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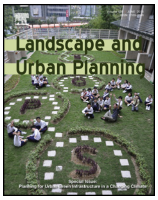

Research paper

Regional Scale wind farm and solar farm suitability assessment using GIS-assisted multi-criteria evaluation

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HIGHLIGHTS

- We have assessed central Southern England for wind and solar energy suitability.
- We apply a method with expert validation to two related types of renewable energy.
- A high number of environmental constraints limit suitability for renewables.
- The region is less suitable for wind energy generation than for solar developments.

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ABSTRACT

As global growth in renewable energy projects accelerates, site identification will come to the forefront, where a key consideration is to minimise the environmental impact of the development. A large area of southern England (17,094 km^2) was assessed for suitability for wind and solar farm developments in three stages using geographic information systems. A multi-criteria decision making framework incorporating an analytical hierarchy process involving expert stakeholders was applied, which is a novel approach for this type of study. A binary constraint layer was created identifying entirely unsuitable locations. A factor layer was developed to indicate suitability in relation to a range of variables. Suitability layers for wind farm and solar farm development were then created covering the region. The environmental constraints used in the model accounted for over 60% of the study area for both wind and solar developments. Suitability for wind energy was generally low, with only 0.5 km^2 accounting for the 'most suitable' category. Solar suitability was higher overall; and a greater area (294 km^2) within the 'most suitable' category, suggesting the region is better suited for solar farm developments. Stakeholder input resulted in higher weightings for economic considerations for the solar model, prompting the most suitable areas to coincide with locations of the national grid connections. A sensitivity analysis indicated that model was generally reliable. This method can be used to assist appropriate site selection for onshore renewable energy projects across large geographical areas, helping to minimise their environmental impacts.

1. Introduction

In response to a range of international and national policy drivers, the installed global renewable energy capacity doubled between 2000 and 2012. Worldwide, wind and solar photovoltaics (PV) were two of the fastest growing electricity generation technologies. For example, in 2012 in the United States, cumulative installed wind capacity increased by nearly 28% and cumulative installed solar PV capacity grew more than 83% from the previous year (US Department of Energy, 2013). China meanwhile has the largest global wind energy capacity, and is seeking to expand from an installed solar PV capacity of 3 GW in 2011 to at least 35 GW by 2015 (Wayne, 2013).

The United Kingdom is following the global trend with commercial onshore wind and solar PV subsidised through government incentives, which helps to promote a diversified energy sector. The Department for Energy and Climate Change (DECC) has updated its 'Renewable Energy Roadmap' and confirmed its stance on increasing renewable energy nationwide (DECC, 2012). This commitment to expanding the renewable energy sector is, in part, a response to international policy drivers—the European Union Renewables

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Directive, 2009/28/EC requires member states to produce a proportion of their electricity from renewable technologies (European Union, 2009), and the UK has set an individual target of 15% from renewable sources by 2020 (DECC, 2012). Wind and solar energy are at the forefront of this expansion, but negative impacts can be associated with these two renewable energy technologies.

The most contentious issue associated with wind farms is the visual impact, which whilst assessed objectively in the literature (e.g. Rodrigues, Montanes, & Fueyo, 2010), is often viewed subjectively by the public (Leung & Yang, 2012) and is a main issue motivating organised political and community opposition to proposals. It has been shown there is a link between the presence of wind turbines and bird mortality, but the death rate per turbine is often low, leading Sovacool (2009) to conclude the number of avian deaths caused by wind turbines is minor compared with fossil fuel sources. Impacts on human health have also been studied, with shadow flicker and operational noise quoted as potential issues (Harding, Harding, & Wilkins, 2008; Torrance & Goff, 2009).

Solar PV farms have only recently begun to match wind power commercially, resulting in fewer assessments and little quantified data on their environmental impacts. Tsoutos, Frantzeskaki, and Gekas (2005) carried out one of the earliest studies to identify negative impacts caused by solar farms, concluding visual and ecological impacts would be minimal, views supported by other studies e.g. Kaygusuz (2009), Turney and Fthenakis (2011). The principal environmental concern with solar farms is the area of land required. Chiabrando, Fabrizio, and Garnero (2009) concluded the large area of land required for solar PV reduces the viability of the technology. However, it was acknowledged by Chiabrando et al. (2009) and Kaldellis, Kapsali, Kaldelli, and Katsanou (2013) that careful design and site selection allow the impacts to be readily mitigated. The UK Government has specifically endorsed an expansion in this form of renewable energy, and a 25-fold increase in capacity has been seen from 2010 to 2013 (DECC, 2013a) reflecting the global trends outlined above; but it has since expressed concerns related to loss of food production, and removed farm subsidy payments available through the EU Common Agricultural Policy for agricultural land used for solar farms (Defra, 2014).

The environmental impacts caused by wind and solar developments are partially dependant on the location of the development, where careful design and appropriate site selection can mitigate the associated negative impacts (Kaldellis et al., 2013). As more renewable energy projects are promoted, viable land will become the key constraint (Grassi, Chokani, & Anhari, 2012), confirming that appropriate site selection will become paramount for the future development of onshore wind farms and solar farms. This stands to become a global challenge as rising populations and modernising economies place pressure on available space for food production (McMichael, Powles, Butler, & Uauy, 2007), housing and environmental protection; while renewable energy technologies will be viewed as favourable, as fossil fuel use may be impacted by climate change policies and the cost of carbon (Arent, Wise, & Gelman, 2011).

When considering geospatial problems such as wind farm or solar farm site selection, there are two key tools available to the decision maker: multi-criteria decision making (MCDM) and geographic information system (GIS). Due to their complimentary nature, they can readily be used in unison (Sanchez-Lozano, Teruel-Solano, Soto-Elvira, & Garcia-Casclaes, 2013). One of the most popular MCDM techniques is the analytical hierarchy process (AHP) which, due to the use of a pairwise comparison of variables, provides a robust method to calculate the relative importance of each variable with regards to the final outcome (Saaty, 1980). As a result, previous studies have used a GIS-MCDM approach when conducting suitability studies for wind farms (e.g. Tegou, Polatidis, & Haralambopoulos, 2010) and solar farms (e.g. Charabi & Gastil, 2011) where few comparative studies have examined both forms of energy generation in a single area.

Whilst there are no UK-specific GIS-MCDM solar farm studies, Baban and Parry (2001) is the only UK specific GIS-MCDM wind farm study, though its focus was predominantly on developing a methodology. Given the low volume of UK-specific literature and the particular challenges of finding locations in a crowded island nation with a developed economy, we use the case study of South Central England to address on-shore wind and solar farm site selection. Using a GIS-MCDM approach, we carry out a regional assessment of the suitability for wind farm and solar farm developments and look to compare the findings with existing developments within the study area. In addition, we use the AHP process to weight our variables and validate the weightings by consulting with expert stakeholders who work in renewable energy site orientation. The experts thus informed our development of constraint layers and factor layers in our analysis of regional suitability—a novel aspect of this research. The study also includes an assessment of the suitability model by conducting a sensitivity analysis.

2. Methods

2.1. Study area

The study area, referred to as South Central England, is situated on the south coast of the UK and occupies an area of 17,094 km^2 (Fig. 1). The region has a population of approximately 5916,600 and the main cities are Bristol, Oxford, Reading and Southampton. Outside of the urban areas the majority of land is agricultural with two areas designated as National Parks. The annual solar irradiation for the region is approximately 1000 kW h m^{-2} yr^{-1} (Laleman, Albrecht, & Dewulf, 2011) with the average wind speed at a height of 45 m being 6.2 m s^{-1} (DECC, 2013b). The region has an installed wind capacity of 23.56 MW with a further 9.32 MW under construction, whilst the installed non-domestic solar capacity is 94.21 MW with a further 142.54 MW under construction (DECC, 2013c).

2.2. Multi-criteria decision making and analytical hierarchy process

Decision makers can use MCDM to consider various subjective and conflicting criteria (Ishizaka & Labib, 2011) whilst assessing the suitability of an area with regards to a specific development. The method is often used in conjunction with GIS (Sanchez-Lozano et al., 2013) whereby the suitability of an area is displayed with visual aids. A review of GIS-MCDM methods was conducted by Pohekar and Ramachandran (2004) which concluded the AHP method was the most widely used technique used in sustainable energy studies. The AHP method was first presented by Saaty (1980) as a way of comparing a number of variables, whereby a pairwise comparison allows a specific weighting of relative importance to be assigned to each variable being considered. Xiang and Whitley (1994) summarised the claims against AHP as a decision making tool into five areas; axiomatic foundation (Dyer, 1990), elicitation questions (Dyer, 1990), the 1 to 9 measurement scale (Holder, 1990), the eigenvalue method (Holder, 1990) and rank reversal (Belton & Gear, 1983; Dyer, 1990). Whilst acknowledging these potential issues with the method, AHP has been shown to be flexible and can allow for its inconsistencies to be checked (Ramanathan, 2001). It allows the importance of each criterion to become clear (Macharis, Springage, De Brucker, & Verbeke, 2004) and it supports decision makers through generation of the geometric mean of the pairwise comparisons (Zahir, 1999). Due to the aforementioned benefits to decision makers, and the method being determined