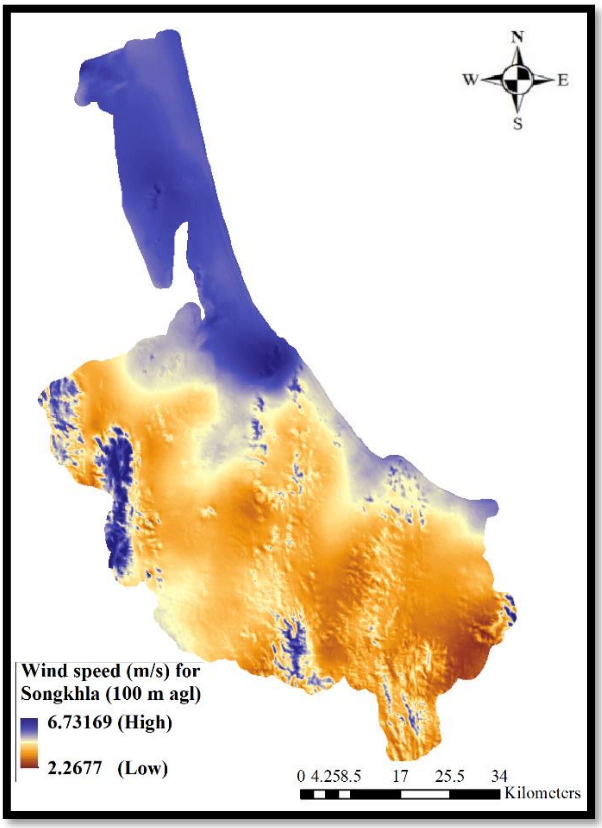

Fig. 4.2 Wind resource map of Songkhla at 100 m AGL. Source: (Waewsak et al., 2013)

Solargis an online resource was accessed to collect the Global Horizontal Irradiance (GHI). The data was available in 1km/spatial resolution covering the period from 2007 to 2015 for Thailand (Ali et al., 2019). The available two formats of a raster gridded data were: GeoTIFF and AAIGRID (Esri ASCII Grid). Actually this data was available for entire Thailand, however, in our study, we are only covering Songkhla province, therefore, the required coordinates data were extracted and was then converted to the shapefile format as per the requirements of the study (see Fig. 4.3) (Solargis, 2018).

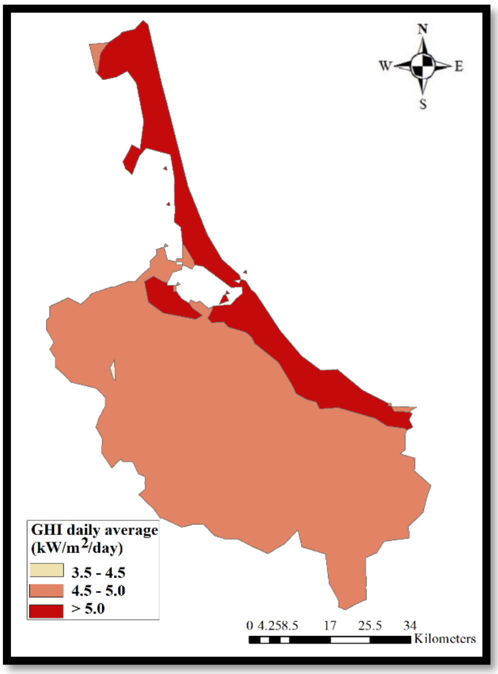

Fig. 4.3 Average daily GHI map for Songkhla (adapted source (Ali et al., 2019; Solargis, 2018)**)**

The remaining data were also edited to the required specifications using the resampling technique in GIS to a common spatial resolution of 100 m. Table 4.1 below describes in detail all the data sources, where they were edited and the original spatial resolutions of each dataset. In addition, 7 experts each for wind and solar were also asked to give their opinion in compliance with the Delphi technique (Watson and Hudson, 2015; Yousuf, 2007), which has been used as an input for decision making purpose, where public opinions have also been incorporated, as first-hand data to conduct this research.

Table 4.1 List of data layers, their types and sources (Ali et al., 2019).

Data Layer	Type	Spatial resolution	Source	Edit Source
Wind	Wind speed	200 m	Wind and solar research unit, Thaksin University (Waewsak et al., 2013)	Edited by Southern Regional Center of Geo-Informatics and Space Technology, PSU (FEM, 2018).
Solar	GHI	1,000 m	Solargis (Solargis, 2018)	
Slope	Topographic Digital Map	100 m	Royal Thai Survey Department, 1999 (RTSD, 2018)	Convert from contour by Southern Regional Center of Geo-Informatics and Space Technology, PSU (2017) (FEM, 2018).
Elevation	Topographic Digital Map	100 m	Royal Thai Survey Department, 1999 (RTSD, 2018)	
Land use	Land Use Map	1,500 m	Land Development Department, 2012	Edited from LandSat by Southern Regional Center of Geo-Informatics and Space Technology, PSU (2015) (FEM, 2018).
Airport	LandSat	30 m	Southern Regional Center of Geo-Informatics and Space Technology, PSU (2015) (FEM, 2018).	
Road	Topographic Digital Map	1,500 m	Royal Thai Survey Department, 1999 (RTSD, 2018)	Edited by Southern Regional Center of Geo-Informatics and Space Technology, PSU (2015) (FEM, 2018).
Transmission line	Transmission line Map	1,500 m	Electricity Generating Authority of Thailand, 2015 (EGAT, 2018)	

4.3 Site selection criteria for wind and solar farms

The selection criteria for this study were decided based on the previous literature which have covered studies of similar nature as well as the nationally and internationally available guidelines (Höfer et al., 2016; Latinopoulos and Kechagia, 2015; Uyan, 2013; Watson and Hudson, 2015).

The appropriateness of wind speed (m/s) and solar irradiance (W/m^2) are not sole aspects to be considered in assessments studies for wind and solar farms (Anwarzai and Nagasaka, 2017; Uyan, 2013), other drivers such as economic and environment were equally essential to be considered for solar and wind farm planning and construction (Anwarzai and Nagasaka, 2017; Latinopoulos and Kechagia, 2015; Van Haaren and Fthenakis, 2011).

Therefore, in this study the following categories were reflected, which were additionally endorsed by experts' opinions i.e., physiographic, environmental and economic aspects and they had surfaced as the main criteria in this study, with sub and sub-sub criteria in a hierarchy in order to obtain the most suitable outcomes, as shown in Fig. 4.4.

The physiographic layer constitutes the variables that may reflect the physical conditions and processes of the Earth such as climate (wind and GHI), topography (slope and elevation) and land use types.

The environmental layer branches out the factors which could have direct or indirect nexus to the environment which could have potential to influence the wind and solar energy facilities such as, buffers to residential areas (rural and urban) and protection buffers to necessary installations (e.g., airports) and scenery (e.g., wetlands and forests).

The economic layers were based on the following two important aspects, i.e. (a) Distance to market which further included the nearness to main roads and transmission lines and (b) the area required for siting wind or solar farms. As these aspects mainly effect the capital and operating costs associated to energy projects.

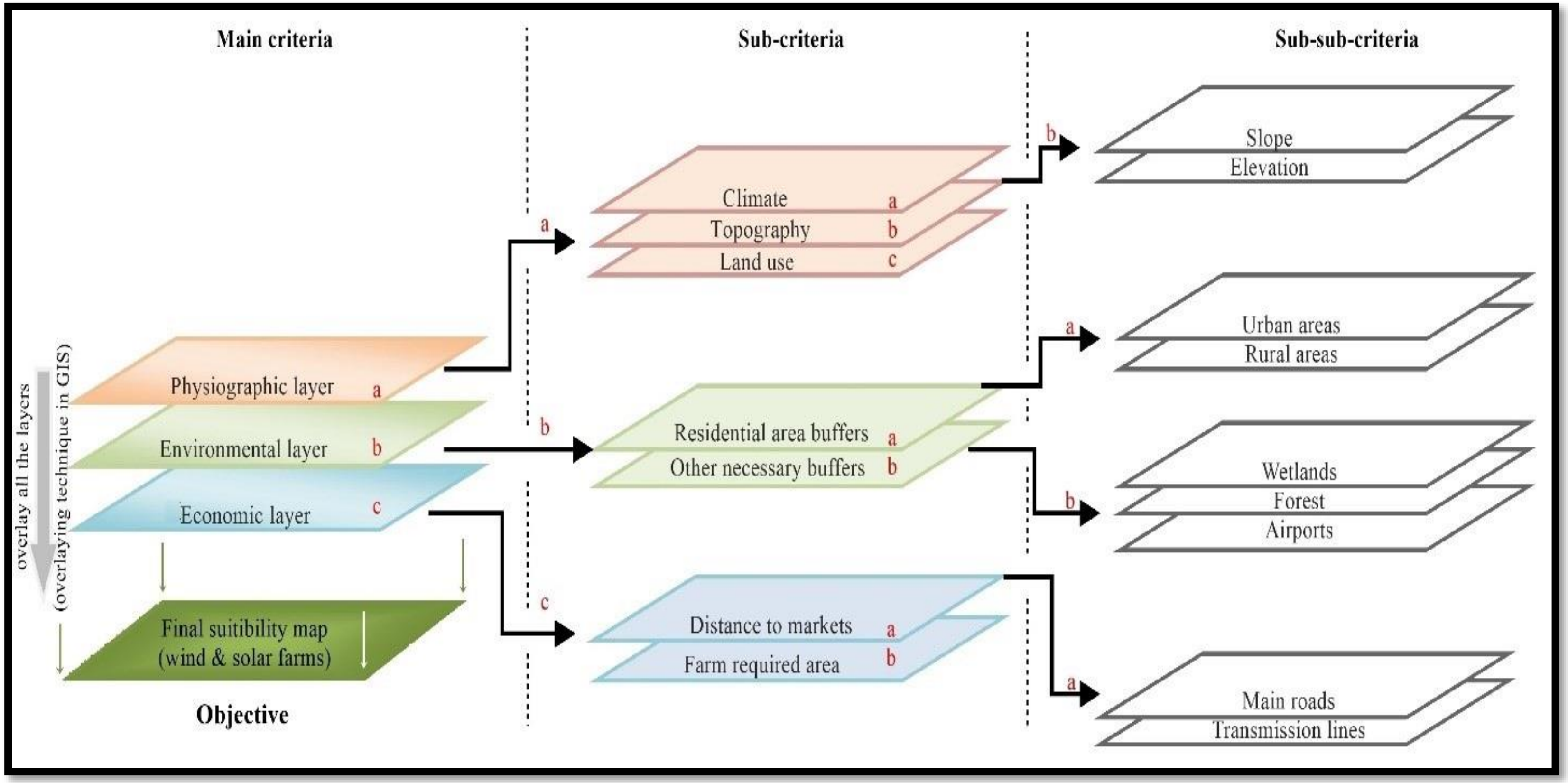

Fig. 4.4 Categorization of the parameters and their overlaying to achieve the study objective (Ali et al., 2019).

4.3.1 Selection of Experts and Public opinions

The experts chosen were restricted to Thailand and were professional engineers, university professors and researchers with strong knowledge of wind and solar energy applications besides their familiarity with the conditions of the study area was also considered. The purpose of incorporating expert's opinion was to validate the literature-based knowledge in the proposed study area, as well as to minimize the conflicts of interest and personal bias in selection and scoring of parameters (Grilli, Balest, De Meo, Garegnani, and Paletto, 2016; Watson and Hudson, 2015). The public who have previously been exposed to energy projects (wind or solar) have also been interviewed and given a right of say in this research to avoid any public opposition (Devlin, 2009; Heras-Saizarbitoria et al., 2011; Kaldellis et al., 2013; Nguyen, 2007).

4.3.2 Physiographic Aspects

4.3.2.1 Climate

Wind speed

Though the handiness of wind resource is not a sole reason to construct a wind farm, yet it is considered as the most important criteria in previous researches (Janke, 2010; Krewitt and Nitsch, 2003; Van Haaren and Fthenakis, 2011; Watson and Hudson, 2015). 5 m/s may be seen as the minimum useable wind speed in previous studies (Noorollahi et al., 2016), however, the threshold for this study was set 4 m/s based on the opinions of regional experts, due to the reason of poor wind speed across Thailand because of positioning close to the equator line f the earth (Ratjiranukool and Ratjiranukool, 2015).

Past studies (Chingulpitak and Wongwises, 2014; Janjai et al., 2014; Waewsak et al., 2013) have described and indicated the access to class 3 wind (above 6 m/s) at various places in southern Thailand which is sufficient to operate wind drives. Furthermore, the evidence may be supported with the operational cut in speed for the Siemens (SWT-2.3-101) horizontal axis wind turbine which is 3-4 m/s, and it has already come to use in wind farm in Korat (Thailand). In a previous study, areas with a wind speed of more than 6 m/s on land heights over 100 m above ground level have been proposed as being highly suitable (Ali et al., 2019; Janjai et al., 2014).

Global Horizontal Irradiance (GHI)

GHI is the most important criterion in the planning and construction of the solar facilities (Al Garni and Awasthi, 2017; Uyan, 2013). When we look at Thailand, its geographical positioning greatly favours the solar energy harnessing, therefore lead all the ASEAN countries in solar energy exploitations. On average Thailand collects a solar irradiation of 5 kW/m^2/day (18.0 MJ/m^2/day) (Chimres and Wongwises, 2016). However, in this study, areas receiving GHI of less than 3.5 kW/m^2/day have constrained (Ali et al., 2019; Anwarzai and Nagasaka, 2017) (see Table 4.2 and 4.3).

4.3.2.2 Topography and land use

Slope and elevation are the fundamentals of topography and land with a sharp and steep slope and high elevation is not recommended for solar and wind projects by almost all the studies, as slope grading may be required otherwise, which will ultimately hike up the developmental costs (Brewer et al., 2015; Krewitt and Nitsch, 2003; Latinopoulos and Kechagia, 2015).

Slope

The slope limit in the wind power projects varies between 10 and 30% (Anwarzai and Nagasaka, 2017; Baseer et al., 2017) and for solar varies between 3 and 5% in previous reports (Ali et al., 2019; Anwarzai and Nagasaka, 2017; Uyan, 2013). In this study, we are considering a slope of 15% for wind and 5% for solar.

Elevation

As the elevations are mostly different for each region or place, however, previous studies (Noorollahi et al., 2016; Uyan, 2013) set an elevation of 2000 m as the final limit in Iran and Turkey for energy purposes. One of the previous studies in southern Thailand by Bennui et al. (Bennui et al., 2007) excluded elevations above 200 m for wind projects. As for our case, the maximum elevation in the study area is not more than 295 m, therefore in this study we have set constrain for regions that violate elevation more than 200 m for both wind and solar energy facilities.

Fig. 4.5 shows the distribution of slope and elevation in the study area also see Table 4.2 and 4.3.

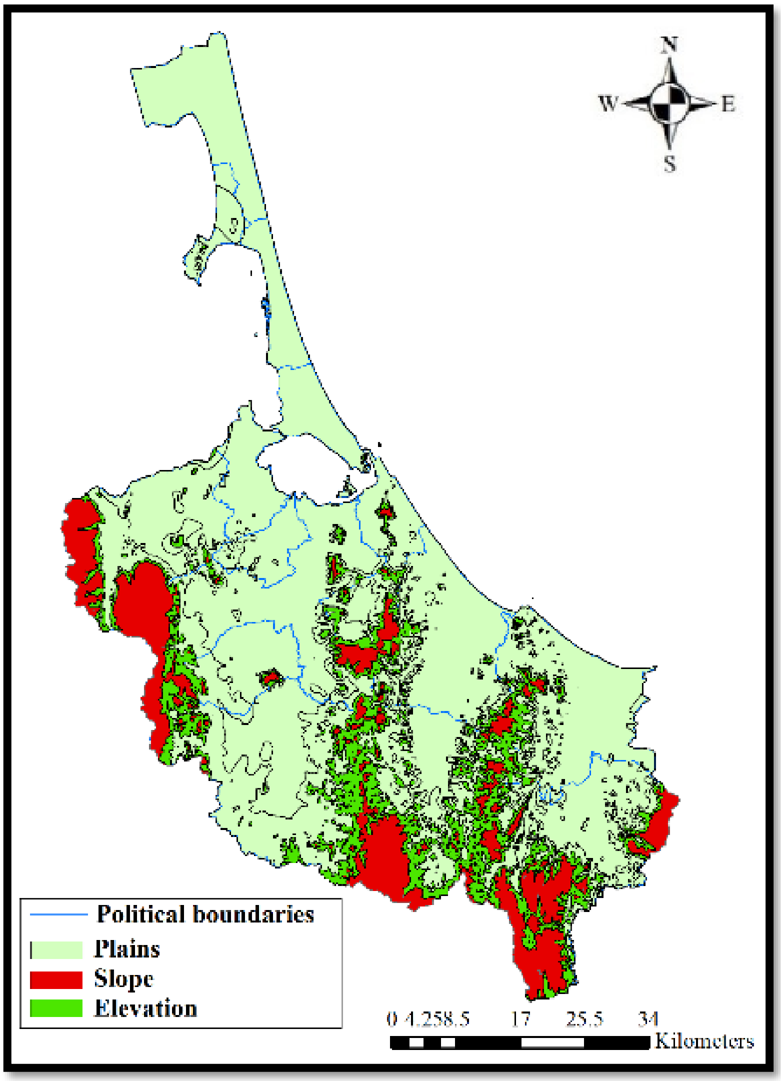

Fig. 4.5 Distribution of slope and elevation in Songkhla Province (Ali et al., 2019).

Land use types

Land use types are indispensable to investigate thoroughly before embarking on any projects. Studies (Jangid et al., 2016; Uyan, 2013) endorse barren land as being highly suitable for both wind and solar energy projects.

Vegetation landscapes are favourited for such projects and shorter vegetation is preferred over taller vegetation as having a taller vegetation nearby will likely accelerate turbulence intensity and on the other hand decelerate the wind speed, which may damage the costly rotary equipment (Gorsevski et al., 2013; Jangid et al., 2016).

Moreover, shorter vegetation also may not obstruct solar insolation (Janke, 2010). The regional experts' opinions also comply with above the land use preferences classification in this study (see Table 4.2 and 4.3) (Ali et al., 2019).

4.3.3 Environmental Aspects

4.3.3.1 Residential buffer

Buffers to residential areas are crucial, so is the reason it has frequently been discussed in all similar studies for wind and solar power generations (Al Garni and Awasthi, 2017; Aydin, Kentel, and Duzgun, 2010; Janke, 2010; Watson and Hudson, 2015). As these are directly related to the comfort of human lives.

At minimum a 500 m residential buffer to urban-rural area has been recommended for solar and wind in previous studies (Uyan, 2013) and (Jangid et al., 2016) and in order to gather information on the reservations and concerns of the people living in vicinity of wind farms, a special field visit was carried out to the Hua Sai District in Nakhon Si Thammarat Province, Thailand during August 2017 (see Fig. 4.6). People were more concerned about the noise nuisance and visual intrusion in during daytime and some of them also complained about the turbine blades reflecting moonlights during night hours which disrupt shrimp farming, as shrimps are sensitive to the radiant lights. We found that buffer to communities has not been given importance as much during the construction of the above farm.

Fig. 4.6 Hua Sai wind farm Nakhon Si Thammarat, Thailand (Ali et al., 2019).

Therefore, in this study, we ought to consider buffers of 500 m for countryside or rural communities and 1,000 m for the city or urban areas for wind farms, where only 500 m for solar facilities for both rural and urban communities. They were kept in alignment with expert opinions as well as public opinion rather than trusting the literature-based knowledge since human comfort is of paramount importance.

Fig. 4.7 shows the distribution of urban and rural populations in the study area (see Table 4.2 and 4.3).

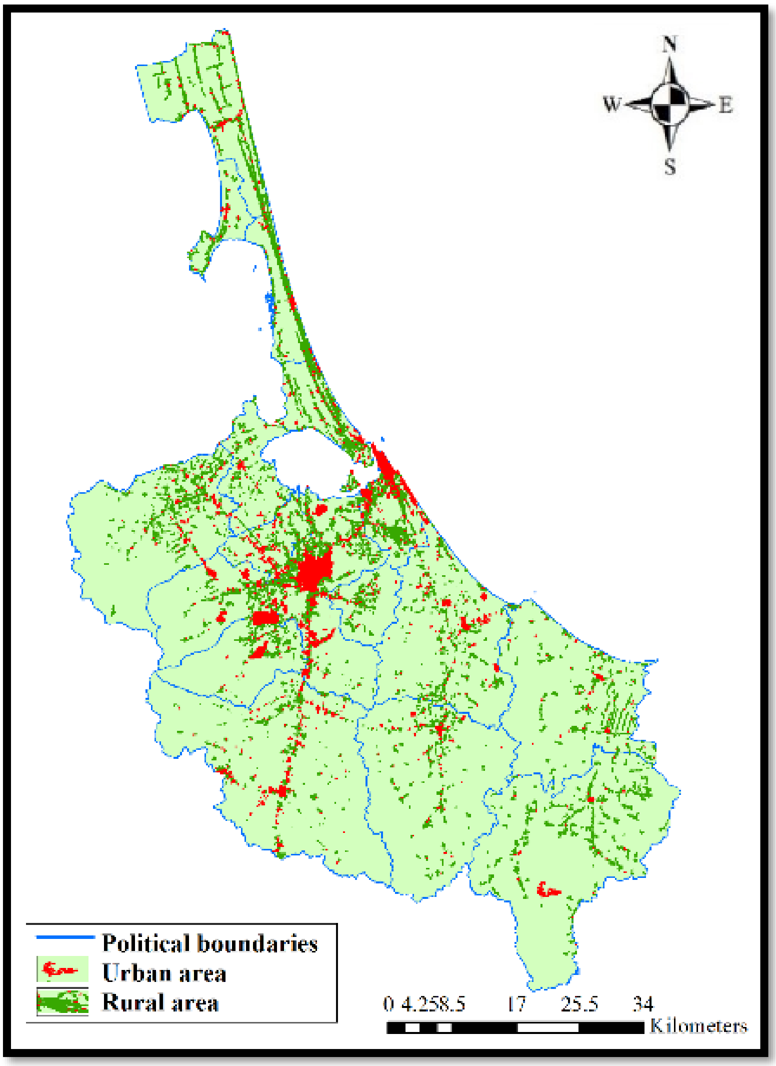

Fig. 4.7 Distribution of urban and rural settlements in Songkhla Province (Ali et al., 2019).

4.3.3.2 Protection buffer

Distance to Airports

Distance to airports has been carefully considered in most of the studies related to wind and solar (Aydin et al., 2010; Bennui et al., 2007; Latinopoulos and Kechagia, 2015), as wind turbines are said to interrupt the airport surveillance radar signals that play a crucial role in air traffic operations. Previous studies (Noorollahi et al., 2016; Siyal et al., 2015) have considered 2500 m and 3000 m (Bennui et al., 2007) buffer to airport versus a wind farm, therefore as a matter of safety, we are considering 3,000 m as minimum buffer limit. However, consultation is essential for any wind farms inside a range of 55 km (Siyal et al., 2015) of an airport.

And for the case of solar, glint and glare (C. K. Ho, Sims, and Christian, 2015; Clifford K. Ho, Ghanbari, and Diver, 2009) from solar panels have the potential of distracting pilots' vision, moreover they allegedly have negative effects on radar systems if solar panels are placed closely together. Therefore, a 1,000 m buffer between airports and solar farms was adopted in this study (see Table 4.2 and 4.3).

Distance to wetland and forests

A buffer to wetlands and forest is essential to nullify any chance of damage to the expensive equipment more it may also be helpful to take preservative measures for the sack of biodiversity and natural reserves (Janjai et al., 2014; Van Haaren and Fthenakis, 2011). There is no defined or acclaimed rule that may highlight this issue, but it has appeared some of the previous studies such as (Siyal et al., 2015) used 100 m and (Van Haaren and Fthenakis, 2011) used 400 m for watercourses in wind energy applications. Moreover employing such facilities much closer to forests may be inefficient due to likely wind turbulence that may generate due to trees in forest otherwise they may also obstruct solar insolation (Jangid et al., 2016). In a previous study, (Yue and Wang, 2006) a cordon of 250 m was permissible between forest and wind energy applications.

However, this study generally trusted on the regional experts' opinions on this feature and their proposition was to tolerate a minimum buffer of 400 m to wetland for the solar and wind applications due to flood history in the study area (Supharatid, 2006; Tanavud, Yongchalermchai, Bennui, and Densreeserekul, 2004) and that the distance to forests should not be less than 1.5 km for wind energy applications and 1 km for solar energy applications (see Table 4.2 and 4.3) (Ali et al., 2019).

4.3.4 Economic Aspects

Proximity to roads and transmission lines decides the economic feasibility of energy developments (Baseer et al., 2017; Janjai et al., 2014; Janke, 2010; Noorollahi et al., 2016; Uyan, 2013), as distant roads and transmission lines possibly will incur higher construction costs, as well as power line losses.

4.3.4.1 Proximity to market

Distance to major roads and transmission lines

The Department of Alternative Energy and Development Efficiency, Thailand (DEDE, 2018) rules propose to ensure a maximum distance of not more than 10 km both from the roads and the electricity substations for any energy project developments (Janjai et al., 2014). Therefore, areas exceeding 10 km in the line of this aspect were ousted in this study. Fig. 4.8 shows the present network of transmission lines and the main road in the study area.

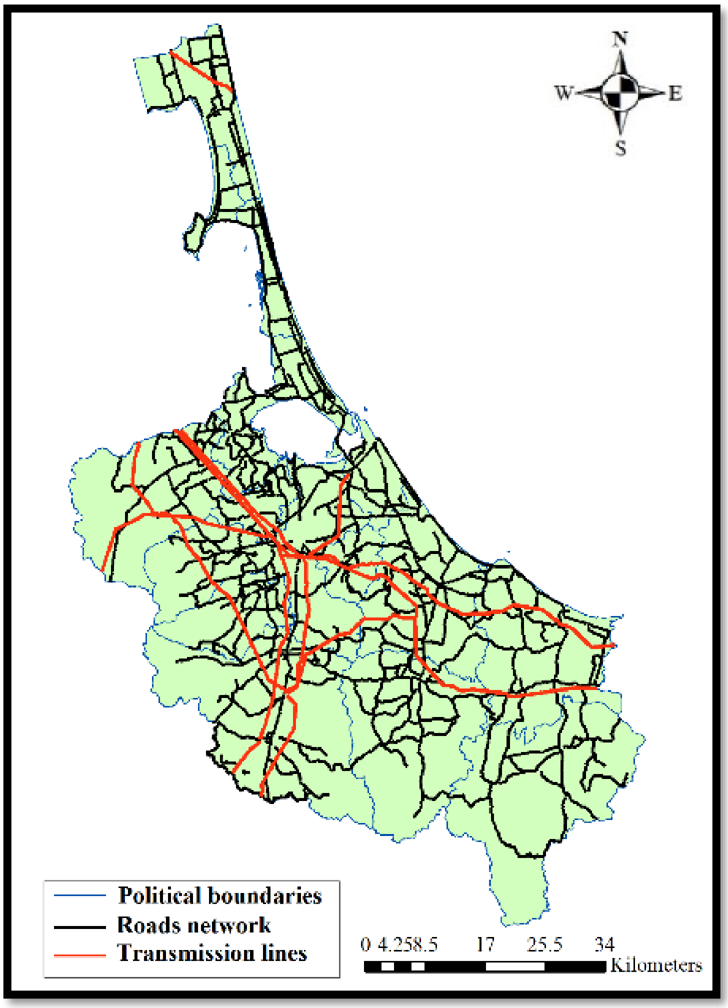

Fig. 4.8 Distribution of transmission line and road networks in Songkhla Province.

4.3.4.2 Farm required area

The area required for solar or wind farms (farm required area) may operate the relative cost per kW of energy and the studies recommends to consider minimum areas of 4 km^2 or 1000 acres for wind energy and 0.4 km^2 or 100 acres for solar energy applications (Ali et al., 2019; Anwarzai and Nagasaka, 2017). This has been strictly obeyed in this study (see Table 4.2 and 4.3).

Table 4.1 Wind farms location selection criteria (Ali et al., 2019).

Factor	Suitability Ranking			
	Highly Suitable	Moderately Suitable	Low suitability	Not suitable
	3	2	1	0
Wind Speed -m/s	>6	5-6	4-5	<4
Slope **%**	0-7	7-12	12-15	>15
Elevation	0-50 m	50-100 m	100-200 m	>200 m
Land use	Barren grassland	Agricultural land	Short vegetation and shrubs	Public settlements, airport, wetland etc.
Distance to urban area	>3 km	2-3 km	1-2 km	<1 km
Distance to rural area	>2 km	1.00-1.99	0.5-1	<0.5 km
Distance to wetland	>1 km	0.5-1 km	0.4-0.5 km	<0.4 km
Distance to forest	>3 km	2-3 km	1.5-2 km	<1.5 km
Distance to airport	>4 km	3.5-4 km	3-3.5 km	<3 km
Proximity to main road	>0.5-2	2-5 km	5-10 km	>10 km
Proximity to transmission line	0-2 km	2-5 km	5-10 km	>10 km
Farm required area	>6.00 km^2	5- 6 km^2	4-5 km^2	<4 km^2

Sources: (Anwarzai and Nagasaka, 2017; Aydin et al., 2010; Brewer et al., 2015; Chingulpitak and Wongwises, 2014; Gorsevski et al., 2013; Höfer et al., 2016; Jangid et al., 2016; Janjai et al., 2014; Janke, 2010; Krewitt and Nitsch, 2003; Latinopoulos and Kechagia, 2015; Ratjiranukool and Ratjiranukool, 2015; Siyal et al., 2015; Tanavud et al., 2004; Uyan, 2013; Van Haaren and Fthenakis, 2011; Watson and Hudson, 2015)

Table 4.2 Solar farms location selection criteria (Ali et al., 2019).

Factor	Suitability Ranking			
	Highly Suitable	Moderately Suitable	Low suitability	Not suitable
	3	2	1	0
GHI **-** $kW/m^2/day$	>5	4.5-5	3.5-4.5	<3.50
Slope **%**	0-1	1-3	3-5	>5
Elevation	0-50 m	50-100 m	100-200 m	>200 m
Land use	Barren grassland	Agricultural land	Short vegetation and shrubs	Public settlements, airport, wetland etc..
Distance to urban	>1.5 km	1-1.5 km	0.5-1 km	<0.5 km
Distance to R**.** A	>1.5 km	1-1.5 km	0.5-1 km	<0.5 km
Distance to W**.** L	>1 km	0.5-1 km	0.4-0.5 km	<0.4 km
Distance to Forest	>1.5 km	1.25-1.5 km	1-1.25 km	<1 km
Distance to airport	>2 km	1.5-2 km	1-1.5 km	<1 km
Proximity to Road	>0.5-2	2-5 km	5-10 km	>10 km
Proximity to transmission line	0-2 km	2-5 km	5-10 km	>10 km
Farm required area	>1.5 km^2	1- 1.5 km^2	0.4-1 km^2	<0.4 km^2

Sources: (Al Garni and Awasthi, 2017; Anwarzai and Nagasaka, 2017; Baseer et al., 2017; Chimres and Wongwises, 2016; C. K. Ho et al., 2015; Clifford K. Ho, Ghanbari, and Diver, 2010; Jangid et al., 2016; Janke, 2010; Krewitt and Nitsch, 2003; Latinopoulos and Kechagia, 2015; Tanavud et al., 2004; Uyan, 2013; Yue and Wang, 2006)

4.4 Multi criteria decision making (MCDM)

Finding suitable locations for wind or solar farms is never an easy task. Since in our research we are supposed to investigate and propose a site, which is suitable in terms of techno-physical, environmental and economic domains. Therefore, it involves various conflicting criteria and multiple objectives. Hence, we need to rely on such a decision method which could have been used for the relevant studies in past. Here, we decided to use MCDM as a decision tool to conduct this research, where the details are as under;

MCDM provides a sophisticated method of handling decision-related problems where previous it has been used in a GIS environment for energy application assessments (Abu-Taha, 2011; Kumar et al., 2017; Sánchez-Lozano et al., 2013).

Abu Taha (Abu-Taha, 2011) reported on the use of MCDM as (see Fig. 4.9);

Multi-Attribute Decision Making (MADM)

Is when there is more than one criterion but a single goal/objective.

- AHP

  Which is a function-based MADM method, highly regarded for energy system problems (Aly et al., 2017). Where a hierarchy is formed, in a way that goal remains at the top. More details are included later.

Multi-Objective Decision Making (MODM)

Is when there are multiple goals and we must optimize.

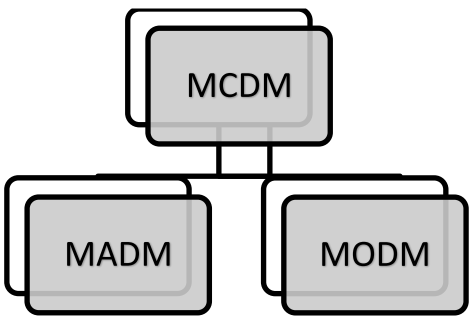

Fig. 4.9 Multicriteria-decision making (MCDM)

4.4.1 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty (Analytic et al., 2006), is an effective tool which is being used for complex decision making, and let incorporates the choices being proposed by the decision makers.

According to Saaty (T. Saaty, 1977; T L Saaty, 2006; Thomas L Saaty, 1990, 2008), AHP is based on four axioms as described,

Reciprocity

Reciprocal property is the essential procedure in conducting the pairwise comparison.

Homogeneity

It is about the characteristic of people's ability for making comparisons among things that are not too dissimilar with respect to a common property.

Synthesis

This axiom demonstrates the dependence of a lower level on the adjacent higher level.

Expectation

The idea that an outcome can only reflect expectations when the latter are well represented in the hierarchy.

However, there are three necessary steps, that are followed as a standard procedure in AHP calculations in any scenario (Aras, Erdoğmuş, and Koç, 2004; T. L. Saaty, 1993; Thomas L Saaty, 2008). The goal has to be defined at the beginning and kept on the top of the hierarchy, which entails to the criteria and the sub-criteria. In our study, the goal was to find suitable sites for wind and solar farms (as shown in Fig. 4.10).

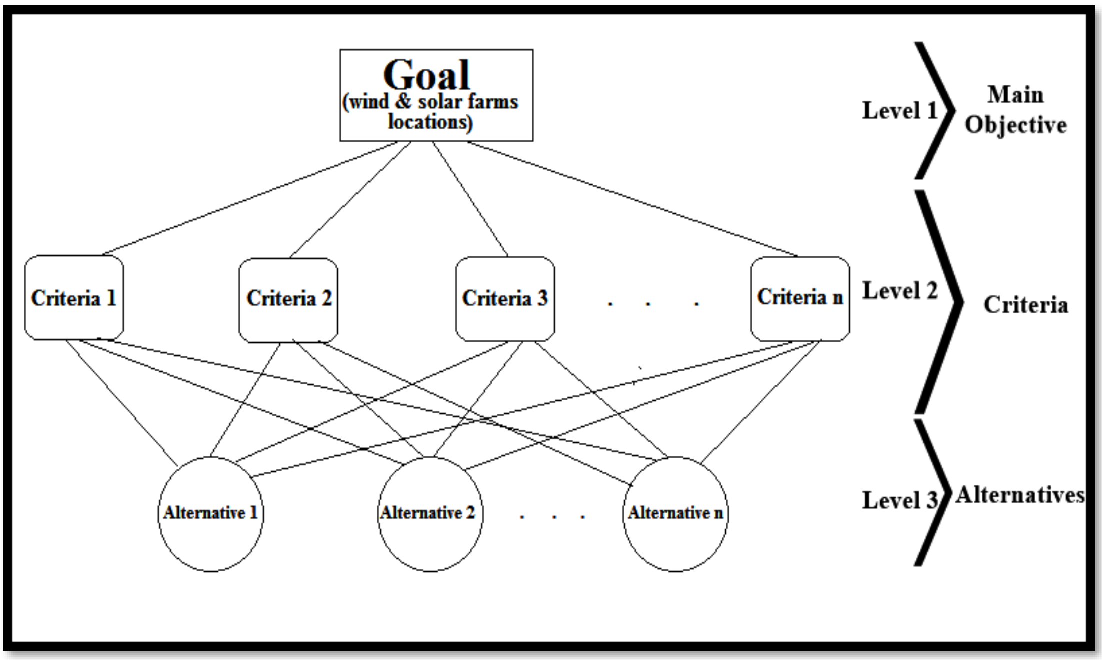

Fig. 4.10 The hierarchy and interconnection of goal, criteria and alternatives in AHP.

As a next step of the AHP rule, pairwise comparison of the criteria has to be conducted. The inputs for the AHP pairwise comparison come from the opinions of experts or decision makers, where they will allot scores to each criterion on a fundamental scale as defined by Saaty (1990) as shown in Table 4.4

Table 3.4 Preference score values as defined by Saaty (Thomas L Saaty, 1990).

Intensity of Importance	Definition	Explanation
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one activity over another
5	Strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	An activity is favoured very strongly, and its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed
Reciprocals	If one activity, *i* has one of the above activities assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*)i.e. 2 = ½ or 0.500(	

In the light of the previous study (Watson and Hudson, 2015) seven experts were asked to assign numerical values for the matrices ($\boldsymbol{M_x}$) for pairwise comparisons in wind and solar site assessment. The scores were to be made by following the Saaty's discrete 9-value scale (Table 4.4) as shown below (1) (Ali et al., 2019).

$$\boldsymbol{M_x} = \begin{vmatrix} \boldsymbol{C_{11}} & \boldsymbol{C_{12}} & \cdots & \boldsymbol{C_{1n}} \\ \boldsymbol{C_{21}} & \boldsymbol{C_{22}} & \cdots & \boldsymbol{C_{2n}} \\ . & . & \cdots & . \\ \vdots & \vdots & \vdots\vdots\vdots & \vdots \\ \boldsymbol{C_{n1}} & \boldsymbol{C_{n2}} & \cdots & \boldsymbol{C_{nn}} \end{vmatrix} \qquad (1)$$

$\boldsymbol{M_x = |C_{ij}|}\ \forall\ \boldsymbol{i, j = 1, 2, \ldots, n}$ for n number of criteria, where, $\boldsymbol{C_{ij}}$ represents the relative significance of the criteria $\boldsymbol{C_i}$ over $\boldsymbol{C_j}$ and the inverse will be $\boldsymbol{C_{ji}}$ or 1/$\boldsymbol{C_{ij}}$ $\forall\ \boldsymbol{i \neq j\ and\ C_{ii} = 1}$ (Thomas L Saaty, 1990). Therefore, all the relevant criteria and sub criteria in this study were evaluated using the matrix as in (1).

Then respective weights were determined by normalizing the individual eigenvectors associated with the maximum eigenvector of the reciprocal ratio matrix (Baseer et al., 2017). The final weights gained for this study as a result of the pairwise comparison using the experts' assigned scores are presented in Table 4.5 and 4.6.

Table 4.5 Criteria divisions and the AHP based weights for wind farms in this study.

Sr. No	Layer 1		Layer 2		Layer 3		Total Weight	Rank
	Main criteria	W1	Sub-Criteria	W2	Sub/Sub-Criteria	W3		
1	Physiographic	0.5294	Climate	0.7443	Wind speed	1	0.3940	1
			Topography	0.1683	Slope	0.3334	0.0297	8
					Elevation	0.6667	0.0594	4
			Land type	0.0873	Land Use	1	0.0462	7
2	Environmental	0.1617	Residential buffers	0.5	Dis. to urban area	0.6667	0.0539	5
					Dis. to rural area	0.3334	0.0269	10
			Protection buffers	0.5	Dis. to wetland	0.0719	0.0058	12
					Dis. to forests	0.3391	0.0274	9
					Dis. to airports	0.5889	0.0476	6
3	Economic	0.3088	Proximity to market	0.3334	Main roads	0.25	0.0257	11
					Transmission line	0.75	0.0772	3
			Available potential area	0.6667	Farm Req. Area	1	0.2058	2
	Total	1.0000					1.0000	

(criteria adapted from sources: (Aroonrat and Wongwises, 2015; Devlin, 2009; Heras-Saizarbitoria et al., 2011; Janke, 2010; Noorollahi et al., 2016))

Table 4.4 Criteria divisions and the AHP based weights for solar farms in this study.

Sr. No	Layer 1		Layer 2		Layer 3		Total Weight	Rank
	Main criteria	W1	Sub-Criteria	W2	Sub/Sub-Criteria	W3		
1	Physiographic	0.5350	Climate	0.6688	GHI	1	0.3578	1
			Topography	0.1137	Slope	0.875	0.0532	5
					Elevation	0.125	0.0076	10
			Land type	0.2173	Land Use	1	0.1163	3
2	Environmental	0.1210	Residential buffers	0.25	Dis. to urban area	0.6667	0.0201	8
					Dis. to rural area	0.3334	0.0100	9
			Protection buffers	0.75	Dis. to wetland	0.4667	0.0423	6
					Dis. to forests	0.0667	0.0060	11
					Dis. to airports	0.4667	0.0423	6
3	Economic	0.3439	Proximity to market	0.3334	Main roads	0.25	0.0286	7
					Transmission line	0.75	0.0859	4
			Available potential area	0.6667	Farm Req. Area	1	0.2293	2
	Total	1					1.0000	

(criteria adapted from sources: (Aroonrat and Wongwises, 2015; Devlin, 2009; Heras-Saizarbitoria et al., 2011; Janke, 2010; Noorollahi et al., 2016))

Owing to the human error, during score assignment by experts', the end result may suffer certain inconsistencies, therefore, Saaty (Thomas L Saaty, 1990) has also developed a method to check the level of inconsistency, which is named as consistency ratio)CR(. The formula for CR)3(has appeared in a number of related to energy assessments (Aly et al., 2017; Baseer et al., 2017; Uyan, 2013; Watson and Hudson, 2015) and first needs the computation of the consistency index (CI) as shown below (2),

$$\boldsymbol{CI} = \left(\frac{\boldsymbol{\lambda max - n}}{\boldsymbol{n-1}}\right) \qquad)2($$

CI is a deviation of consistency where '$\boldsymbol{\lambda max}$' is the maximum eigenvalue and **n** is the matrix size)n x n) in a pairwise comparison. This ultimately allows to find CR, which is computed by dividing the CI by the random consistency index)RI(. RI values for different matrix size are shown in Table 4.7 (Thomas L Saaty, 1990).

$$\boldsymbol{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}} \qquad)3($$

Table 4.5 Random index values for different matrix sizes in pairwise comparisons (Thomas L Saaty, 1990).

No.	1	2	**3**	4	5	6	7	8	9	10
Rand Index (RI)	0.00	0.00	**0.58**	0.90	1.12	1.24	1.32	1.41	1.45	1.49

CR values less than 0.10 are tolerable, but, a CR more than 0.10 identifies a major inconsistency in the scores (judgment) made by the experts, that needs a thorough rechecking and reassessment (Watson and Hudson, 2015). The similar procedure was adopted in this study and fortunately, the score assigned by experts in this study were perfectly consistent i.e. less than 0.10, that validates that the judgments of the experts were appropriate.

As a next step, the computed weights were used to create various thematic maps in the GIS environment. ArcGIS 10.3.0 (ESRI, 2016) tool was used to produce maps on a 4-point suitability scale of 0 for unsuitable, 1 for low suitability, 2 for moderately suitable and 3 for highly suitable (Ali et al., 2019). All the maps were resampled to a spatial common resolution of 100 m to bring them to the same scale by the use of filter function in GIS (Janke, 2010).

They were all combined within the 'attribute table' using function 'add field' inside the GIS toolbox. All the maps were then overlaid using the overlay function in GIS in order to produce the desired map for both the wind and solar cases. The total suitability score was computed using following the formulae (4) (Ali et al., 2019):

$$\boldsymbol{S} = \sum_{i=1}^{i=N} \boldsymbol{WiPi} \qquad (4)$$

$\boldsymbol{Wi}$ = *i*th criterion weight, *Pi* = criterion score of *i*th factor, N = no. of factor and $\boldsymbol{S}$ = the classifying suitability value in output map.

CHAPTER 5

RESULTS and DISCUSSION

5.1 Overview and AHP calculation results

This study was unique in its terms of using GIS-MCDM approach to evaluate the ideal locations for wind and solar farms in Songkhla, Thailand. In total twenty-four criteria where twelve criteria each for wind and solar were chosen. They were categorized into three forms; psychographic, economic and environmental aspects. The map for each criterion was prepared using ArcMap 10.3.0 (ESRI, 2016), using the weights obtained from AHP calculation, which highly relied on the opinions of the experts. The weights obtained in this study are in Table 5.1.

Table 5.1 Final weight for wind and solar farms

Main criteria	Sub-criterion	Sub-sub criterion	Final Weight	
			Wind	Solar
Physiographic	Climate	Resources	0.3940 *	0.3578 *
	Topography	(wind/solar)	0.0297	0.0532
		Slope	0.0594	0.0076
	Land type	Elevation	0.0462	0.1163
		Land Use		
Environmental	Residential buffers	Dis. to an urban area	0.0539 *	0.0201
		Dis. to a rural area	0.0269	0.0100
		Dis. to wetland	0.0058	0.0423 *
	Protection buffers	Dis. to forests	0.0274	0.0060
		Dis. to airports	0.0476	0.0423 *
Economical	Proximity to market	Proximity to main roads	0.0257	0.0286
		Proximity to the transmission line	0.0772 *	0.0859 *
	Available potential area	Farm required area	0.2058 *	0.2293 *
* indicates the highest weighting factors			Sum = **1.000**	**1.000**

5.2 Highest weighting factors in this study

Based on the calculated weights, climate within the psychographic aspect was the most dominant criterion for both wind and solar having weights of 0.3940)39.4%(and 0.3578)35.78%(respectively, which complies with the findings of previous studies (Janke, 2010; Krewitt and Nitsch, 2003), as, resource availability is the most important step in planning of energy projects. The expert's opinion were in line with the literature based knowledge, therefore these outcomes signify the validity of both experts and the literature guidelines.

Farm required area within the economic aspect was the second most important criterion according to the experts and that was allocated weights of 0.2058)20.58%(and 0.2993)29.93%(for the cases of wind and solar respectively. This emphasis on a prior consideration of a reasonable area for utility-scale energy projects, otherwise its feasibility in the economic domain may be unprofitable. Because a heavy investment is required to construct energy projects, especially wind farms, therefore using up large amounts of money for small scope projects is pointless.

The experts assigned weights of 0.0772 (7.72%) and 0.0859 (8.59%) respectively for wind and solar in the case of the transmission line, therefore it emerged as the third most important criterion. Moreover, a buffer to urban areas was yet another significant criterion after the transmission line having a weight of 0.0539)5.39%) for the case of the wind farm, while for solar farms, buffers for wetlands and airports stood equally on weight scale i.e. 0.0423)4.23%(after the transmission line. This strengthens the information on public opposition related to these projects where solar farms receive comparatively less public opposition than wind farms.

5.3 Thematic maps produced against each criterion

The maps produced for each parameter using literature guidelines and experts' suggestions have been presented in Figure (s) (5.1 to 5.17) as under;

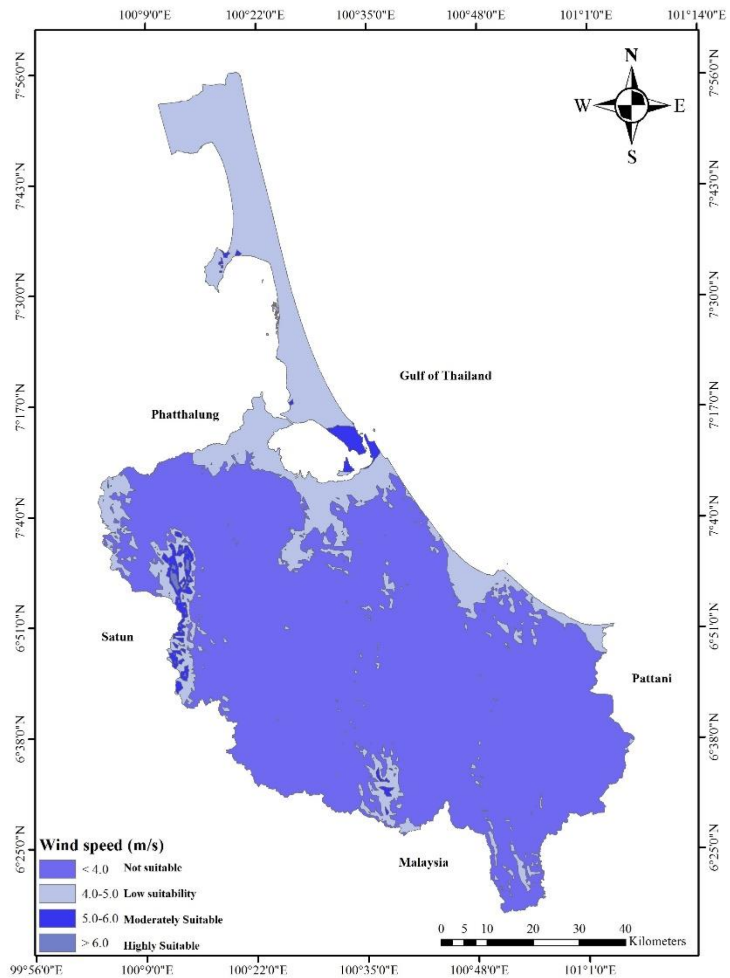

Fig. 5.1 Wind resource map for Songkhla Province, in this study.

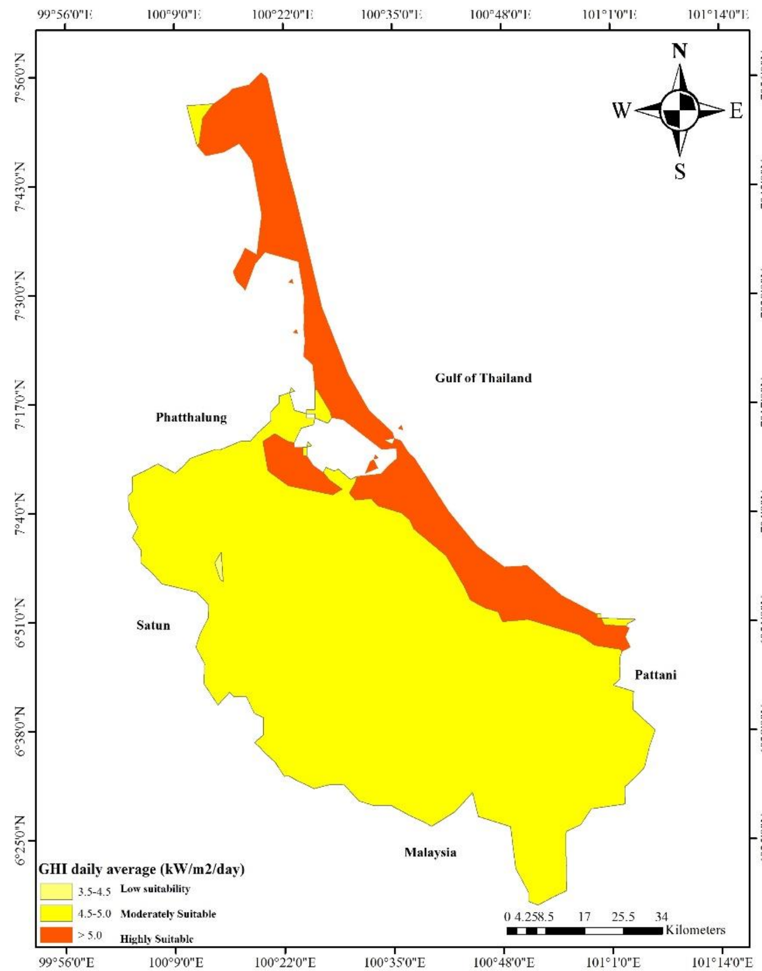

Fig. 5.2 Solar resource map (GHI) for Songkhla, in this study

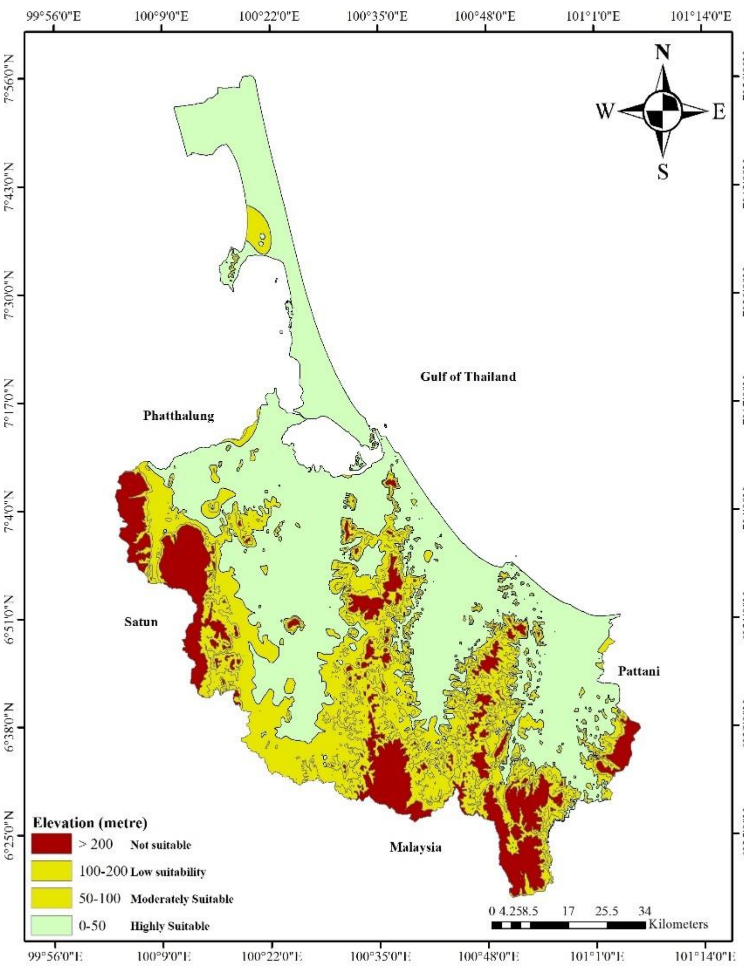

Fig. 5.3 Elevation map (both wind and solar cases)

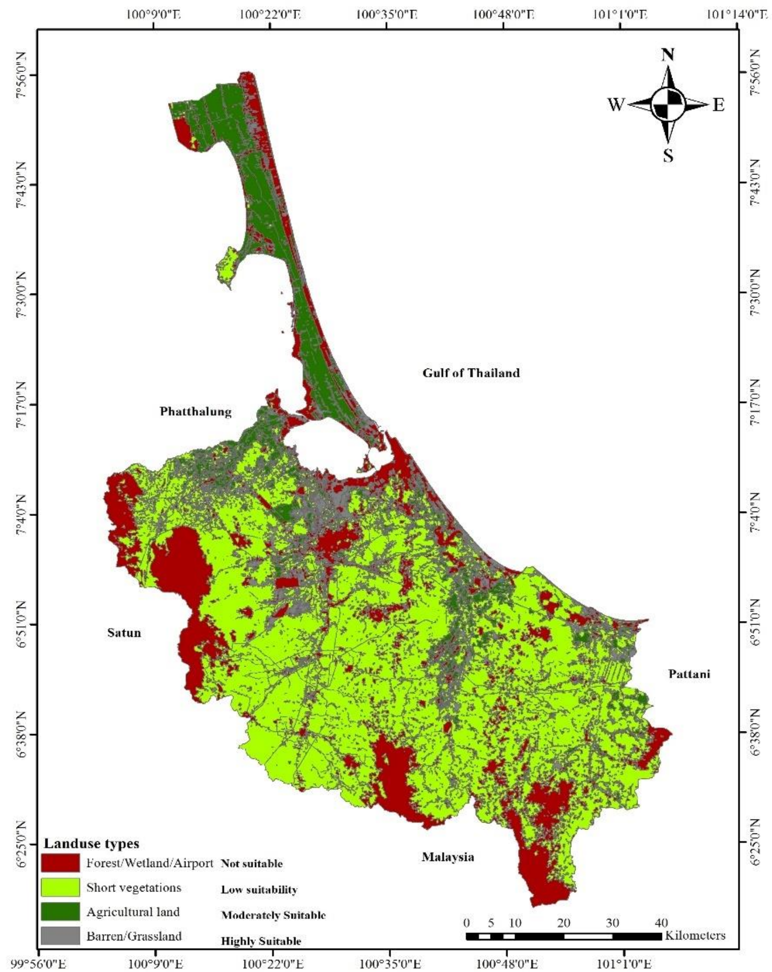

Fig. 5.4 Land use types (both wind and solar cases)

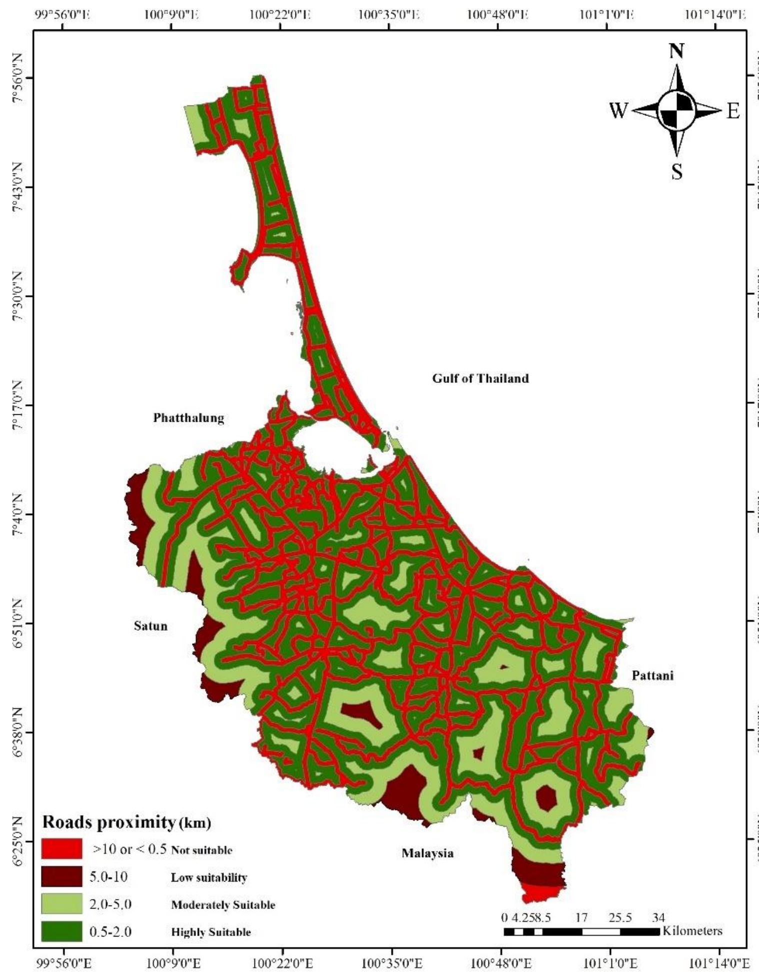

Fig. 5.5 Proximity to road networks

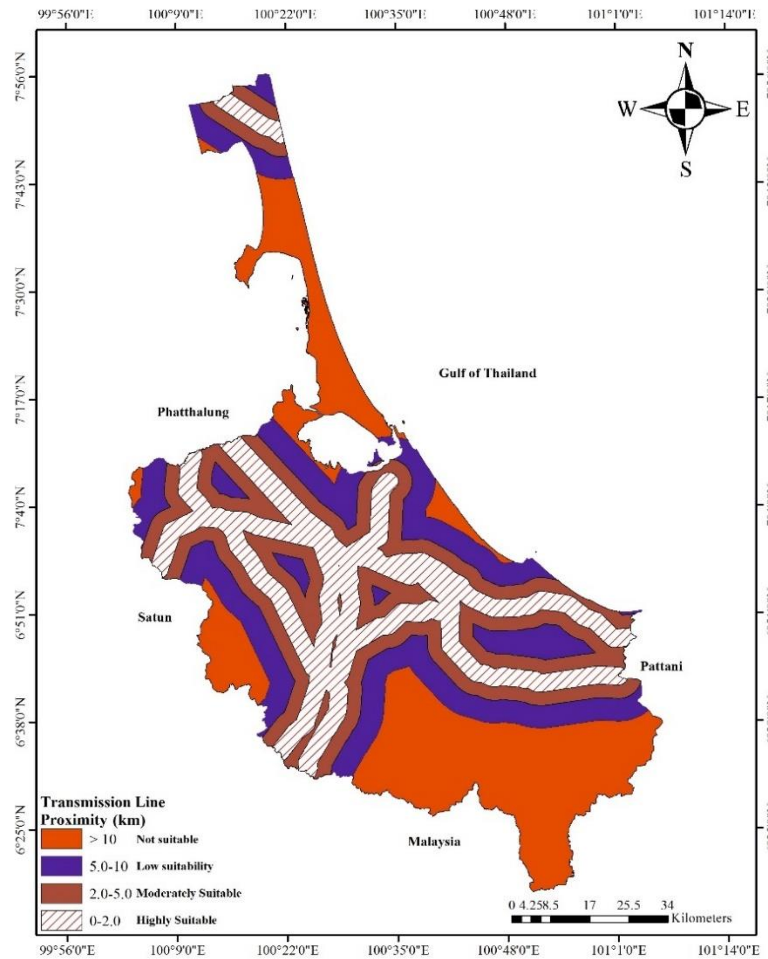

Fig. 5.6 Proximity to transmission lines

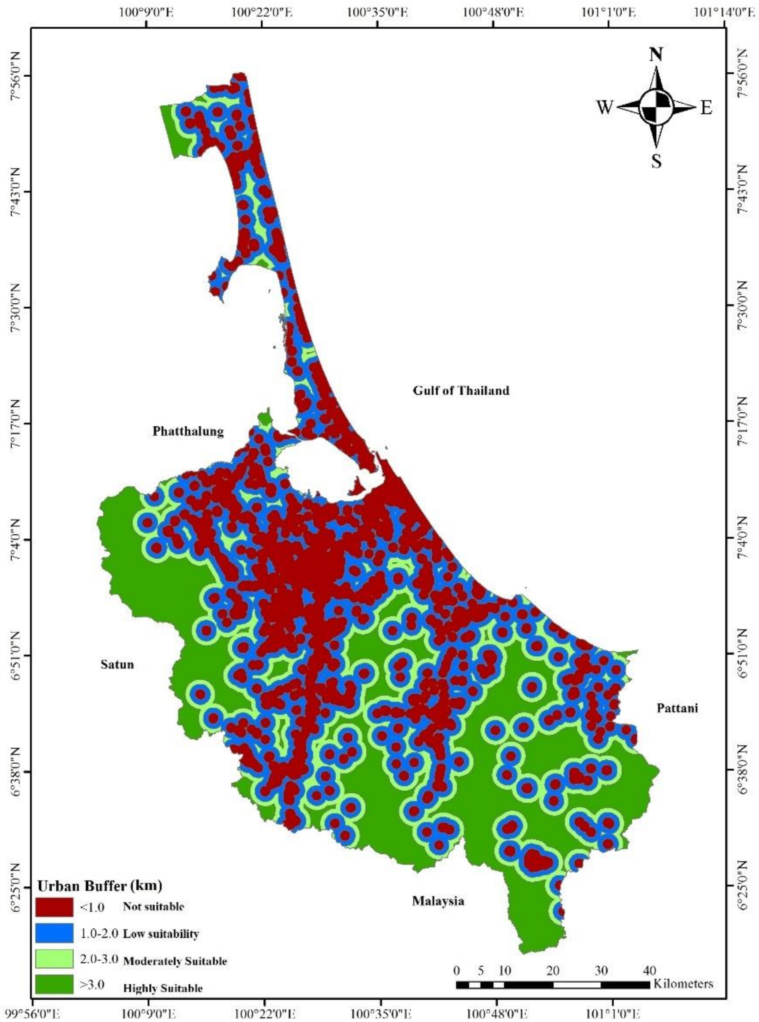

Fig. 5.7 Buffer to urban areas (wind case)

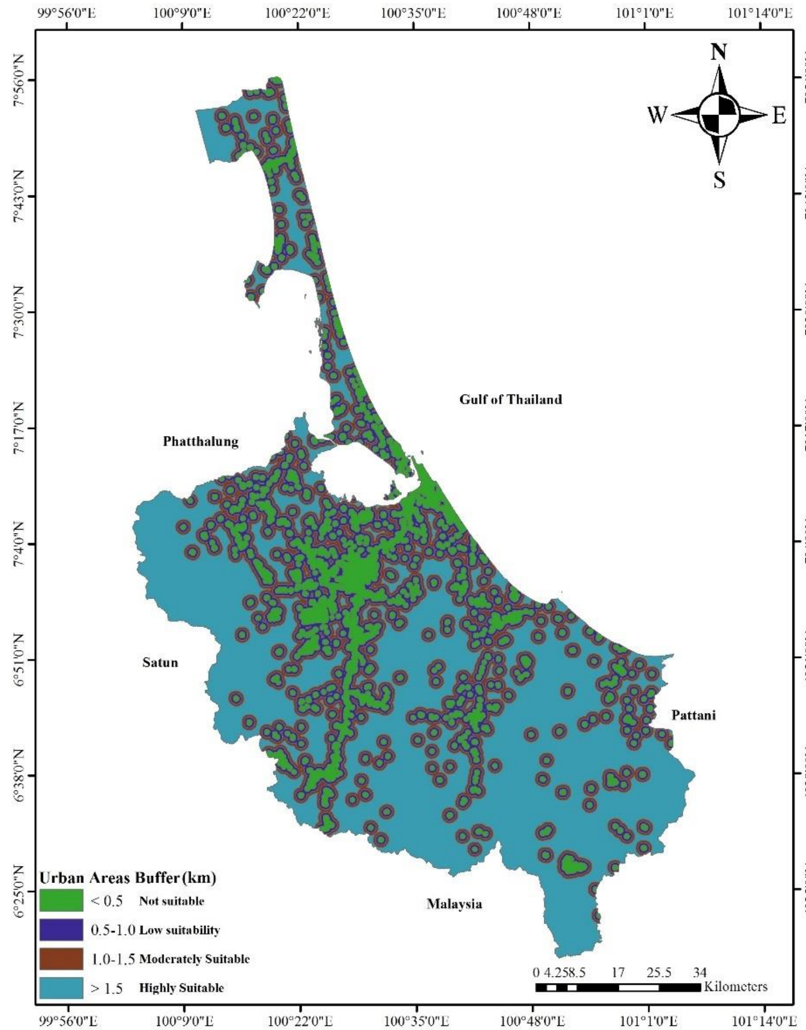

Fig. 5.8 Buffer to urban areas (solar case)

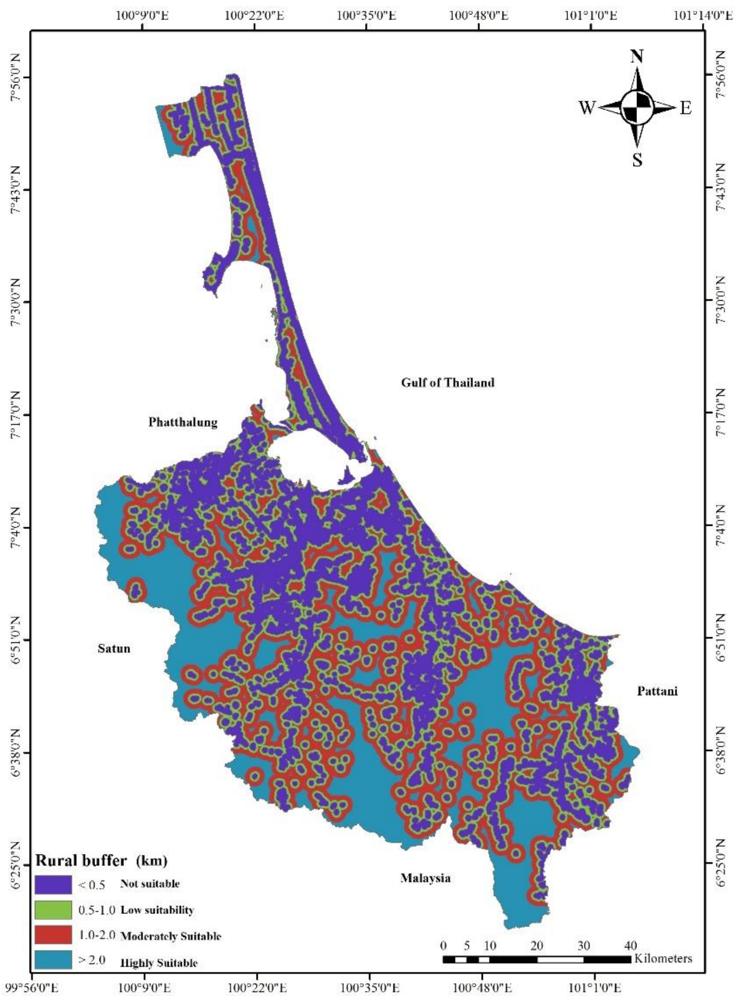

Fig. 5.9 Buffer to rural areas (wind case)

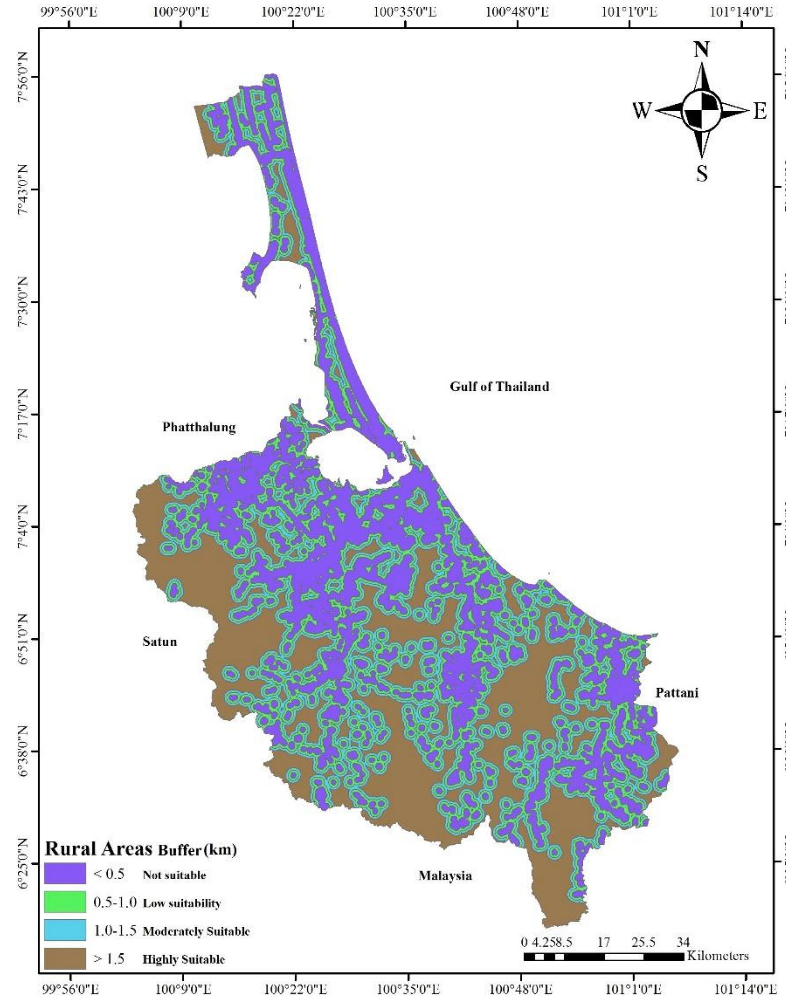

Fig. 5.10 Buffer to rural areas (solar case)

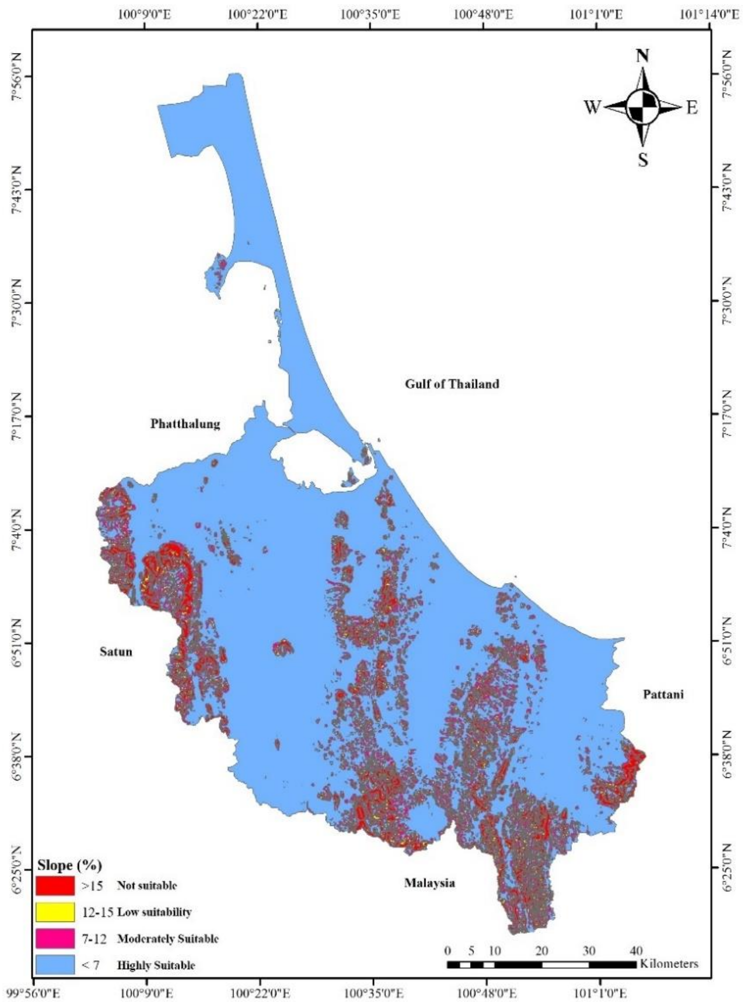

Fig. 5.11 Slope (wind case)

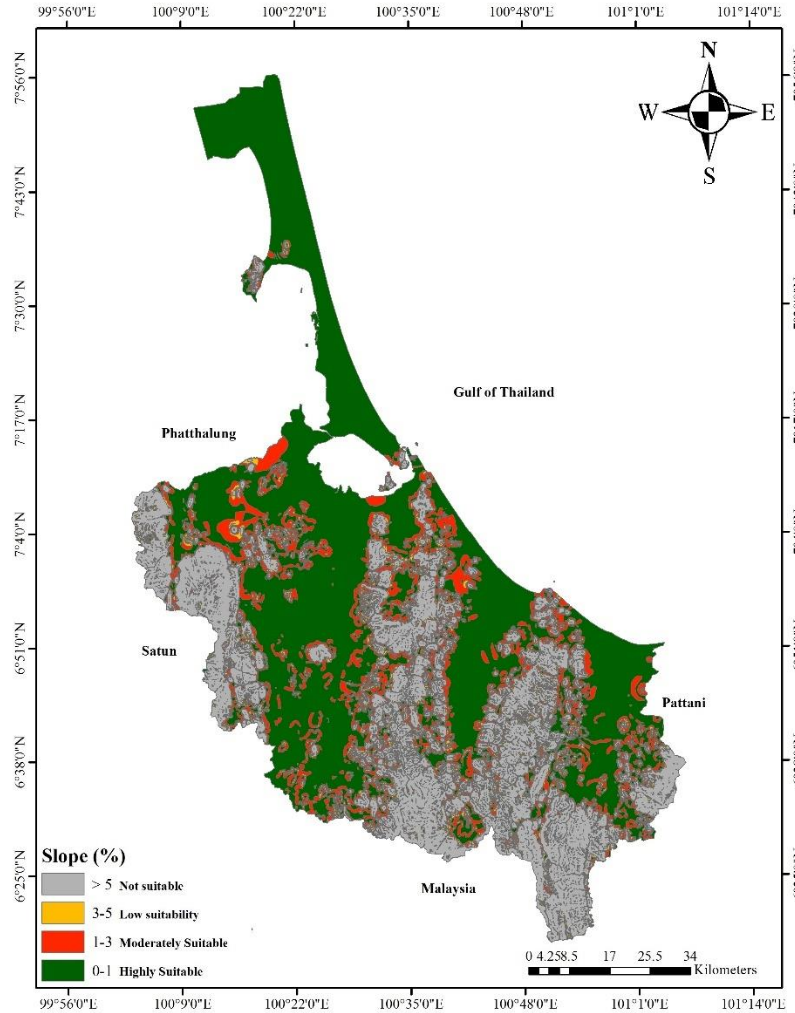

Fig. 5.12 Slope (solar case)

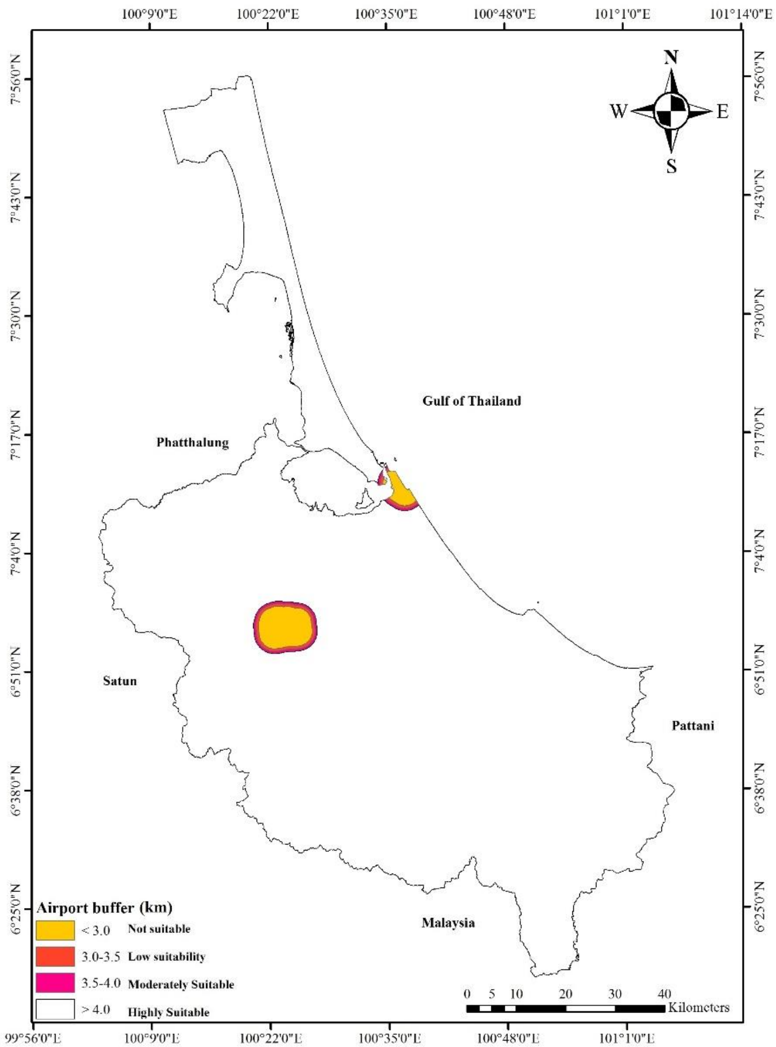

Fig. 5.13 Airport Buffer (wind case)

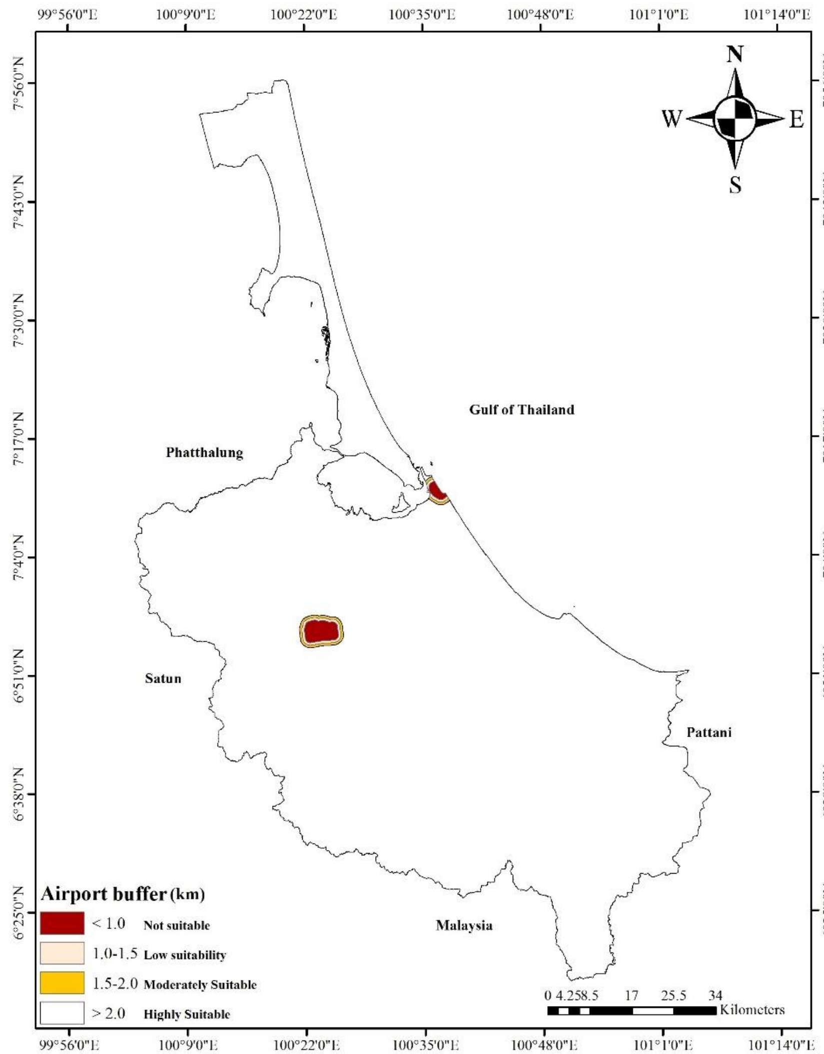

Fig. 5.14 Airport Buffer (solar case)

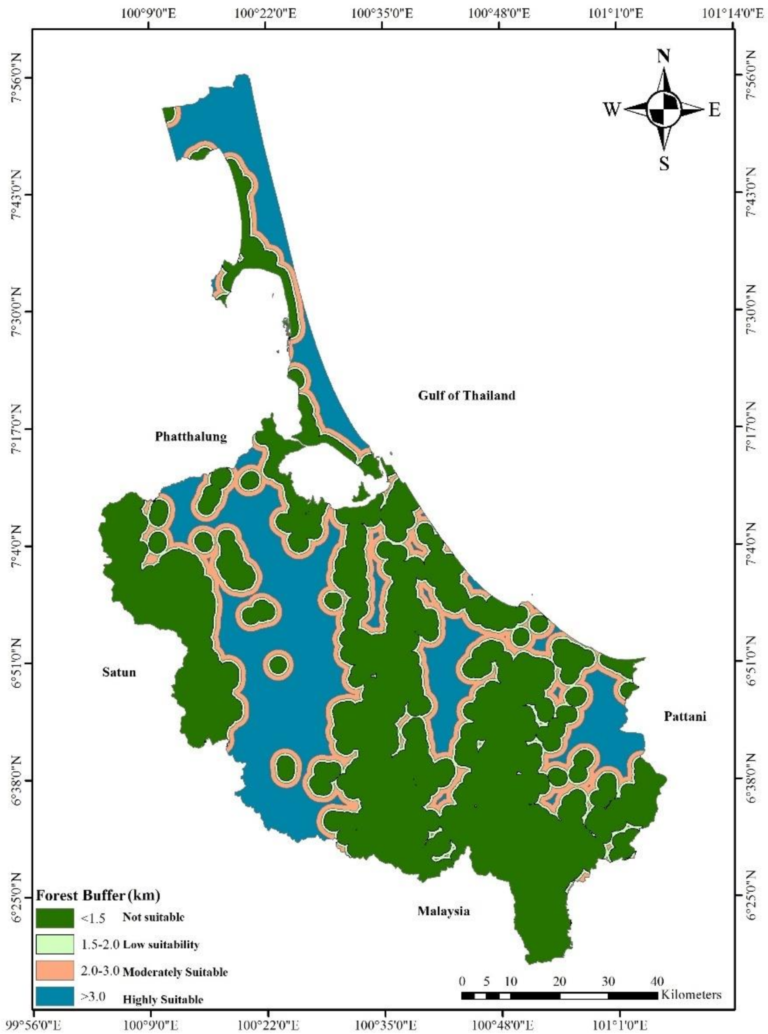

Fig. 5.15 Forest buffer (wind case)

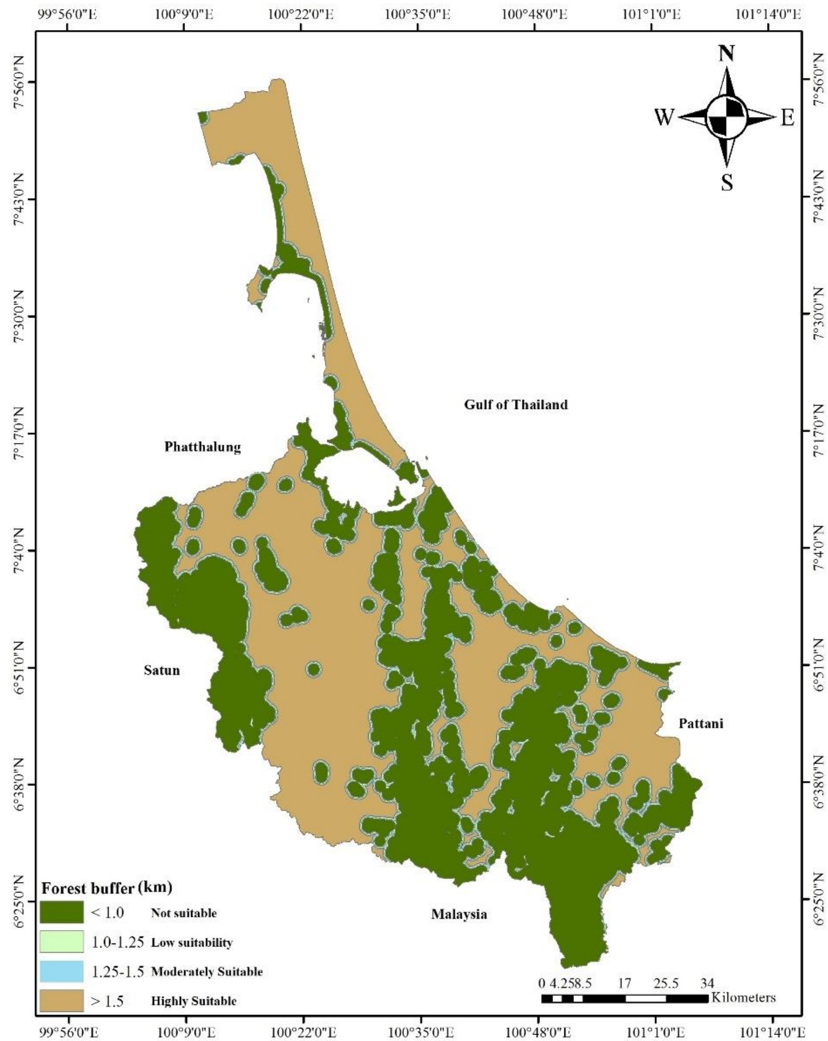

Fig. 5.16 Forest Buffer (solar case)

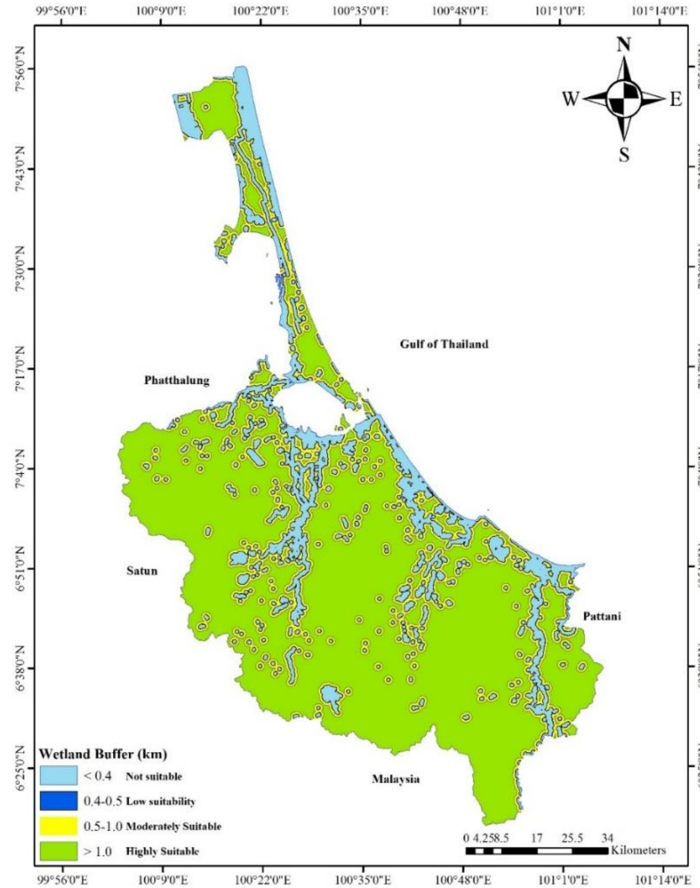

Fig. 5.17 Buffer to the wetland (both wind and solar cases)

5.4 Final suitability map for wind and solar farms

This study initially found potential areas 66.113 km^2 for wind and 844.93 km^2 for solar which contribute up to 0.89% and 11.42% respectively, of the total area of Songkhla Province which is 7,394 km^2. However, in the above-mentioned area, the limitations of required area for utility-scale farms were not considered. The acquired maps were categorized into four suitability classes as "highly suitable", "moderately suitable", "low suitability" and "not suitable", where, the "restricted areas" denotes the areas which were eliminated prior to the application of the farm required area criterion. The outcomes of the study clearly signify the obtainability of "highly suitable" areas for both wind and solar in northernmost district of Songkhla, known as Ranot. Fig. 5.18 presents the final suitability map for utility-scale wind farms and that of solar farms is presented in Fig. 5.19.

Of about 38.749 km^2 or 4.94% out of the total area of 783.8 km^2 of Ranot is identified as "highly suitable" for utility-scale wind farms, however, no area was detected in terms of "moderately suitable" land, it was for the reason that doesn't qualify the criterion of required farm area which has to be used for utility-scale purpose, and for solar power generation, 56.592 km^2 or 7.22% of the area of Ranot has the prospects of establishing utility-scale solar farms. Table 5.2 shows the numerical values of the remaining area's suitability and Fig. 5.20 compares the results of the assessment for wind and solar power in this study.

Table 5.2 Statistical distribution of suitable areas in each district of Songkhla Province (Ali et al., 2019).

District or Amphoe	Not Suitable[1] km²		Low Suitability km²		Moderately Suitable km²		Highly Suitable km²		Total km²	
	Wind	Solar	Wind	Solar	Wind	Solar	Wind	Solar	Wind	Solar
Bang Klam	0.113	4.447	---	6.47	---	4.611	---	---	0.113	15.528
Chana	2.508	15.895	---	10.708	---	34.34	---	1.144	2.508	62.087
Hat Yai	1.843	15.874	---	11.813	---	72.023	---	---	1.843	99.71
Khlong Hoi Khog	---	23.202	---	2.567	---	40.161	---	---	---	65.93
Khuan Niang	1.325	3.84	---	5.673	---	10.204	---	---	1.325	19.717
Muang Songkhla	0.038	1.171	---	0.665	---		---	---	0.038	1.836
Na Mom	---	8.196	---	1.374	---	5.355	---	---	---	14.925
Na Thawi	---	17.443	---	6.136	---		---	---		23.579
Ranot	11.709	3.015	4.687	7.016	---	2.848	38.749	56.529	55.145	69.408
Rattaphum	0.62	20.8	---	11.283	---	47.218	---	---	0.62	79.301
Sabayoi	---	23.816	---	5.507	---	0.031	---	---	---	29.354
Sadao	---	78.247	---	18.99	---	162.448	---	---	---	259.68
Thepha	4.521	41.229	---	19.827	---	30.445	---	11.836	4.521	103.33
Total in km²	22.677	257.175	4.687	108.029	---	409.684	38.749	69.509	66.113	844.39

[1] Not suitable in a view of the minimum area required to be used for utility scale wind and solar farms.

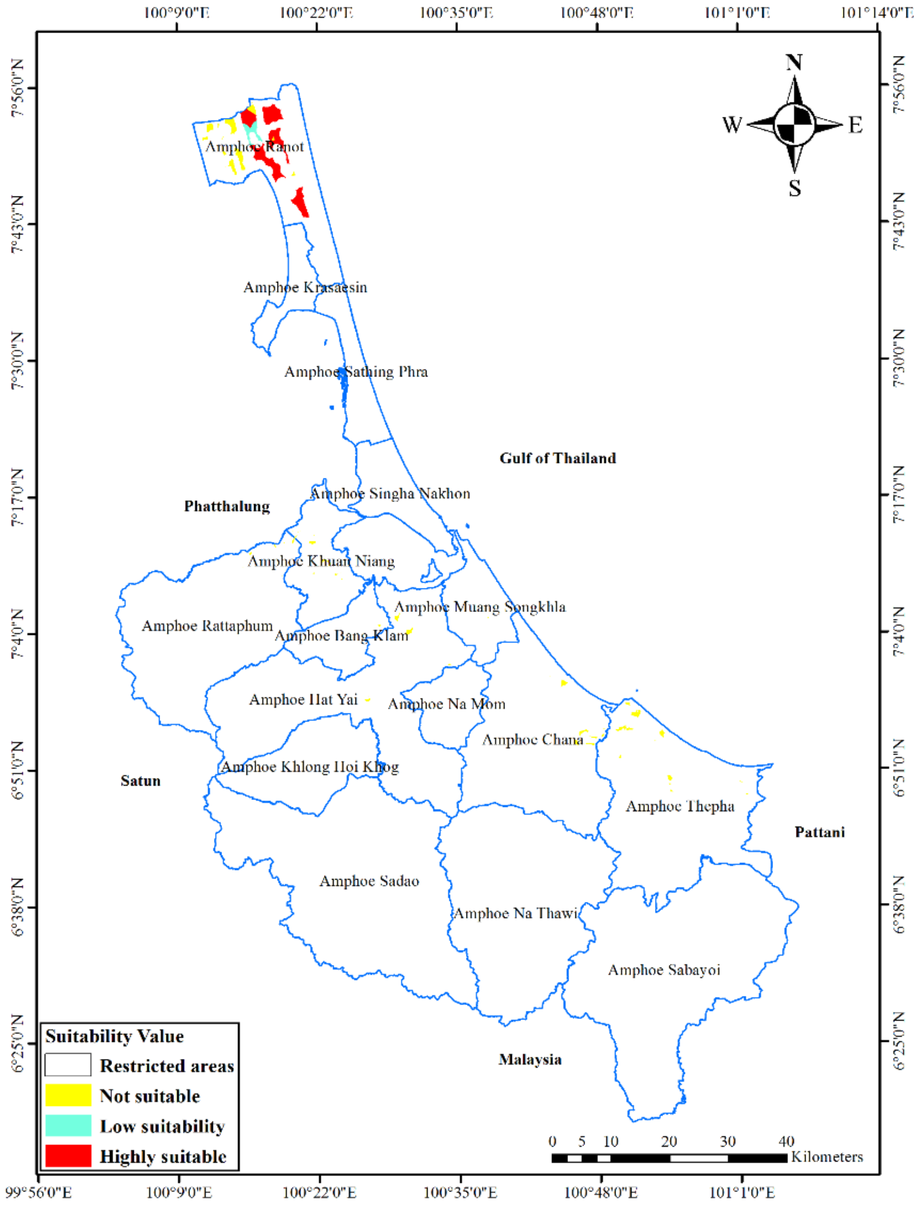

Fig. 5.18 Final suitability map for wind farms in Songkhla Province (Ali et al., 2019)

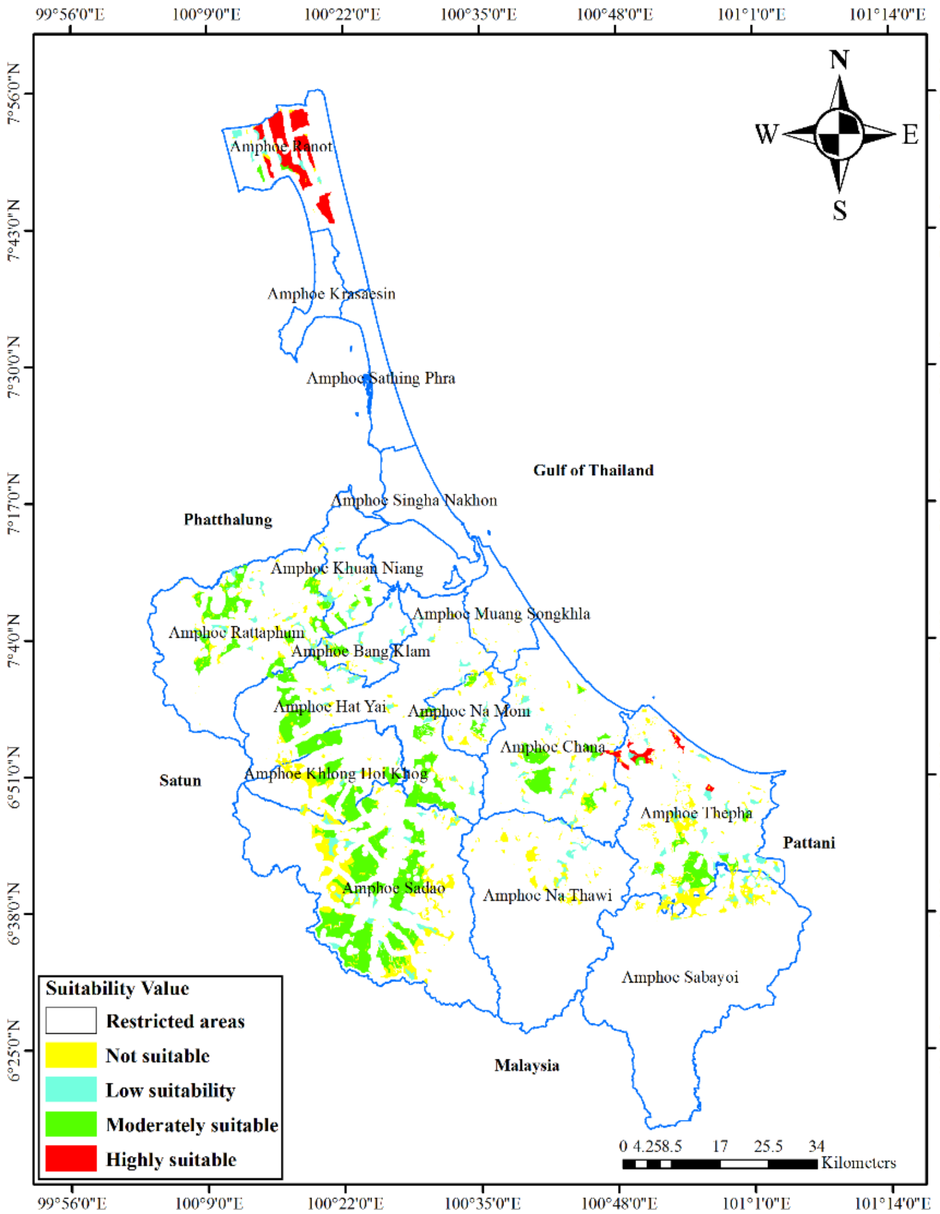

Fig. 5.19 Final suitability map for solar farms in Songkhla Province (Ali et al., 2019).

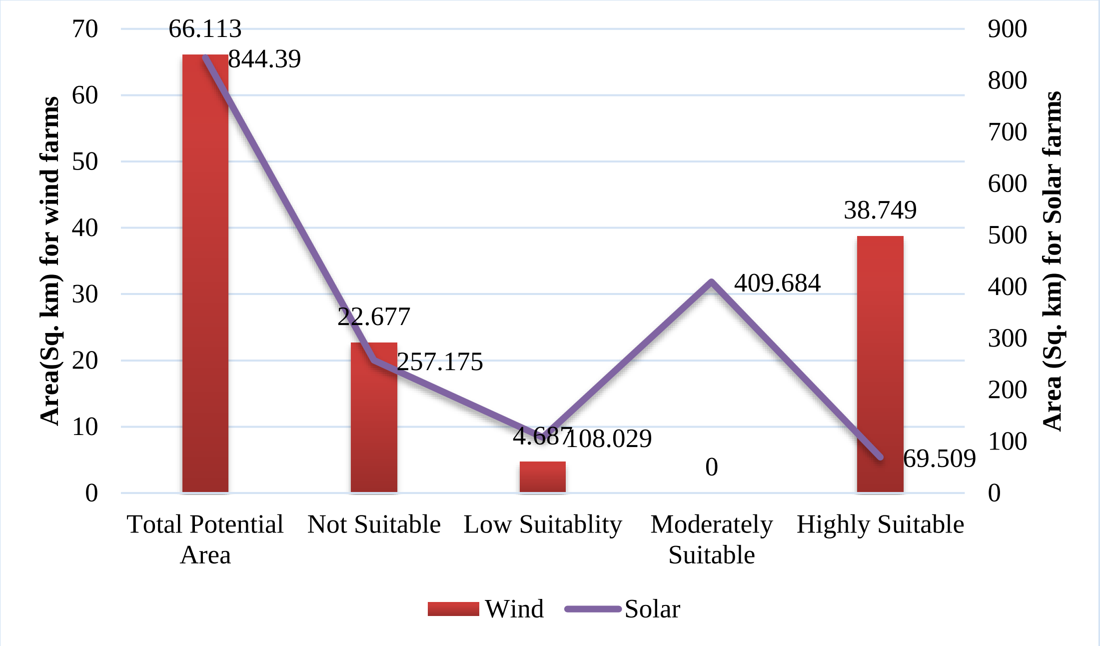

Fig. 5.20 Graphical interpretation of the results (both wind and solar) (Ali et al., 2019).

The results of studies such as this are highly dependent on the type of the criteria, which are selected, however, in this study, the criteria were scrutinized based on the previous literature which was additionally confirmed in consultation with the with the regional experts**.** One of the great discoveries of this study was to identify the Ranot District in Songkhla Province as the most ideal location for the construction of both wind and solar farms. Having both wind and solar farms nearby or together would be proving essential to mitigate the intermittency challenges related to renewable energy such as wind and solar, as they may act as a backup source to each other to ensure the reliable and sustainable energy supply.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

This study shows the identification of ideal locations for utility-scale wind and solar farms in Songkhla province, Thailand by the integrated use of the GIS-MCDM method. As the assessment of the ideal location is the prior task to be carried in any project such as energy applications. The MCDM approach is well known for solving the complex problems, thus solving the decision making complications and it works well with the GIS tool. In this study physiographic, environmental and economic parameter was investigated considering the previous studies and regional experts' and public opinions, as the later one helps to increase the significance of the study in social perspectives as well. AHP, which is a structured technique for analyzing in MCDM, was used to assess the weight and the importance of the selected criterions. The AHP based weights were then used to develop twelve thematic maps in GIS environment for wind and solar farms respectively, which were then overlaid to obtain the final suitability maps.

This study found that Ranot District has the most suitable locations for wind and solar farms, the remaining districts of the Songkhla province couldn't perform so well due to certain constraints to the set conditions in this study. Therefore, this study proposes to preserve Ranot district for the construction of renewable energy projects. This study also found that adjacent district to Ranot such as Karasae-Sin, Sathing-Phra and Singha-Nakhon, would have also *a* highly suitable area, however, the access to transmission lines appears as a major con*strai*nt. Dispersed informal settlements were observed in some locations around Ranot, Karasae-Sin, Sathing Phra and Singha-Nahkon, for which inves*t*igations may be required to evaluate how these dispersed settlements might interface with future energy developments.

To summarize, this study provides a scientific basis to resolve the complications associated with site selection in the wind and solar farms development in Songkhla Province. Therefore, this will prove integral in boosting the confidence of stakeholders to invest in solar and wind energies in Songkhla Province, which will be helpful to achieve Thailand’s aim of reducing the consumption of fossil fuels overall.

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APPENDICES

APPENDIX A

AHP weight calculation for wind farms.

Parameters	Weight Calculation					
	Physiographic	Environmental	Economic	Rank	Rank/Range Range=nk-n	Weight
Physiographic	1	3	2	6	0.428571429	0.52941176
Environmental	0.333333333	1	0.5	1.833333333	0.130952381	0.16176471
Economic	0.5	2	1	3.5	0.25	0.30882353
					0.80952381	1
	Wind speed	Topography	Land Use	Rank	Rank/Range	Weight
Wind speed	1	6	7	14	1	0.7443038
Topography	0.166666667	1	2	3.166666667	0.226190476	0.16835443
Land Use	0.142857143	0.5	1	1.642857143	0.117346939	0.08734177
					1.343537415	1
	Dis. WL	Dis. Forest	Dis. PA	Rank	Rank/Range	Weight
Dis. WL	1	0.2	0.142857143	1.342857143	0.095918367	0.07190209
Dis. Forest	5	1	0.333333333	6.333333333	0.452380952	0.3391127
Dis. PA	7	3	1	11	0.785714286	0.58898521
					1.334013605	1

	Municipality	Buffer	Rank	Rank/Range	Weight
Municipality	1	1	2	0.285714286	0.5
Buffer	1	1	2	0.285714286	0.5
				0.571428571	1

	Dis. Market	Potential Area	Rank	Rank/Range	Weight
Dis. Market	1	0.5	1.5	0.214285714	0.33333333
Potential Area	2	1	3	0.428571429	0.66666667
				0.642857143	1

	Slope	Elevation	Rank	Rank/Range	Weight
Slope	1	0.5	1.5	0.214285714	0.33333333
Elevation	2	1	3	0.428571429	0.66666667
				0.642857143	1

	Dis. UA	Dis. RA	Rank	Rank/Range	Weight
Dis. UA	1	2	3	0.428571429	0.66666667
Dis. RA	0.5	1	1.5	0.214285714	0.33333333
				0.642857143	1

	Dis. Road	Dis. T/L	Rank	Rank/Range	Weight
Dis. Road	1	0.333333333	1.333333333	0.19047619	0.25
Dis. T/L	3	1	4	0.571428571	0.75
				0.761904762	1

AHP weight calculation for solar farms.

Parameters	Weight Calculation					
	Physical	Environmental	Economical	Rank	Rank/Range Range=nk-n	Weight
Physical	1	4	2	7	0.5	0.53503185
Environmental	0.25	1	0.333333333	1.583333333	0.113095238	0.12101911
Economic	0.5	3	1	4.5	0.321428571	0.34394904
					0.93452381	1
	GHI	Topography	Land Use	Rank	Rank/Range	Weight
GHI	1	5	4	10	0.714285714	0.66889632
Topography	0.2	1	0.5	1.7	0.121428571	0.11371237
Land Use	0.25	2	1	3.25	0.232142857	0.2173913
					1.067857143	1
	Dis. WL	Dis. Forest	Dis. PA	Rank	Rank/Range	Weight
Dis. WL	1	7	1	9	0.642857143	0.46666667
Dis. Forest	0.142857143	1	0.142857143	1.285714286	0.091836735	0.06666667
Dis. PA	1	7	1	9	0.642857143	0.46666667
					1.37755102	1

	Municipality	Buffer	Rank	Rank/Range	Weight
Municipality	1	0.333333333	1.333333333	0.19047619	0.25
Buffer	3	1	4	0.571428571	0.75
				0.761904762	1

	Dis. Market	Potential Area	Rank	Rank/Range	Weight
Dis. Market	1	0.5	1.5	0.214285714	0.33333333
Potential Area	2	1	3	0.428571429	0.66666667
				0.642857143	1

	Slope	Elevation	Rank	Rank/Range	Weight
Slope	1	7	8	1.142857143	0.875
Elevation	0.142857143	1	1.142857143	0.163265306	0.125
				1.306122449	1

	Dis. UA	Dis. RA	Rank	Rank/Range	Weight
Dis. UA	1	2	3	0.428571429	0.66666667
Dis. RA	0.5	1	1.5	0.214285714	0.33333333
				0.642857143	1

	Dis. Road	Dis. T/L	Rank	Rank/Range	Weight
Dis. Road	1	0.333333333	1.333333333	0.19047619	0.25
Dis. T/L	3	1	4	0.571428571	0.75
				0.761904762	1

APPENDIX B

Online questionnaires used for experts' interviews in this research (Google forms)

9/18/2018 Research Questionnaire (Wind Farm) แบบสอบถามการวิจัย (ฟาร์มกังหันลม)

Research Questionnaire (Wind Farm) แบบสอบถามการวิจัย (ฟาร์มกังหันลม)

Questionnaire for Feasibility Study of Wind Power Plant [The study is for the high speed wind turbine above the height of 100 m] (Songkhla Thailand)

* Required

1. **Email address** *

Personal Details (ข้อมูลส่วนตัว)

The information is merely to keep record and to support the originality of research data collection. I assure you that your information will not be misused. (ข้อมูลนี้เป็นเพียงเพื่อเก็บบันทึก. มีความปลอดภัย)

2. **Name (ชื่อ):** *

3. **Qualification (คุณสมบัติ)** *
   Check all that apply.
   - [ ] PhD (ปริญญาเอก)
   - [ ] Masters (Researcher) (ปริญญาโท)
   - [ ] Professional Engineer (วิศวกร)
   - [ ] Other:

4. **Organisation (องค์กร)**

Parameters Selection Ranges (พารามิเตอร์)

Symbols: Equal or less than (≤), Equal or more than (≥), meter (m), Kilometer (km), meter per second (m/s), Square Kilometer (Sq. km)

5. **Wind Speed (ความเร็วลม)** *
   Mark only one oval.
   - ( ) ≥5 m/s (equal or more than)
   - ( ) Other:

https://docs.google.com/forms/d/1T1_-kDM_w3pJf-3eRi3w06H3y9-VRY4oC86NDGpUq2Q/edit 1/5

9/18/2018 Research Questionnaire (Wind Farm) แบบสอบถามการวิจัย (ฟาร์มกังหันลม)

6. **Slope (degree) (ลาด)** *

Mark only one oval.

- ( ) ≤15% (equal or less than)
- ( ) Other: ____________________

7. **Elevation (meter) (การยกระดับ)** *

Mark only one oval.

- ( ) ≤200 m (equal or less than)
- ( ) Other: ____________________

8. **Land Use (ประเภทที่ดิน)** *

Check all that apply.

- [ ] Agriculture (การเกษตร)
- [ ] Barren (ภัยแล้ง)
- [ ] Grassland (ทุ่งหญ้า)
- [ ] Other: ____________________

9. **Distance to Roads (both lower and upper limits)(ระยะทางไปยังถนน)** *

Mark only one oval.

- ( ) 500 m to 10 km (not less than 500 m (buffer) and not more than 10 km)
- ( ) Other: ____________________

10. **Distance to Transmission Line (ระยะห่างจากสายไฟฟ้า)** *

Mark only one oval.

- ( ) ≤20 km (equal or less than)
- ( ) Other: ____________________

11. **Distance to Urban Area (Buffer) (ระยะห่างจากตัวเมือง)** *

Mark only one oval.

- ( ) ≥2.0 km (equal or more than)
- ( ) Other: ____________________

12. **Distance to Rural Area (Buffer) (ระยะทางถึงหมู่บ้าน)** *

Mark only one oval.

- ( ) ≥1.0 km (equal or more than)
- ( ) Other: ____________________

13. **Distance to Forest (ระยะห่างจากป่า)** *

Mark only one oval.

- ( ) ≥1.5 km (equal or more than)
- ( ) Other: ____________________

https://docs.google.com/forms/d/1T1_-kDM_w3pJf-3eRi3w06H3y9-VRY4oC86NDGpUq2Q/edit 2/5

14. **Distance to Wet Land [rivers, lakes] (ระยะห่างจากพื้นที่น้ำ)** *
Mark only one oval.

- ◯ ≥400 m (equal or more than)
- ◯ Other: ____________________

15. **Distance to Protected Areas (Airport) (ระยะห่างจากสนามบิน)** *
Mark only one oval.

- ◯ ≥3.0 km (equal or more than)
- ◯ Other: ____________________

16. **Farm Required Area** *
Mark only one oval.

- ◯ ≥4.0 Sq. km (equal or more than)
- ◯ Other: ____________________

Select the priority level among the various parameters as under (เลือกคะแนนความสำคัญสำหรับพารามิเตอร์)

Scale is in between 1 to 9 (Note: 1= Lower Importance , 9= Higher importance) [Please select accordingly]
(1 มีความสำคัญต่ำกว่า) (9 มีความสำคัญมากขึ้น)

17. **Wind Speed (ความเร็วลม)** *
Mark only one oval.

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

18. **Slope (ลาด)** *
Mark only one oval.

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

19. **Elevation (การยกระดับ)** *
Mark only one oval.

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

20. **Land Use (ประเภทที่ดิน)** *
Mark only one oval.

1	2	3	4	5	6	7	8	9

21. **Distance to Roads (ระยะทางไปยังถนน)** *
Mark only one oval.

1	2	3	4	5	6	7	8	9

22. **Distance to Transmission Line (ระยะห่างจากสายไฟฟ้า)** *
Mark only one oval.

1	2	3	4	5	6	7	8	9

23. **Distance to Urban Areas (ระยะห่างจากตัวเมือง)** *
Mark only one oval.

1	2	3	4	5	6	7	8	9

24. **Distance to Rural Areas (ระยะทางถึงหมู่บ้าน)** *
Mark only one oval.

1	2	3	4	5	6	7	8	9

25. **Distance to Wet Land (ระยะห่างจากพื้นที่น้ำ)** *
Mark only one oval.

1	2	3	4	5	6	7	8	9

26. **Distance to Forest (ระยะห่างจากป่า)** *
Mark only one oval.

1	2	3	4	5	6	7	8	9

27. **Distance to Protected Areas (Airports) (ระยะห่างจากสนามบิน)** *

Mark only one oval.

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

28. **Farm Required Area**

Mark only one oval.

1	2	3	4	5	6	7	8	9
◯	◯	◯	◯	◯	◯	◯	◯	◯

29. **Any Comment/Suggestion which is important to know (Please suggest) (ข้อเสนอแนะใด ๆ ที่สำคัญ)**

Thank you so much for your valuable time (ขอบคุณมากสำหรับเวลาของคุณ).

Warm Regards
Shahid Ali/Research Candidate
TEH-AC Scholar, PSU (Hatyai) Thailand.
Email: shahid_maidi@hotmail.com
Contact:(+66)654930800

A copy of your responses will be emailed to the address you provided

Note: Similar questionnaires were used for the solar case.

APPENDIX C

Questionnaires used to collect public opinions during face to face meetings to Hua Sai Wind Farm

Sr. No code	Theme	Questions	Response			
			Code	Description	Code	Description
1	Visual contact	Do you see wind turbines from your home?	0	NO	1	YES
2	Noise volume	How do you evaluate the noise produced by wind turbines?	1	Very Unpleasant	5	Very pleasant
3	Attitude	How do you evaluate the existing wind farm?	1	Very negative	5	Very Positive
4	Information	How much are you aware of wind turbine benefits?	0	Very low	5	Very high
5	Approval	Were you asked before installation of an existing wind farm?	0	NO	1	YES
6	liabilities	Do you consider the firms are responsible for compensation in case of accidents?	0	NO	1	YES
7	Cheap electricity	Do you think that wind farms generate electricity at a cheap rate?	0	NO	1	YES
8	Proper Planning	Do you think proper planning is necessary for new investments?	0	NO	1	YES
9	Climate Change	Do you consider climate change is a real challenge?	0	NO	1	YES
10	Clean energy	Do you believe wind turbine helps to avoid pollution?	0	NO	1	YES
11	Visual intrusion	Do you consider wind turbines are disturbing to your visuals?	0	NO	1	YES
12	Affect livestock	Do you consider that wind farms affect livestock?	0	NO	1	YES
Further comments (based on personal observations)						

APPENDIX D

Published Papers (as a first author)

1. RENEWABLE ENERGY – JOURNAL ELSEVIER (Impact Factor 4.98; Indexing ISI Web of Science)

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GIS based site suitability assessment for wind and solar farms in Songkhla, Thailand

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A B S T R A C T

The objective of this study was to identify ideal sites to locate utility-scale wind and solar farms in Songkhla, a province in southern Thailand. Geographic Information System (GIS) and analytical hierarchy process (AHP) were used to assess various physiographic, environmental and economic siting criteria. The data used in this work were primarily obtained from governmental organizations. Additionally, a Global Horizontal Irradiation (GHI) solar map with a spatial resolution of 1 km/pixel for the years 2007–2015 was obtained from Solargis as well as a 200 m resolution wind resource map of 100 m above ground level obtained from previous research conducted in the study area. The results of the study indicate that Songkhla has potential land areas of up to 66.113 km^2 and 844.93 km^2 available for wind and solar farms respectively, though only areas of 38.749 km^2 and 69.509 km^2 respectively were judged as being "highly suitable". Most of these highly suitable areas were located in the Ranot District. The results of this study provide an important starting point for stakeholders interested in investing in renewable energy in Southern Thailand. Knowledge of the suitability of sites will provide a greater level of confidence and therefore likely expedite the renewable energy investment process.

1. Introduction

Energy plays a leading role in the economic and industrial growth of the entire world [1,2]. Fossil fuels have been the primary source of energy traditionally used by all countries on which the, International Energy Agency (IEA) reported in 2015 [3], noting that fossil fuels fulfill 80% of energy demand worldwide and are responsible for 90% of energy related emissions in the form of CO_2. Rising environmental concerns, depleting reserves and high energy prices have driven the search for renewable energy options [4,5] of which wind and solar energy are the best-known, with mature technologies, the use of which is rapidly expanding around the world [2,6–8].

Thailand's energy scenario is not as such different to that in other countries with demand increasing yearly. In 2012 the electricity generated in Thailand was 32600 MW [7,9] which had increased to 42163 MW by October 2017 (EPPO, 2017), with, over 67% being produced from natural gas [10]. Thailand's Ministry of Energy power development plan 2010 (PDP 2010) predicted that the net installed capacity of electricity generation in Thailand will reach 70,868 MW by 2030 [11]. However, the Alternative Energy Development Plan (AEDP) for Thailand, aims to replace fossil fuels up to 30% by 2036 under PDP 2015–2036 [12]. This objective

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[1] Not suitable in a view of the minimum area required to be used for utility scale wind and solar farms.

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Assessment of land use suitability for natural rubber using GIS in the U-tapao River basin, Thailand

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ABSTRACT

The assessment of available land resources for crops is an essential step in achieving sustainability in agricultural development. Thailand has been the world's leading rubber producing country since the 1990s. This research was conducted to assess the land use suitability for rubber trees in the U-tapao River basin. A geographical information system and multi-criteria decision making were used in parallel to establish the suitability of land for use as rubber plantations in accordance with the Food & Agriculture Organization framework. Various bio-physical and socio-economic factors were considered together with expert opinion. The weighting of each factor was conducted using an analytic hierarchy process. This study concluded that 14.46 percent of the basin area was highly suitable for rubber, 84.48 percent was moderately suitable, and the remainder was less suitable or unsuitable for the cultivation of rubber. This research will facilitate designing agriculture policies for sustainable agriculture development of the region.

Introduction

In Asia, especially in the Southeast Asian region, countries like Thailand, Malaysia and Indonesia have dominated global rubber cultivation over the last five decades (Somboonsuke, 2001). Thailand has been the world's leading rubber producing country since 1995, with an annual increase of 4–7 percent per year (Somboonsuke, 2001). Rubber is, therefore, one of the most important cash crops in Thailand and also has socio-economic importance owing to its productive value, the income from exports, and the job opportunities in this sector (Jawjit, Kroeze, & Jawjit, 2010). Rubber plantations dominate forest areas throughout Thailand where, the total planted area of rubber has increased by 1.71 percent per annum with an almost three-fold increase during the last four decades (Viswanathan, 2007). Compared to other parts of Thailand, the southern region has a higher concentration of rubber plantations, with 1,708,800 ha, or 84.62 percent of the total rubber planting area in Thailand situated in the region (Krukanont & Prasertsan, 2004). Within the southern region, Songkhla province has the highest density of rubber plantations covering 66.58 percent of the total planted area of the region. Since, the climate of the southern region is tropical (Khedari, Sangprajak, & Hirunlabh, 2002), it is highly suitable for rubber. Therefore, the area devoted to rubber plantations has been increasing rapidly accompanied by improving living standards among the local people (Simien & Penot, 2011; Somboonsuke, 2001).

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APPENDIX E

Conferences Certificates

CERTIFICATE

Faculty of Environmental Management, PSU and Research and Development Centre, Nepal present the certificate to

Shahid Ali, Saroj Gyawali, Juntakan Taweekun, Kuaanan Techato

as

Presenter/Presenters

For the paper entitled

Evaluation of Land Use Suitability of Natural Rubber by Using Geographic Information Systems (GIS) in U-tapao River Basin, Thailand

International Conference on Sustainable Energy Management for Climate Change Adaptation and Mitigation on August 17th, 2017 at Siam Oriental Hotel Hat Yai, Songkhla, Thailand

Assoc. Prof. Dr. Banchong Witthayawirasak
Dean, Faculty of Environmental Management

Asst. Prof. Dr. Kuaanan Techato
GSEM2017 Training Director

Dr. Saroj Gyawali
Chair of the International Conference

CERTIFICATION OF ATTENDANCE

This certifcate is awarded to

Shahid Ali

for presentation on

"A Multi-Criteria Evaluation approach to delineation of suitable areas for forest"

in ASSURING SUSTAINABILITY via University with Research: Towards a sustainable development (ASSURE 2018) International Conference

23th January 2018
Ranong Room Siam Oriental Hotel
Hatyai, Songkhla, Thailand

Assoc. Prof. Dr. Banchong Witthayawirasak
Dean, Faculty of Environmental Management
Prince of Songkla University

VITAE

Name SHAHID ALI

Student ID 5910920048

Educational Attainment

Degree	Name of Institution	Year of Graduation
Bachelor of Science (B.S) in Electrical (Power) Engineering	COMSATS Institute of Information Technology, Abbottabad, Pakistan	2016

Scholarship Awards during Enrolment

1. Thailand Education Hub for ASEAN Countries (TEH-AC) Grant No. TEH-AC Contract no. 104/2016
2. Received fellowship of ProSPER.Net 2018 Young Researcher's School Scholarship - Kanagawa, Tokyo Japan hosted by United Nation University – IAS (UNU-IAS) during March 2018.

Work – Position and Address

1. Trainee Electrical Engineer in Water and Power Development Authority (WAPDA) on Sadpara Hydro-power Project, during April 2016-December 2016 (9 months)
2. Internship as an Electrical Engineer in Sitara Energy Ltd. Faisalabad Pakistan during January 2016 – March 2016 (3 months)

List of Publication and Proceeding

Journal Publications

(As the first author)

1. Shahid Ali[a], Juntakan Taweekun[c], Kuaanan Techato[b], Jompob Waewsak[d], Saroj Gyawali [d] : "GIS based site suitability assessment for wind and solar farms in Songkhla, Thailand" - Renewable Energy https://doi.org/10.1016/j.renene.2018.09.035 (Impact factor 4.9; ISI Web of Science)
2. Shahid Ali[a], Kuaanan Techato [b], Juntakan Taweekun [c], Saroj Gyawali [d]: "Assessment of land use suitability for natural rubber using GIS in the U-tapao River basin, Thailand" - Kasetsart Journal of Social Sciences https://doi.org/10.1016/j.kjss.2018.07.002 (SCOPUS)

(As Co-author)

1. Applied Ecology and Environmental Research http://dx.doi.org/10.15666/aeer/1602_17671781 (ISI)

Conference proceedings

1. Shahid Ali[a]: "MCDM approach to delineate a suitable area for the forest" at Assuring Sustainability via University with Research: Towards a sustainable development (ASSURE 2018) International Conference, 23 January, Ranong Room Siam Oriental, Hotel, Hat Yai, Songkhla, Thailand
2. Shahid Ali[a], Saroj Gyawali [b], Juntakan Taweekun [c], Kuaanan Techato [d]: "Evaluation of land use suitability for natural rubber by using Geographic Information System (GIS) in U-tapao river basin Thailand" at International Conference on Sustainable Energy Management for Climate Change Adaptation and Mitigation on August 17th, 2017 at Siam Oriental, Hotel, Hat Yai, Songkhla, Thailand.

3. Shahid Ali[a], Kuaanan Techato[b], Juntakan Taweekun[c], Adul Bennui[d]: "Expected wind power generation capacity in Songkhla Thailand" at International Conference on Energy Systems and Environmental Management (ESEM) 2018 on 22nd June 2018, at Hat Yai, Thailand.

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