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Assessment of solar and wind energy potential in Far North Queensland, Australia

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Abstract

The study aims at selecting suitable sites for solar and wind power developments in remote areas of Far North Queensland (FNQ), Australia. A Geographical Information System (GIS) based multi-criteria approach has been introduced to map potential locations for solar and wind, considering various aspects such as climatic, technical, topography, social, environmental, and economic. The potential of solar and wind energy in suitable land areas has been assessed based on the technologies and site conditions. Analysis of the present study shows that the total suitable areas in selected regions are 57,705.46 km^2 (70.56% of total selected land areas) with a power potential of 5,956.14 GW for solar and 58,482.79 km^2 (71.51% of total selected land areas) with a power potential of 421.12 GW for wind energy developments. In addition, the study shows that Carpentaria shire has the highest suitable area of 45,689.55 km^2 for solar and 46,115.27 km^2 for wind, while Injinoo shire has the lowest implementable area of 105.74 km^2 for solar and 137.75 km^2 for wind. This study provides a significant pathway for parties interested in investing in renewable energy in FNQ.

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Keywords: Renewable energy; Solar; Wind; Power potential

1. Introduction

Rural communities in Far North Queensland (FNQ), Australia are living in very unsustainable ways. At present, they are heavily dependent on diesel generators for basic energy needs [1], but diesel is associated with continuous price fluctuations and climate pollution [2]. A truck or ship is also required to transport diesel fuel to remote areas. Fuel reservation on-site is essential because power demand can be higher than expected or the area can be cut off

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by any weather event. On the other hand, local renewable resources can enable remote communities to reduce their power costs, reduce energy losses during transport, and have a secure and consistent power supply with diminished carbon emissions due to less or no diesel use. It can also create opportunities for local economic development and provide independence from increasingly depleting energy resources [3].

Solar and wind resources have the bright potential for the development of sustainable pathways in FNQ. Solar photovoltaic (PV) and wind power have proven to be good commercial pairing. This is because solar and wind can complement one another and thus mitigate the adverse effects of intermittent production and utilisation of renewable resources [4]. Solar and wind power do, however, pose some challenges, despite their many advantages, both economically and environmentally. The most concern is wind technology's visual intrusion and noise nuisance, while solar technology has issues of land degradation and habitat loss [5,6]. A careful assessment of the location, however, can mitigate such issues [7].

Geographical Information System (GIS) has recently appeared as the most convenient and proficient tool for assessing renewable energy potentiality [8]. GIS-based analyses are useful for characterising spatial data in a digital environment and producing informative visualisations. The present study has novelty that it explores potential locations for developing solar and wind energies by the multi-criteria GIS modelling techniques and calculates solar and wind power potential for regional FNQ. The multi-criteria GIS technique has never been used so far to identify suitable renewable energy locations in remote areas of FNQ.

2. Materials and methods

FNQ is the northernmost part of Queensland in Australia, having an area of 3,80,748.3 square kilometres. In this study, seven remote areas from FNQ such as Carpentaria, Doomadgee, Mornington, Kowanyama, Pormpuraaw, Aurukun, and Injinoo have been selected for applying GIS-based multi-criteria approach to determine solar and wind energy potential areas.

Fig. 1 shows the geographical location of the selected regions with highlighting every region's boundary by different colours. Every selected region's boundary and the name is being highlighted by the same colour. ArcMap 10.8.1 (developed by Esri in the United States of America) is used for GIS-based analysis. The topographical data in Table 1 are all extracted from different digital databases. Unsuitable locations have been omitted using ArcGIS tools. Firstly, a data management toolbox is utilised for projecting all GIS data layers (vector and raster) on a similar coordinate system, a project tool for vector data, and a project raster tool for raster data. Then different GIS activities have been conducted for each layer to fulfil the renewable energy development criterion, as described below:

- Land cover information and digital elevation data for selected areas are extracted using the global land use land cover model and digital elevation model respectively.
- Slope model creation from extracted elevation model.
- Reclassification of elevation, slope, and land cover models to exclude unsuitable land.
- Application of suitable buffer to water bodies, urban and built-up areas, protected areas, road, and rail networks.
- Excluding unsuitable sites from reclassified land cover to generate a final map of potential areas.

After preparing the final suitable map, the clip tool is used for extracting the suitable land of selected areas with the aid of the administrative boundary of Australia. Then, the suitable land area in the selected regions is attained by computing their geometry in the attribute table. Based on the suitable land-use factors, the maximal limits of solar and wind power generation capacity are ascertained for each selected region that reveals the power potential of renewable energy.

2.1. Site screening criteria

The site screening to identify a suitable place for solar or wind farm is influenced by various aspects such as climatic, technical, topography, environmental, economic, social, etc. It is important that the area has a suitable climate. Central and Northern Queensland including FNQ are receiving the highest amount of solar irradiation in the globe [9]. The sunny climate and latitude of FNQ show promising potential for a solar energy system. Solar radiation of 4 kWh/m^2/day is the minimum limit for any area to be potential for solar power development [10].

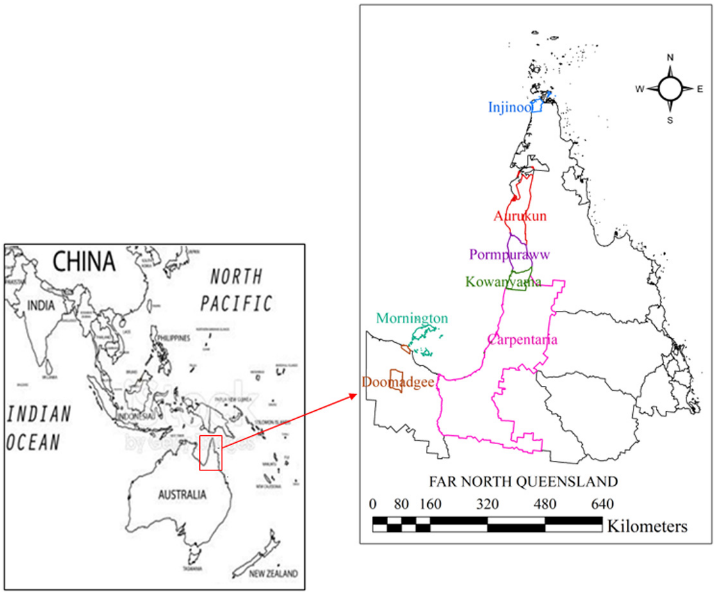

Fig. 1. The geographical position of the selected regions. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1. Data for GIS operations.

Data	Type of data	Source	Spatial resolution
Administrative boundary	Vector	GADM, version 1.0 [11]	–
Water bodies	Vector	DIVA-GIS [11]	–
Protected sites	Vector	WDPA [12]	–
Airports	Vector	Data Share [13]	–
Urban and rural built-up area	Vector	SEDAC [14]	–
Rail and road network	Vector	DIVA-GIS [11]	–
Land use land Cover	Raster	GlobCover [15]	10 arcsec
Digital elevation model	Raster	CGIAR SRTM [11]	30 s

Fig. 2 depicts the monthly mean daily global horizontal solar irradiation in the selected remote areas of FNQ for 32 years (from 1990 to 2021). Solar radiation in the selected areas of FNQ varies from 4.5 kWh/m^2/day to 7.5 kWh/m^2/day [16]. Fig. 2 shows that the annual average solar radiation for selected regions such as Injinoo, Pormpuraaw, Carpentaria, Aurukun, Kowanyama, Doomadgee, and Mornington are 5.77, 6.00, 6.12, 5.93, 6.06, 6.12, 6.18 kWh/m^2/day respectively. It is also seen that Mornington Island peaked in November recording 7.3 kWh/m^2/day. Doomadgee and Injinoo have shown peak at 7.1 and 6.7 kWh/m^2/day respectively in October and November. On the other hand, Aurukun, Carpentaria, and Kowanyama have recorded a maximum of 7.2 kWh/m^2/day in October, followed by Pormpuraaw at 7.1 kWh/m^2/day. In addition, the annual average daily sunshine duration is 7 to 8 h here in FNQ. So, all selected areas can be considered climatically suitable and included for solar analysis in this study.

In the context of wind energy, wind speed is a crucial criterion for wind power development. FNQ experiences winds ranging from 5.6 m/s to 10 m/s at 80 m above ground level [17]. The minimum threshold for mean daily wind velocity used in a previous study was 4 m/s [18] for wind power development. Furthermore, the mean operational cut in velocity is 3 m/s for the Vestas V117-3.45, horizontal axis wind turbine, which is used at Mount Emerald wind farm in Arriga, FNQ, Queensland, Australia [19,20]. Hence, the selected areas are also climatically suitable for wind energy.

Slope and elevation are the prime of topography. Land with low slopes and low elevations is suitable to develop solar and wind energy systems [21]. The allowable range of slope can be 10 to 30 degrees for installing a wind turbine [21] and for solar photovoltaic, it can be between 3 and 5 degrees [21,22]. In this study, land with a slope

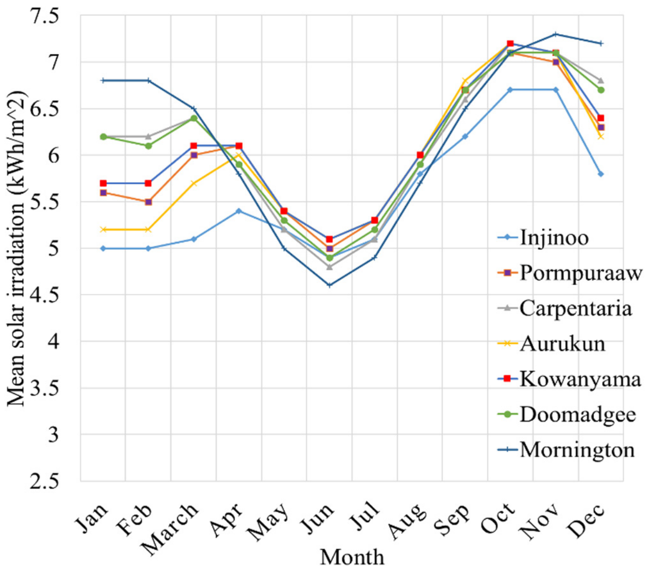

Fig. 2. Monthly mean daily global solar irradiation in selected regions of FNQ for 32 years (from 1990 to 2021) [16].

of a maximum of 5° for solar analysis and a maximum of 15° for wind analysis are included. In the context of the elevation, 2000 m is considered as a maximum limit for both solar and wind according to the published literature [22]. A buffer of 400 m for both solar and wind farms is used for conserving natural resources, and reservoirs such as seas, rivers, and lakes [18]. The airport buffer of 1000 m for solar is to prevent mystifying the pilot's vision from solar panels' glimpse and glint [18]. The airport buffer of 3000 m for wind is to protect the radar system from interfacing with wind turbines [18]. A buffer of 1 km is adopted to conserve the protected locations such as world heritage sites, national parks, and sanctuaries [23]. A 5 km buffer of urban and rural built-up area is for avoiding inconvenience to human life from the noise of wind turbines [23]. 500 m buffer [24] is applied with existing rail and road networks for solar and wind analysis, as rail and road networks are not feasible for any plant installation.

In this assessment, UN global land cover data is utilised. As per the criterion of a previous study [25], irrigated, rain-fed croplands, mosaic cropland, shrubland, grassland, sparse vegetation, and bare areas are considered suitable for wind plants. For solar, a similar suitability criterion is used, which is implemented for wind, except for irrigated, rainfed croplands. Other land categories such as mosaic vegetation, broad-leaved deciduous or semi-deciduous forest, needle-leaved evergreen forest, mixed forest, mosaic forest and grassland, woody wetlands, artificial areas, water bodies, snow or ice are considered unsuitable for any power plant installation.

3. Results and discussions

This study aims at exploring suitable places to install solar and wind energy systems in FNQ utilising a GIS-based multi-criteria approach. The present study is the first kind of work to investigate potential sites in FNQ for the development of solar and wind energy systems utilising GIS modelling techniques. Potential lands have been assessed separately for solar and wind. Initially, the selected regions are assumed only for being solar projects, and later only for the wind project. The attained outcomes of favourable places for solar PV and wind turbines have been mapped in Figs. 3 and 4 respectively. The maps represent the administrative boundaries of different regions of FNQ. Different colours in both figures are used to highlight selected region-wise applicable places for solar and wind energies. Hence, there are implementable areas, totalling 57,705.46 km^2 for solar power and 58,482.79 km^2 for wind power in the selected regions. It is noticeable that huge areas from selected regions are suitable for installing solar or wind farms. These include Carpentaria (72% of total land area for solar and wind), Doomadgee (57.4% for solar and 56.6% for wind), Mornington (50.6% for solar and 65% for wind), Kowanyama (61% for solar and 62.6% for wind), Pormpuraaw (62% for solar and 63.8% for wind), Aurukun (80.2% for solar and 80.9% for wind), and Injinoo (14% for solar and 18.2% for wind).

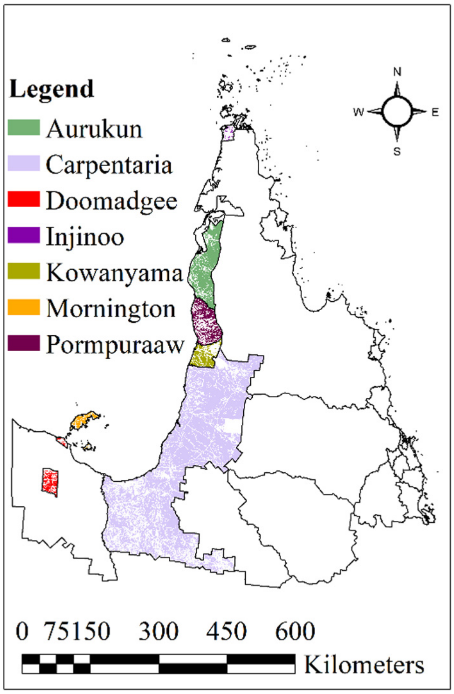

Fig. 3. Applicable potential areas for solar power installation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

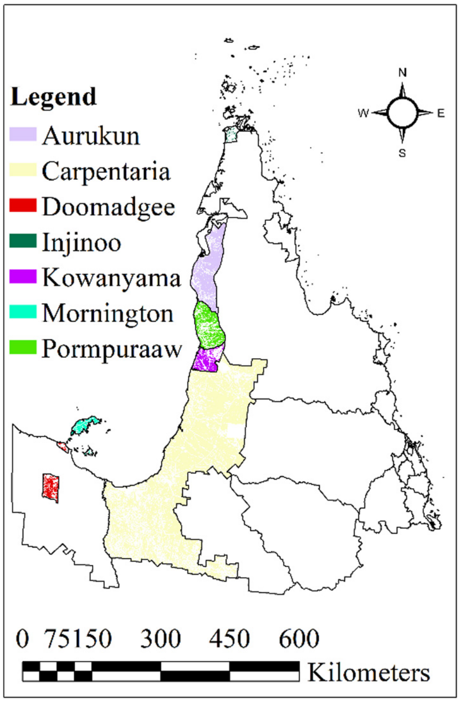

Fig. 4. Applicable potential areas for wind power installation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.1. Solar and wind power potential

Solar and wind power potential depends on available area, Solar PV, and wind turbine types, including the plant's facility requirements. Solar power potential can be calculated by the following equation [26]:

$$P_{solar} = G \times SA \times AF \times \eta \tag{1}$$

where Psolar is the solar power potential (MW), G is the annual mean horizontal solar irradiation in kWh/m^2/day, SA is the suitable land area (m^2), AF is the area factor (%), and η is the solar panel efficacy (%). Here, the area factor reveals the maximal places covered by the solar panels with a minimal shadow effect. The area factor is considered 70% as used in the previous study [26]. Daily average solar irradiation data for selected regions are collected from the Bureau of Meteorology, Australia. The study has used the First solar series 4™ PV module (advanced thin film solar module), used in Kidston solar farm on the site of Kidston gold mine of FNQ, Queensland, Australia. The maximum efficiency, 17% of the module [27] is used in this study to determine the maximum possible solar power generation. Table 2 represents the calculated solar power potential including suitable areas for the selected sites.

Table 2. Theoretical solar power potential.

Selected site	Solar radiation (G) (kWh/m^2/day)	Suitable area (m^2)	Theoretical power potential (MW)
Carpentaria	6.12	45,689,555,002.00	4,738,006.90
Doomadgee	6.12	1,049,736,835.00	108,857.70
Mornington Island	6.18	632,097,742.50	63,399.40
Kowanyama	6.06	1,546,394,148.00	160,361.06
Pormpuraaw	6.00	2,733,477,907.00	278,814.80
Aurukun	5.93	5,948,460,436.00	596,630.60
Injinoo	5.77	105,737,663.10	10,066.22

Wind power potential can be evaluated by the following equation [21,26]:

$$P_{wind} = SA \times AF \tag{2}$$

where, P_{wind} is the wind power potential (MW), SA is the suitable land area (m^2), and AF is the area factor (MW/m^2). In this study, wind turbines have been arranged at 7D × 5D [26], where D is the rotor diameter. Area factor (AF) can be calculated as follows [21].

$$AF = Capacity/(7D \times 5D) \tag{3}$$

The study has used Vestas V117-3.45 wind turbine specifications to calculate wind power potential, as this turbine is used at Mount Emerald Wind Farm in Arriga, FNQ, Queensland, Australia [19]. The turbine capacity and rotor diameter are 3.45 MW and 117 m respectively [20]. Table 3 represents the calculated theoretical wind power potential including suitable areas for the selected regions.

The remote communities of FNQ need a clean and sustainable energy supply system, but renewable power development is very slow here. A lack of proper planning, insufficient proof of energy resources, absence of political inspiration, and high investment costs may be a great hindrance. However, the outcome of the study is expected to help decision-makers and investors for expediting renewable installation in remote areas. Moreover, the outcomes can be further utilised in detailed feasibility assessments for the areas of interest. This is the first-ever study of FNQ to use a GIS-based multi-criteria approach, that would give worthy information for transitioning to a sustainable and clean energy system.

4. Conclusions

Assessment of suitable places to install solar and wind energy systems is the preliminary and important step before the exploitation of these resources. In this study, remote sensing and GIS are used to map the potential areas for solar and wind energy development in remote FNQ, considering climatic, technical, environmental, topography, economic, and social factors. The obtained results show great solar and wind potential areas in selected locations. The total maximum potential areas are found at 57,705.46 km^2 (70% of total selected area) for solar and at 58,482.79

Table 3. Theoretical wind power potential.

Selected site	Suitable area (m^2)	Theoretical power potential (MW)
Carpentaria	46,115,274,994.00	332,065.80
Doomadgee	1,035,985,866.00	7459.90
Mornington Island	811,595,814.20	5844.11
Kowanyama	1,581,502,920.00	11,388.05
Pormpuraaw	2,806,975,362.00	20,212.40
Aurukun	5,993,704,069.00	43,159.31
Injinoo	137,748,431.80	991.90

km^2 (71% of total selected area) for wind. Hence, the maximum power potential goes up to 5956.14 GW for solar and 421.12 GW for wind. In this study, seven remote areas are selected to determine applicable areas and power potential for solar and wind. A GIS-based multi-criteria approach can be applied to other remote areas of FNQ for further study. The solar and wind potential results depicted in this study are expected to facilitate planners and investors to make sound decisions in developing solar and wind farms at the most suitable sites.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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