Developing Online Mapping and Analysis Tools for the Spatial Integration of Energy and Environmental Policies in England

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Abstract: Increased use of electricity generation from renewable sources has led to a growing recognition of the need to consider interactions between energy and environmental objectives. Addressing these planning challenges and potential trade-offs requires greater attention to the spatial dimension of infrastructure investment and planning, as well as their implications for landscapes. This paper presents online mapping tools developed to support local authorities in southeast England in their assessment of land use and other environmental factors. In particular, it examines differences in the relative importance of current siting constraints and highlights the need for better means of evaluating trade-offs if the current objectives for energy system transformation are to be achieved.

Keywords: Renewable energy, land use, landscapes, siting criteria, decision support tools

1 Introduction

The recent World Energy Outlook publication highlights that investment in clean energy has increased by 40% since 2020 (INTERNATIONAL ENERGY AGENCY 2023, 7). In many countries there has been a substantial increase in electricity generation from renewable sources such solar photovoltaics (PV), wind turbines, hydropower and bioenergy. This has led to recognition of a new phase in the relationship between energy development and landscape transformation, as well as much debate on the design and planning issues associated with such 'energy landscapes' (e. g. STREMKE & VAN DEN DOBBELSTEEN 2013, FROLOVA et al. 2015, DE JONG & STREMKE 2020).

One feature of these renewable source is that they have lower power densities and larger land footprints than the fossil fuels they are replacing (SMIL 2016). Renewable electricity generation also has a range of externalities, including impacts arising from land use change (both direct and indirect) on species, habitats and water resources, as well as on landscape aesthetics. All of this has led to increasing recognition of the need to consider the interactions between energy and environmental objectives. For instance, the COALITION LINKING ENERGY AND NATURE (2023, 4) notes that "scaling up the deployment of renewable energy needs to balance the impact on climate and biodiversity".

In 1998 solar PV, onshore and offshore wind, hydropower and bioenergy generated 3% of electricity in the UK. By 2022 it was 41% (ENERGY TRENDS 2023). The most recent strategy (HM GOVERNMENT 2023) envisages further investment in renewables with, for example, a fivefold increase in currently installed solar capacity by 2035. However, it is also recognised that there are considerable threats to these plans due to delays in planning systems and the provision of additional electricity network infrastructure (ELECTRICITY NETWORKS COMMISSIONER 2023). In addition, there is evidence of multiple land use pressures which led a

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recent report by the ROYAL SOCIETY (2023, 17) to conclude " … if existing land-based policy commitments are added together, one finds that the UK's land area already risks being 'over-promised'".

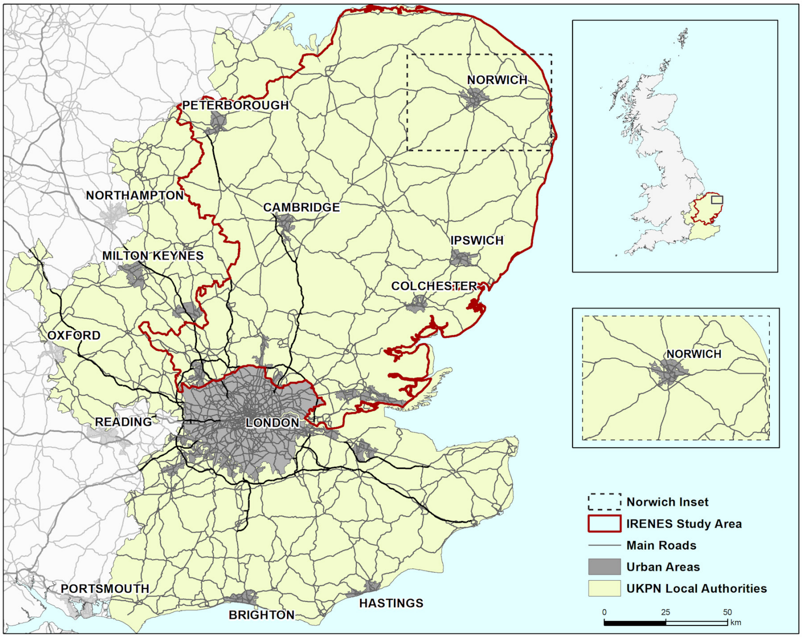

Fig. 1: The study areas

Many studies have examined spatial variations in renewable energy generation potentials (e. g. VAN DEN DOBBELSTEEN et al. 2011, OAKLEAF et al. 2019) and others have assessed how factors such as land use, water resources and infrastructure provision can influence regional or site suitability (e. g. PRICE et al. 2018, RYBERG et al. 2020). The extent of planning restrictions on renewable energy developments varies across Europe (e. g. see RYBERG et al. 2018). In England, for example, there are planning regulations that restrict developments in the vicinity of certain facilities (e. g. airfields), but no national strategic or zoning framework. However, several guidance reports have been published (e. g. SQW ENERGY 2010, NATIONAL INFRASTRUCTURE COMMISSION 2020) and other studies have examined spatial variability in suitability of land for renewables (e. g. LOVETT et al. 2014, WATSON & HUDSON 2015, PALMER et al. 2019, MCKENNA et al. 2022). The ELECTRICITY NETWORKS COMMISSIONER (2023) has now recommended that a Strategic Spatial Energy Plan should be produced, and the Government has committed to publishing a land use framework for England. Another development has been the use of Local Energy Planning (LAEP). This seeks to provide a whole-systems and place-specific approach to energy planning (COLLINS & WALKER 2023). Creating an LAEP is not a statutory requirement in the UK and, to date, has been completed by only some 20 local authorities, usually through the assistance of additional funding to hire consultants. One of the difficulties involved is the variety of data sets that need to be considered and this paper discusses initiatives in southeast England (see Fig. 1) to assist local authorities and other stakeholders in their assessment of land use and other environmental factors.

Our research began as part of the IRENES project funded by Interreg Europe[1] IRENES focused on the synergies and trade-offs between the exploitation of renewable energy sources and the delivery of ecosystem services. During the project we undertook such an evaluation for five counties in eastern England (see Fig. 1), using publicly available data sets and GIS techniques to produce digital maps within standalone software. Our stakeholders asked if these resources could be made more accessible, and funding from the Greater South East Net Zero Hub[2] and UK Energy Research Centre[3] allowed us to create online query and analysis capabilities in the Parish Online platform[4]. UK Power Networks (UKPN, the regional distribution network operator for electricity) were part of the steering group for this initiative and subsequently commissioned further data compilation and analysis for their CLEO platform[5] . This will support local authority energy planning across a larger operating area (see Fig. 1). The remainder of this paper first outlines the data and methods we have used and then presents some example results, focusing on the relative importance of possible siting constraints and the extent to which the current spatial pattern of generation can be predicted by classifications of such factors. These findings also identify renewable energy 'opportunity' or 'acceleration' areas (THE NATURE CONSERVANCY 2023) that could be used by local authorities in spatial planning that harmonises energy and environmental policy objectives.

2 Materials and Methods

The overall approach combined data on renewable energy generation potentials with other maps representing environmental or socio-economic factors. This is similar to many studies, such as the steps outlined by SOCHI et al. (2023). Figure 2 summarises the main stages.

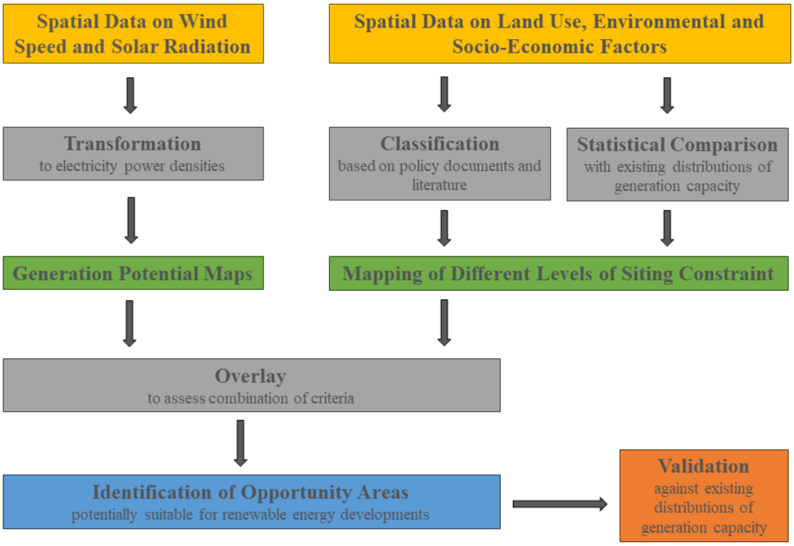

Fig. 2: The overall methodology

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[1] https://projects2014-2020.interegeurope.eu/irenes/

[2] https://www.gsenetzerohub.org.uk/

[3] https://ukerc.ac.uk/

[4] https://www.parish-online.co.uk/

[5] https://innovation.ukpowernetworks.co.uk/projects/collaborative-local-energy-optimisation

Table 1 list the different data layers and sources involved. All of the data sets were in the public domain or usable under terms such as the Creative Commons license.

Table 1: Data sources used in the analysis

Feature	Source URL
Motorways, A & B Roads	https://osdatahub.os.uk/downloads/open/VectorMapDistrict
Railways	https://osdatahub.os.uk/downloads/open/VectorMapDistrict
Rivers, Canals, Lakes & Reservoirs	https://osdatahub.os.uk/downloads/open/VectorMapDistrict
Urban Areas	https://osdatahub.os.uk/downloads/open/VectorMapDistrict
Census 2021 Output Area Centroids	https://ukdataservice.ac.uk
Airports & Airfields	https://ec.europa.eu/eurostat/data/dadatabase, https://hub.arcgis.com/
Ministry of Defence Land	https://osdatahub.os.uk/downloads/open/OpenMapLocal
Slopes	https://osdatahub.os.uk/downloads/open/Terrain50
Risk of Flooding from Rivers and Sea	https://data.gov.uk
Monuments & Heritage Sites	https://historicengland.org.uk/listing/the-list/data-downloads/
Registered Parks and Gardens	https://data.gov.uk
Open Greenspace	https://osdatahub.os.uk/downloads/open/OpenGreenspace
National and Local Nature Reserves	https://naturalengland-defra.opendata.arcgis.com/
International Nature Reserves	https://magic.defra.gov.uk/MagicMap.aspx
Green Belt	https://data.gov.uk
National Parks	https://data.gov.uk
Areas of Outstanding Natural Beauty	https://naturalengland-defra.opendata.arcgis.com/
Ancient Woodland	https://data.gov.uk
Managed Woodland	https://data-forestry.opendata.arcgis.com/
Agricultural Land Classification	https://data.gov.uk
Wind Speed	https://map.neweuropeanwindatlas.eu/
Solar Radiation	https://solargis.com/maps-and-gis-data/overview

Renewable energy resource potentials were calculated from wind speed and solar radiation data, with assumptions about equipment efficiencies and spacings to estimate theoretical power densities (Tab. 2). Values for solar PV were approximately double those for onshore wind, a similar contrast to that presented by SMIL (2016, 203).

Table 2: Example renewable energy potential calculations (MACKAY 2009, microgen-database.sheffield.ac.uk and Solar Trade Association data)

Calculation Steps	Calculation Results
Wind Speed	
Example wind speed	7.5 m/s
Power density = (0.5 * Density of Air) * (Wind Speed)^3	(0.5 x 1.3) x (421.9) = 274.2 W/m^2
Maximum extractable power (59%)	0.59 x 274.2 = 161.8 W/m^2
Power of turbine 80 m diameter and 100 m hub height	161.8 x (3.1416 x 40^2) = 813,297 W
Turbine minimum spacing (5 diameters)	
Power density (power of turbine / land area of turbine)	813,297 / (5 x 80)^2 = 5.1 W/m^2
Theoretical energy (as power density)	5.1 W/m^2
Solar Radiation	
Example Global Irradiation at Optimum Tilt (GTI)	140 W/m^2
Assumed panel efficiency (17.5%)	0.175 x 140 = 24.5 W/m^2
Ratio of panel area to plant area (40%)	0.4 x 24.5 = 9.8 W/m^2
Theoretical energy (as power density)	9.8 W/m^2

Two complementary approaches were used to evaluate land use and other siting factors. Information from the literature (e. g. GOVE et al. 2016 and studies cited in Section 1) was used to distinguish different levels of siting constraints based on known physical or regulatory limitations and softer considerations (e. g. linked to heritage or nature conservation designations). Secondly, grid references and generation capacity details for all operational or under construction onshore wind or ground solar PV installations were extracted from the Renewable Energy Planning Database (REPD)[6]. GIS software was then used to overlay these points on the polygons for the different land use factors. This made it possible to assess the extent to which the distributions coincided and therefore the degree to which different factors appeared to exclude current generation facilities. These results were then used to group siting factors into different classes of likely development constraint.

3 Results

Figure 3 illustrates the constraint levels defined from literature for solar PV and incorporated into the Parish Online platform. The maps depict the area around the city of Norwich (highlighted in Fig. 1). Level 1 was based on constraints from infrastructure and urban areas, Level 2 added buffer zones and habitats such as woodland, Level 3 included heritage or conservation designations and Level 4 added higher quality agricultural land. Platform users could examine individual layers or switch the combinations in different levels on/off to assess the constraints associated with potential sites. We also developed a Prospecting Tool which allowed a user to digitise sites and then see their calculated electricity generation potential.

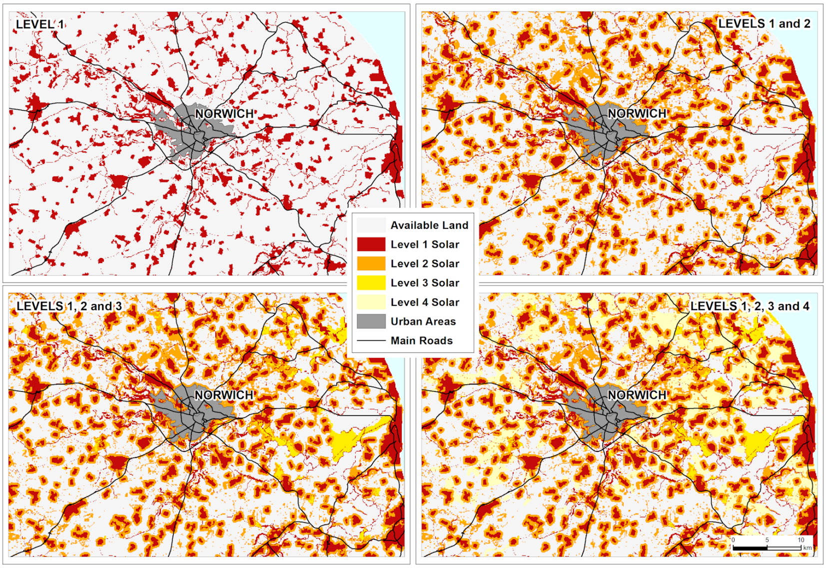

Fig. 3: Different levels of constraint for solar PV developments in the vicinity of Norwich

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[6] https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract

Table 3 lists the hectares covered by different land use factors within the UKPN local authorities. Several of these had buffer zones defined around them based on suggestions in the literature. For each factor the table also lists the number of solar PV sites and their total electricity generation capacity (in MW) that occurred within the polygons. It is clear from this that some factors completely or largely excluded solar sites (e. g. National Parks), whilst in other cases they were quite common (e. g. Grade 2 agricultural land). Since the sites also varied in capacity an overall measure of likely absence was calculated as the ratio of the percentage of total regional capacity within the factor polygons divided by the percentage of the UKPN authorities area they occupied. With this measure a low value (e. g. at or close to zero) implies that few existing sites occurred where the factor was present, whilst a higher value (e. g. above 1.0) suggests that it was not an important constraint. From these results it is clear that proximity to infrastructure, populated area, various designations and high flood risk were important siting constraints, whilst higher quality agricultural land had less influence. However, relatively few factors were an absolute prohibition (i. e. with a ratio of 0.00).

Table 3: Land use siting assessment for solar PV

Solar Siting Factor	Area in Hectares	Solar Sites	Capacity in MW	% Capacity / % Ha Ratio
Main Roads + 15 m Buffer	49,926	0	0	0.00
Railway Tracks + 15 m Buffer	12,991	0	0	0.00
Main Water Courses + 150 m Buffer	263,417	20	74	0.32
Lakes and Reservoirs + 150 m Buffer	31,880	3	11	0.39
Airports + 500 m Buffer & Military Land	93,203	18	115	1.41
Designated Nature Reserves	233,988	2	14	0.07
Ancient Woodland	134,313	0	0	0.00
Managed Woodland	381,341	6	70	0.21
Monuments & Heritage Sites	11,881	0	0	0.00
Registered Parks & Gardens	57,031	1	Not Known	Not Known
OS Open Greenspace	108,969	6	40	0.42
National Parks	139,480	0	0	0.00
Areas of Outstanding Natural Beauty	469,115	6	30	0.07
Green Belt	531,247	31	219	0.47
Slope (>5%)	605,974	21	125	0.24
Agricultural Land Grade 1	218,332	33	259	1.36
Agricultural Land Grade 2	739,067	84	872	1.35
High Flood Risk	147,538	0	0	0.00
Medium Flood Risk	231,655	13	86	0.43
Census Centroids + 200 m Buffer	415,313	27	121	0.33
Census Centroids + 500 m Buffer	954,441	81	387	0.46
Census Centroids + 1 km Buffer	1,946,636	187	1190	0.70
Total	3,553,296	337	3,098	-

Similar results were generated for onshore wind turbines and then the capacity/ha ratios were used alongside discussions in policy documents to produce classifications of siting constraint.

Figure 4 shows the variations for electricity power density for solar PV and onshore wind. These results were then overlaid with the site constraint maps shown in Figure 5 to produce the overall opportunity maps in Figure 6. Little of the region was unviable in terms of power densities so the constraint maps were the dominant influence on the final classifications.

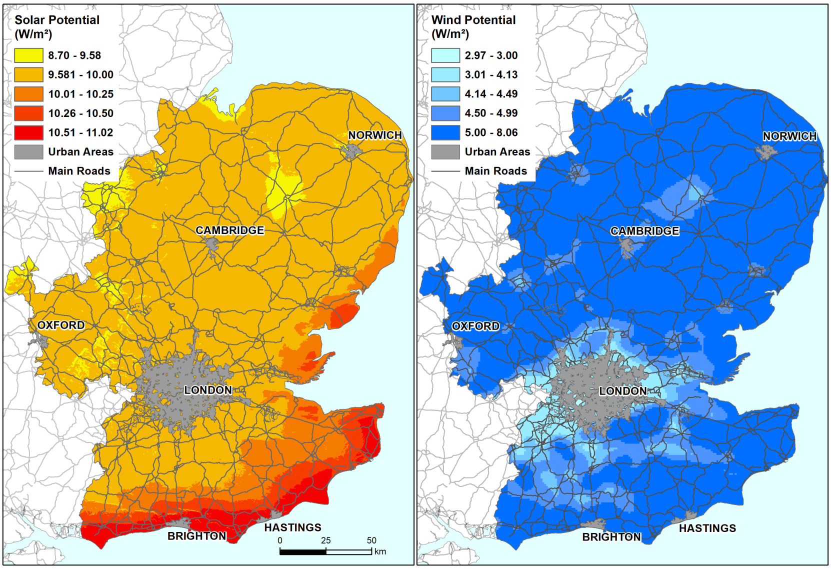

Fig. 4: Electricity generation potential maps for solar PV and onshore wind

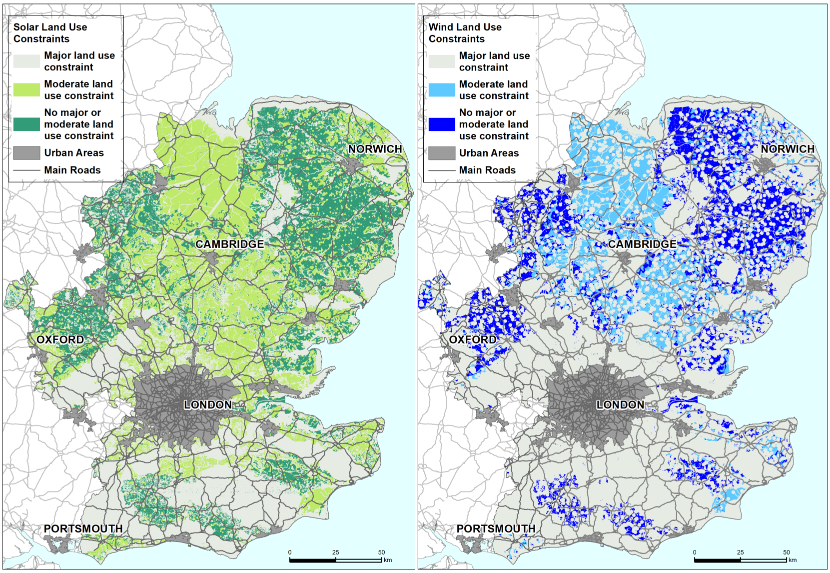

Fig. 5: Classifications of siting constraints for solar PV and onshore wind

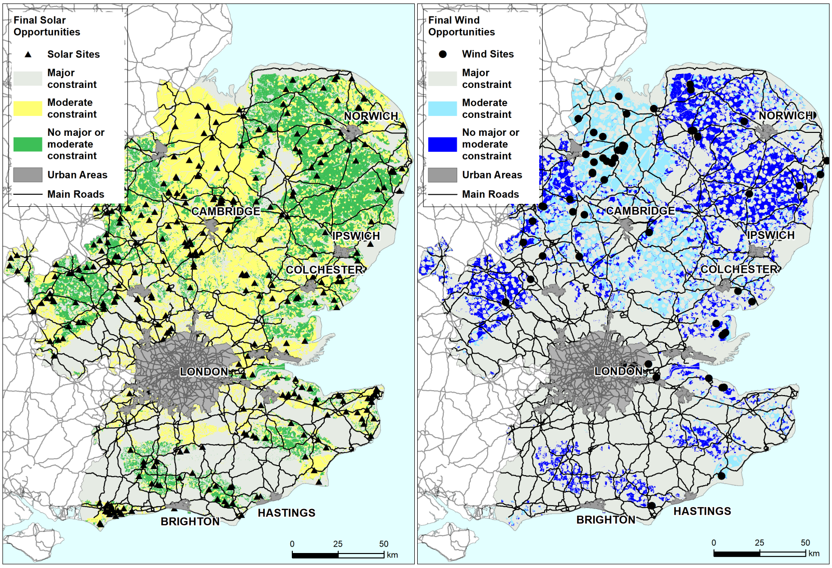

Fig. 6: Final classifications of opportunity areas for solar PV and onshore wind

For solar PV 20% of the region was assessed as without major or moderate constraint, with the equivalent proportion for onshore wind being 12%. The maps in Figure 6 also plot the current solar PV and onshore wind sites and it is apparent how existing generation capacity is quite concentrated in certain parts of the region. Particularly around London there are landscape designations which are substantial restrictions on where renewable energy generation takes place. Tables 4 and 5 summarise the results of the final validation exercise and indicate how the values of the % capacity / % ha ratios vary between the classifications.

Table 4: Classification validation results for solar PV

Classification	Area in Hectares	Total Sites	Total Capacity (MW)	Ratio % Capacity / % Ha
No Major or Moderate Constraint	668,054	105	1,407	2.41
Moderate Constraint	1,146,595	167	1,427	1.42
Major Constraint	1,728,219	65	264	0.17
Total	3,542,868	337	3,098	

Table 5: Classification validation results for onshore wind

Classification	Area in Hectares	Total Sites	Total Capacity (MW)	Ratio % Capacity / % Ha
No Major or Moderate Constraint	421,979	16	183	2.24
Moderate Constraint	360,424	31	369	5.28
Major Constraint	2,760,465	22	134	0.25
Total	3,542,868	69	686	

Table 4 shows a clear trend for solar PV with, as would be hoped, decreasing ratios as the expected level of constraint increases. For onshore wind in Table 5 the ratio for 'major constraint' is by far the lowest, but that for 'moderate constraint' is actually rather higher than that for the category where neither type of constraint is present. The map in Figure 6 indicates that one reason is some large wind farms on higher quality agricultural land in Fenland and another feature is a cluster of sites along the Thames estuary and into east London. Overall, the results suggest that the current distributions of renewable generation capacity can be quite well predicted by classifications of siting factors, though the trends are clearer for solar PV than offshore wind. This, in turn, provides some confidence that the identified opportunities are credible options for spatial planning purposes.

4 Conclusions

We have received positive feedback from local government and regional stakeholders regarding the tools and resources we have created and there are now plans to further expand the capabilities involved. This will include making the information available to local communities. The analysis demonstrate how it is possible to model the influence of environmental and land use factors on the distribution of renewable energy generation, though it is important to appreciate that other factors such as electricity network capacity also have an impact at more local scales. It also provides a framework that can be readily updated if planning policies and siting constraint change in the future.

Current energy landscapes inevitably reflect societal preferences (e. g. regarding where developments should not be permitted) and although the types of exclusion zones defined and assessed in this research are a common policy instrument it also needs to be recognised that they can increase the generation and environmental costs of renewable energy deployment (LEHMANN & TAFARTE 2014). There is consequently a growing need for better tools to quantify the trade-offs that different choices involve (DELAFIELD et al. 2024). It is also important to appreciate that renewable energy landscapes can take many different forms (STREMKE et al. 2023). Design and planning will therefore be central to inculcating the sense of 'learning to love the landscapes of carbon neutrality' (SELMAN 2010) that will be essential if the current objectives for energy system transformation are to be achieved.

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